

METEOSAT TRANSITION PROGRAMME

Meteorological Products Extraction Facility (MPEF)

Algorithms Specification Document

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DOCUMENT CHANGE RECORD

<u>ISSUE</u>	<u>DATE</u>	<u>DCN No</u>	<u>CHANGED PAGES</u>
1.0	16/04/93		
1.1	01/07/93		Section 2.3, 2.4, 2.5 and 2.12 - some amended text (and one changed formula) to improve understanding of Radiation Model, the Calibration process, and the PI product algorithm; Appendix A - updated version of Segment Processing sub-model and inclusion of draft version of On-Line Data Preparation and Off-Line Data Preparation sub-models (SADT diagrams only) ; Data Dictionary - updated to be consistent with other documents
2.0	01/12/96		New release to reflect the operational algorithms implementation.

1. INTRODUCTION

1.1 Purpose and Scope of Document

The purpose of the document is to provide an introduction into the meteorological product extraction subsystem of the MTP/Meteorological Products Extraction Facility (called in the following just MPEF) and to provide detailed descriptions of the algorithms that have been implemented in order to extract meteorological products from rectified Meteosat image data. It also contains relevant supplementary and background information to the algorithms concerning, among other things, their domain of application, their origin and evolution and potential for future improvements.

The document is intended to be a stand-alone document describing the implemented algorithms as completely as possible. The document does not provide an introduction into MPEF as a system and its embedding into the MTP Ground Segment. For the latter purpose the ADD might be used.

The readership is expected to be staff of the OPS/MPEF team requiring a general introduction into the product extraction subsystem or seeking detailed knowledge of individual algorithms.

1.2 Structure of Document

The document comprises the following sections:

Chapter 1 is this introduction.

Chapter 2 contains an introduction into the meteorological product extraction subsystem and provides an overview how the algorithms work together.

Chapter 3 contains basic descriptions of the algorithms themselves along with supplementary and background information.

Appendix A contains detailed descriptions of the algorithms using :

- data flow diagrams (DFDs) following the SADT method which illustrate the logical structural breakdown of the main functionality of MPEF's algorithms
- accompanying process specifications which describe the functions of processes illustrated by the DFDs
- data dictionary reports which describe the various data flows illustrated by the DFDs.

1.3 Reference Documents

The following is a reference document which provide some supplementary information on the Meteosat Transition Programme and the MTP Ground Segment.

'The Meteosat System', Eumetsat 1996, EUMTD05.

2. INTRODUCTION INTO THE ALGORITHMS SUBSYSTEM

This introduction provides an overview of the algorithms subsystem to outline the general concept, and to allow the individual algorithms to be put in context before they are described in detail in other chapters.

2.1 Generation of Products

The objective of the Meteorological Products Extraction Facility is to analyse the METEOSAT images produced every half an hour in order to derive quantitative meteorological parameters from them and distribute these extracts in form of the following meteorological products to the meteorological community:

- CDS: Climate Data Set
- CLA: Cloud Analysis
- CMW: Cloud Motion Wind
- CTH: Cloud Top Height
- IDS: ISCCP Data Set
- PI: Precipitation Index
- SST: Sea Surface Temperature
- UTH: Upper Tropospheric Humidity

and, in addition, IR and WV channel calibration data for inclusion into the Interpretation Data Block of the High Resolution Image Dissemination format.

2.2 Analysis of the Images

The generation of the meteorological products is performed for most of the products by analysing the images piece by piece, ie the images are "segmented" into segments of 32 pixels times 32 pixels (the VIS image being reduced to IR image resolution), from which the product values are derived. Since a lot of steps of processing an image segment is common to the derivation of the different products, a preparatory process called Segment Processing (SEG) has been defined which tries to find in the image segments sets of pixels with similar radiation characteristics, so-called clusters. It is assumed that the pixel values of a cluster stem from one scene type, ie sea, land surface type or cloud at a certain height level (semi-transparent clouds being an exception). It should be noted that the pixels of a cluster do not necessarily represent a contiguous set of pixels in the image segment since Segment Processing applies a statistical analysis method rather than analysing the segment as an image. Therefore, even scattered clouds, as long as they are on the same height level, can be identified by a cluster.

2.3 Classification of the Image Pixel Clusters

The identification of the source of the radiation contributing to a cluster is performed by the Cluster Classification process. This process compares the cluster characteristics with the characteristics (expected to be seen by the satellite) of the earth surface scenes known to be present in the segment

and of clouds at three standard height levels. The cluster is classified by the scene which fits best, as long as the fit is not too bad.

2.4 Prediction of the Characteristics of Scenes

Which scene characteristics are likely to be seen by the satellite is estimated by the Scenes Prediction (SCE) process. Since the amount of radiation from a scene received by the satellite varies with the time of the day and the day in the year according to surface temperature, sun and spacecraft angles and atmospheric conditions, the prediction of the scene characteristics is quite a complex process. Which surface scenes are contained in a segment is described by the Surface Reflector Map. For each surface scene and for low, medium and high clouds, IR and VIS values that are likely to be measured by the satellite are predicted, whereas WV values are not estimated.

The IR value prediction is based on forecast temperature and humidity profiles provided by ECMWF. Starting with the predicted temperature of the surface or of the atmosphere at the height of the three standard cloud layers, the IR radiation emitted by the scene is calculated assuming that the scene radiates like an ideal black body, corrected by a scene type specific emissivity factor. The forecast temperature and humidity profiles are used to determine, by means of a radiative transfer calculation, the attenuation effects caused by the atmosphere on the radiation on its way from the scene's surface towards the satellite. A fraction of the expected IR radiation leaving the top of the atmosphere towards the satellite is measured by the satellite, according to the channel response function of its IR sensor. The measured radiance is (inversely) calibrated into 8 bit IR channel engineering counts modelling the electronics and the IR channel A/D converter of the radiometer. Since forecast profiles are available only for the main synoptic hours, the predicted IR counts are improved by taking into account the diurnal variation of the temperatures. Additionally, the IR predictions are modified, as a feedback correction, by the differences between the predictions and the actual satellite measurements from the previous slot.

The VIS value predictions for the scenes in a segment are based on scene type specific bi-directional reflectance data, that describe the fraction of reflected VIS radiation that is seen by the satellite. This fraction is dependent on the angle of incidence of the sunshine and the viewing angle of the satellite. These angles are derived for the centre of the segment from the azimuth and zenith angles of the sun and the spacecraft, which are contained in the header records of the rectified image data. The amount of VIS radiation incident on earth is calculated from the solar constant and the distance of the earth's surface to the sun. The calculation of the VIS counts expected to be delivered by the satellite is performed by calibrating the expected measured VIS radiation using the calibration coefficients derived during off-line VIS channel calibration campaigns (see chapter Calibration of the VIS Channel).

2.5 Transfer of Radiation through the Atmosphere

The radiative transfer calculation to estimate the attenuation of the radiation on its way through the atmosphere towards the satellite per segment, is performed by the Scenes Prediction process not by simulating all the absorption and re-emission processes, but by using a radiation absorption table pre-calculated by a process called Radiation Scheme (RAD). The Radiation Scheme also produces tables that support the correction of the cluster characteristics of semi-transparent clouds, the generation of the UTH product and a table that relates attenuated radiance, pressure and height (in metres).

The tables are calculated on the basis of the forecast temperature and humidity profiles. Image pixel data is not taken into account by any means. If no forecast data is available the Radiation Scheme derives its tables from climatological data that provides static temperature and humidity profiles for the middle of each month. If a fall-back to climatology is performed the quality of several derived meteorological products deteriorates significantly.

2.5.1 IR Radiation Atmospheric Absorption

The Radiation Scheme creates a segmented IR Radiation Atmospheric Absorption Table that relates, for each segment of the processing area, surface black body temperature equivalent radiances to the radiances that would be measured by the satellite according to its IR channel spectral response function. The attenuation of the IR radiation emitted at the surface of a scene (earth surface, cloud at standard height level) according to its black body temperature is calculated by simulating, based on the forecasted temperature and humidity profiles provided by ECMWF, the absorption and re-emission processes of the atmosphere in a number of homogeneous layers, resulting in the attenuated IR radiation exiting the top of the atmosphere in the direction of the satellite. The attenuated IR radiances are convoluted with the IR channel spectral response function to provide the measured radiance. Additionally, the table includes the theoretical measured radiances in the direction of the satellite at the top of each atmospheric model layer.

In the course of the generation of the meteorological products it is often required to interpret the image pixel counts in terms of physical units (radiance), and to derive from those values, by a process of inverse attenuation, the amount of radiation emitted from the surface of the scenes, and the corresponding black body temperature. In order to relieve the product generation processes from the radiative transfer calculations, the Radiation Scheme process extends the Radiation Atmospheric Absorption Table by repeating the radiative transfer calculations for a surface temperatures warmer than the forecasted one, enabling the product generation processes to interpret the pixel counts simply by table interpolation.

2.5.2 Semi-Transparency Correction

Additionally to the IR channel radiation transfer calculations, the Radiation Scheme also performs similar transfer calculations per segment for the WV channel, on the basis of the forecast (or climatological) temperature and humidity profiles, in order to generate the so-called Semi-Transparency Correction Table. The segmented Semi-Transparency Correction Table characterizes opaque clouds at various heights by means of the IR and WV radiances that are expected to be measured by the satellite, according to its spectral response functions. This table is used to check whether the values of cloud clusters are contaminated by radiation passing through the cloud from scenes below, feigning a lower height of the cloud. For that purpose, the determined characteristics of cloud clusters are compared (as a processing step of Segment Processing) with the opaque cloud curve values of this table, so as to flag clouds that deviate significantly from the curve as semi-transparent, and to correct their IR and WV counts such that they fit the curve. The semi-transparency correction of the cloud cluster counts leads to a better estimate of the clouds' height and cloud top temperature.

2.5.3 Upper Tropospheric Humidity

A third table is generated by the Radiation Scheme, the segmented Upper Tropospheric Humidity Table. This table is used by the UTH product generation process to derive, by interpolation, an

estimate of the upper tropospheric relative humidity between 600 hPa and 400 hPa for a cloud-free atmosphere from the WV and IR counts of the image pixels of each segment not belonging to medium or high cloud or contamination clusters.

The generation of the table requires IR and WV channel radiation transfer calculations to be performed. Both transfer calculations are carried out for a set of artificial humidity profiles with constant relative humidities in the upper troposphere, assuming that the temperature profile is as forecasted. The table contains for each chosen constant upper tropospheric relative humidity value a set of IR and WV radiances for clouds at different pressure levels. These radiances are the radiances that are likely to be measured by the satellite according to its spectral response functions.

2.5.4 Attenuated Radiance to Pressure Relation

A fourth table is generated by the Radiation Scheme, the Radiance/Pressure Table. The generation of the table requires IR channel radiation transfer calculations to be performed. The transfer calculations are based on the forecasted temperature and humidity profiles. The table provides, for each segment, the theoretical IR radiances expected to be measured by the satellite according to the spectral response function of the IR sensor for a set of opaque clouds at different pressure levels.

Additionally, the table provides the height in metres of the different pressure levels. The heights are determined by calculating the thickness of the pressure layers due to the barometric equation and summing up, for each layer, the thickness of the layers underneath.

This table can be used to estimate the height of a cloud in terms of a pressure level and also in terms of metres by its potentially semi-transparency corrected measured IR radiance as it is done e.g. by the CTH generation process to assign to the 3*3 IR superpixel a height classes in kilometres.

2.5.5 Atmospheric Radiation Attenuation Calculation

2.5.5.1 Modes of the Attenuation Calculation

The calculation of the attenuation of the IR radiation due to atmospheric absorption is used in MPEF in two different modes:

- In Scenes Prediction, the forecasted temperatures of the earth surface (sea, land), and of clouds at three different standard height levels, are used to calculate (according to Planck's law and the scene specific emissivity) the amount of IR radiation that is emitted from the scenes in the direction of the satellite. The emitted radiance is attenuated on its way through the atmosphere. Finally, the attenuated radiance exiting the atmosphere is measured by the radiometer according to the sensor's spectral response. The measured radiance is calculated from the emitted radiance by means of the IR Radiation Atmospheric Absorption Table, produced by RAD. The expected measured IR radiance is (inversely) calibrated to the predicted IR counts. These IR counts are expected to be delivered by the satellite if the corresponding scene is visible for the satellite.
- MPEF uses the IR counts delivered by the satellite to derive meteorological products. For some of the products, eg SST, it is necessary to calculate the temperature of the radiating scene. For that purpose, the IR counts are calibrated to the radiance measured by the satellite's sensor. The

IR Radiation Atmospheric Absorption Table is used to compensate the effect of the IR channel's spectral response function, and to perform an "inverse" atmospheric absorption attenuation calculation on the radiance incident on the IR sensor, to eliminate the radiation attenuation effects of the atmosphere, and to calculate the IR radiance emitted by the observed scene. From the emitted IR radiance, the scene's temperature is calculated according to the emissivity of the scene and Planck's law.

2.5.5.2 Clarification of Terms

Diverse terms of temperature, radiance and counts are defined in the following that have been used in the past in a sometimes inconsistent manner making confusion easy. In order to minimize the possibility for confusion the terms are grouped into those no longer to be used and those to be used in future.

Terms no longer to be used

i. Uncorrected IR mean count:

This term was misleading since it was used to identify:

- in the segment processing output, the cluster IR mean count derived from the original measured IR image pixels.

This count value corresponds to a scene's mean radiance measured by the IR sensor of the satellite according to its spectral response function,

- in the CDS product, the cluster IR mean count corrected inversely for the effect of the spectral response function and the atmospheric absorption.

This count value corresponds to the IR radiance flowing from above the surface of a scene in the direction of the satellite being potentially contaminated by the radiation from below if the scene is a semi-transparent cloud.

ii. Corrected IR mean count:

This term was misleading as well since it was used to identify:

- in the segment processing output, the cluster IR mean count corrected for potential semi-transparency.

This count value corresponds to the radiance emitted by the surface of a radiator excluding the potential radiance from radiators below (in case of semi-transparent clouds), attenuated due to the atmospheric absorption in the direction of the satellite and measured by the IR sensor due to its spectral response function. This count is semi-transparency corrected only for semi-transparent clouds otherwise identical to the original measured mean count,

- in the CDS product, the cluster IR mean count corrected for potential semi-transparency and corrected inversely for the effect of the spectral response function and the atmospheric absorption.

This count value is equivalent to the IR radiance emitted by the surface of a scene in the direction of the satellite excluding the potential radiance from radiators below.

- iii. Semi-transparency corrected IR mean count:

This term was synonymously used to "corrected IR mean count".

- iv. Atmospheric absorption corrected IR mean count:

This count value is the potentially semi-transparency corrected IR mean count inversely corrected for the effect of the spectral response function and the atmospheric absorption attenuation.

- v. Surface temperature:

It is the temperature of the surface of a scene, eg of the top of a cloud, not necessarily the temperature of the earth's surface.

Terms to be used

Physical entities spanning from temperature to count:

- vi. Temperature of a scene:

It is the temperature of the surface of a scene, eg of the top of a cloud.

- vii. Emitted IR radiance of a scene:

It is the IR radiance emitted from the surface of a scene in the direction of the satellite, eg from the top of a cloud not including the potential radiance of radiators from below even if the cloud is semi-transparent.

- viii. Attenuated IR radiance of a scene:

It is the IR radiance exiting the top of the atmosphere in the direction of the satellite emitted from the surface of a scene and attenuated due to the atmospheric absorption.

- ix. Brightness temperature:

It is the temperature of a virtual ideal black body (emissivity = 1) that corresponds to the attenuated IR radiance of a scene.

- x. Incident IR radiance of a scene:

It is identical to the attenuated IR radiance of a scene, ie incident into the radiometer of the satellite.

xi. Measured IR radiance of a scene:

It is the part of the incident IR radiance of a scene that is measured by the IR sensor according to its spectral response function.

xii. Measured IR count of a scene:

It is the IR count that corresponds to the measured IR radiance of a scene.

Note: In the course of the document, radiances and counts derived from temperatures are often accompanied by attributes like "predicted", "expected" or "theoretical" to indicate that they are not based on real measurements of the satellite but calculated by SCE or another process.

Physical entities spanning from counts to temperature:

xiii. Measured IR cluster mean:

It is the mean of the IR pixel counts of a cluster as measured and delivered by the satellite. This value is equivalent to the measured IR count of a scene if the scene is opaque.

xiv. Potentially semi-transparency corrected IR cluster mean:

It is the measured IR cluster mean potentially corrected for semi-transparency effects. This value is equivalent to the measured IR count of a scene being opaque or even semi-transparent.

xv. Inversely attenuated IR cluster mean:

It is the IR count value that is derived from the measured IR cluster mean by calibrating it to measured IR radiance, inversely correcting the measured IR radiance for the effect of the spectral response function and the atmospheric absorption to get the emitted IR radiance and inversely calibrating the emitted IR radiance to a count. This count corresponds to the emitted IR radiance of a scene if the scene is opaque and to the contaminated emitted IR radiance if the scene is a semi-transparent cloud.

xvi. Inversely attenuated, potentially semi-transparency corrected IR cluster mean:

This count corresponds to the emitted IR radiance of a scene being opaque or even semi-transparent.

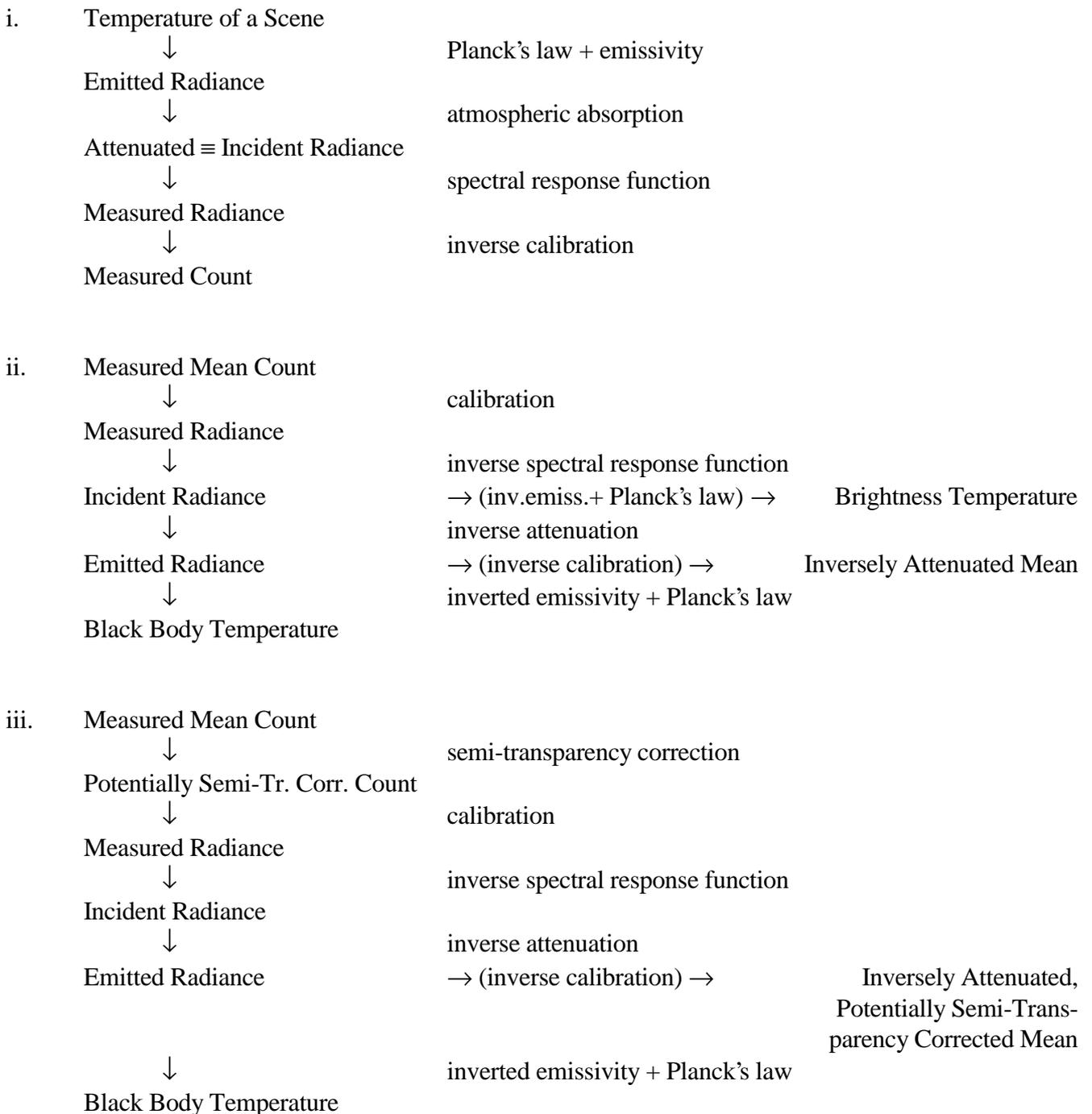
xvii. Black body temperature:

This temperature is derived from the inversely attenuated potentially semi-transparency corrected IR pixel mean of a classified cluster by calibrating the mean count to the

emitted radiance and applying to the emitted radiance the classifying scene's emissivity factor and Planck's law.

2.5.5.3 Relationship between Quantities and Transformations

The relationship between the quantities defined by the terms above and the processes transforming a quantity into another is graphically represented as follows:



2.5.5.4 Inter-Algorithms Interfaces

The inter-algorithms interfaces with respect to the atmospheric radiation attenuation, the inverse attenuation, spectral response function effects, semi-transparency correction and calibration are summarized below.

2.5.5.4.1 Radiation Model

The tables created by RAD, ie the Atmospheric IR Radiation Absorption Table, the Semi-Transparency Correction Table, the Upper Tropospheric Humidity Generation Table and the Radiance/Pressure Table, are based on measured IR radiances, ie the atmospheric radiation attenuation and the spectral response function of the satellite's sensors are taken into account. The inverse calibration of the measured radiances into measured counts is not done by RAD; this is left to the individual product generation processes, to avoid the need to run RAD whenever a calibration coefficient changes.

2.5.5.4.2 IR and WV Channel Calibration

The IR and WV channel calibration processes deal with measured counts as delivered by the satellite. Therefore the output of Segment Processing does not require further transformation. On the other hand, the NCEP (former NMC) SST temperatures from the National Center of Environmental Prediction in Washington DC, which are contained in the ECMWF forecast data, and the temperatures contained in the radiosonde data are transformed into theoretical measured radiances. This transformation is performed by application of Planck's law and the corresponding emissivity factor, calculation of the atmospheric absorption and filtering the attenuated radiance due to the spectral response function of the corresponding imaging channel. The atmospheric absorption is calculated for the IR channel radiation emitted by the sea surface according to the forecasted temperature and humidity profiles, and for the WV channel radiation according to the measured profiles of the radiosondes. The radiances that can be expected to have been measured by the satellite are then linearly correlated with the counts actually measured by the satellite.

If no forecast data is available then the IR channel calibration is not performed. The same applies for the WV channel calibration in the case that no radiosonde data has been received.

2.5.5.4.3 Segment Processing

SEG provides the measured IR mean count and the potentially semi-transparency corrected IR and WV mean counts which are calculated by means of the Semi-Transparency Correction Table provided by RAD.

2.5.5.4.4 CDS Product Generation

The CDS product provides the inversely attenuated measured IR mean count and the inversely attenuated, potentially semi-transparency corrected IR mean count. Therefore, the CDS product generation process derives from the IR mean counts provided by SEG the corresponding inversely attenuated IR mean counts by calibrating them to measured radiances, converting the measured radiances to incident radiances by applying the inverse spectral response function and derive the emitted radiances by an inverse attenuation calculation (the last two processing steps are performed by

applying the IR Radiation Atmospheric Absorption Table from RAD) which are then inversely calibrated to counts.

The potentially semi-transparency corrected WV count remains unchanged as provided by SEG.

2.5.5.4.5 CMW Product Generation

The CMW product generation process uses the potentially semi-transparency corrected IR mean counts to determine the height of the cloud tracers. If several clouds are close enough together according to a threshold then they are merged. The merged potentially semi-transparency mean count is calibrated to a measured radiance which is converted to an incident radiance and then inversely attenuated to an emitted radiance. The emitted radiance is transformed into a black body temperature according to Planck's law and the emissivity factor of clouds. The black body temperature is used to determine the cloud's height from the forecasted temperature/pressure profile.

2.5.5.4.6 SST Product Generation

The SST product values describe the skin temperature of the sea. The values are derived from the warmest 3*3 superpixel mean counts of those segments where a sea cluster has been identified. A transformation of the IR superpixel mean count into a black body temperature by means of calibration, application of the inverse spectral response function, inverse attenuation calculation and application of the emissivity factor of sea and Planck's law is therefore performed.

2.5.5.4.7 CLA Product Generation

Since the CLA product generation process deals with the temperature and the pressure at the cloud top it has to transform the potentially semi-transparency corrected IR mean count of the cloud cluster into a black body temperature by means of calibration, application of the inverse spectral response function, inverse attenuation calculation and application of Planck's law and the emissivity factor of clouds. The black body temperature is used to determine the cloud's height from the forecasted temperature/pressure profile.

2.5.5.4.8 UTH Product Generation

The UTH product generation process deals with the measured IR and WV radiances. Consequently, the measured IR and WV mean counts need merely be calibrated to measured radiances. The measured radiances are used to derive an upper tropospheric humidity value from the Upper Tropospheric Humidity Generation Table provided by RAD.

2.5.5.4.9 CTH Product Generation

The CTH product generation process deals with superpixels of 3*3 original IR image pixel counts. In order to determine the height of the radiation emitting scene for each superpixel, an attempt is made to correct the mean IR count of the superpixel for semi-transparency, using the warmest IR cluster of the segment as background. The minimum of the potentially semi-transparency corrected IR superpixel mean and the coldest IR pixel of the superpixel is taken as the characteristic superpixel value. An

inverse attenuation calculation need not be performed since the Radiance/Pressure Table used for the height assignment is based on measured IR radiances. Consequently, the characteristic superpixel count merely might need be calibrated to a measured radiance to determine the height or, as it is implemented, to inversely calibrate the measured radiances stemming from clouds at a level of the bounds of the height classes to IR counts.

2.5.5.4.10 PI Product Generation

The PI product generation process takes the IR counts directly from the segmented image. There is no interface to SEG. The IR pixel counts of a segment are calibrated to measured radiances which are converted into attenuated radiances by applying the inverse spectral response function. The attenuated radiances are converted into brightness temperatures according to Planck's law. The statistics of the PI product are produced by sorting the image pixels into predefined temperature intervals according to their corresponding brightness temperature.

2.5.5.4.11 IDS Product Generation

The IDS product generation process takes the required information directly from the image file. There is no interface to SEG. No pixel count transformation is required.

2.5.5.4.12 Scenes Prediction and Segment Processing Feedback

SEG provides IR mean counts that are equivalent to the radiances measured by the satellite's sensor according to its spectral response function. SCE predicts the scenes characteristics in terms of theoretical measured IR counts so that the cluster classification process can compare like with like. The predicted IR counts are derived by SCE from the forecasted temperature and humidity profiles by applying Planck's law, scene specific emissivity factors, atmospheric absorption calculations, the spectral response function and calibration.

The cluster classification process of SEG compares the potentially semi-transparency corrected IR mean counts with the predicted IR counts since the potentially semi-transparency corrected IR mean count is the characteristic value of a potentially semi-transparent cloud and not the original measured IR mean count which might be contaminated by the radiation of scene below.

The difference between the measured mean count of a classified cluster and the predicted counts of the corresponding scene is used by SCE as a feedback to adjust the predictions for the next image slot. Since the location and the appearance of clouds might change very rapidly from slot to slot the feedback mechanism is not applied to clouds.

2.6 Normalisation of VIS Channel Data

The bi-directional reflectance data used by SCE to predict the VIS channel characteristics of the scenes contained in the segments are adjusted by a normalisation factor, ie the secant of the sun zenith angle. SCE does not compensate for this normalisation. Consequently, the VIS counts predicted by SCE are normalised.

SEG performs the image data analysis on the original non normalised VIS counts. When it comes to the classification of the extracted image histogram clusters the VIS mean counts of the clusters are converted to normalised counts to allow the classification process to deal with likes when it compares the extracted cluster characteristics with the predictions. The output of SEG contains, nevertheless, non normalised VIS counts. So does the CDS product.

When SEG feedback, ie the difference between prediction and extraction, from the previous slot is available SCE normalises the non normalised VIS mean counts from SEG for the feedback purpose.

2.7 Calibration of the Imaging Channels

The interpretation of the image pixel counts as provided by the satellite is very much dependent on the performance of the radiometer, ie the mapping of the radiation incident on the radiometer onto the image pixel counts. This mapping is not a time independent function since aging of the electronics, on board temperature variation (diurnal, eclipse) and ice contamination (due to moist air carried aloft during lift-off of the satellite) of the sensors have an impact on the radiometer's performance. Therefore, it is tried within MPEF to determine and compensate such changes of the mapping function. The mapping of incident radiation onto pixel counts is, for that purpose, split within MPEF per spectral channel into two functions.

The first function takes into account that the sensors' sensitivity varies within the spectral range of the corresponding image channel causing the contribution of the incident radiation to the pixel counts to be dependent not only on the radiation's frequency but also on the sensor's spectral response function. Consequently, the spectral response function describes the mapping of the incident radiation onto the measured radiance.

The second function describes the mapping of the measured radiance onto the pixel counts modelling the electronics and the A/D converter of the imaging channel. This function is assumed to be linear.

It is to be noted that the spectral response functions are determined by measurements on ground and that changes of them due to e.g. aging and ice contamination cannot directly be measured once the satellite is in orbit. The spectral response functions are therefore regarded as static. Nevertheless, changes in the spectral response functions are compensated in MPEF in one step together with changes of the measured radiance to pixel counts mapping functions by a process performing an (inverse) linear calibration of the imaging channels. The linear calibration might not describe the effects fully correctly when changes in the spectral response functions are involved since the impact is probably nonlinear.

2.7.1 Gain Changes and Decontamination

A deterioration of the performance of the radiometer indicates itself by the fact that the pixel counts are not spread any more over the optimum dynamic range of 0 to 255. Nevertheless, such a deterioration can be compensated for by spacecraft control operations. The simplest measure is to change the sensitivity of the thermal IR and WV channels by gain changing telecommands (change of the gain level by one step corresponds to a change of the sensitivity by about 20%). If the range of possible gain changes (level 0 to 15) is exhausted a decontamination process has to be carried out to remove the ice contamination from the thermal sensors by electrical heating followed by a gain change of several steps to desensitize the sensors. Usually, a decontamination is already performed before gain

level 15 is reached since an increase of the gain not only amplifies the sensitivity of the sensor but also the noise in the signal.

To interpret the image pixel counts in terms of physical units (radiance or temperature derived from the radiance) MPEF calibrates the pixel counts. Any gain change is reflected by changing the calibration function accordingly. But, for the generation of high quality meteorological products from the satellite images the adjustment of the calibration coefficients in steps of 20% following gain changes is far too rough. Therefore, two different methods of calibration have been made available to allow compensation of slight changes in the mapping function.

2.7.2 Black Body Calibration

The first method makes use of on-board black body radiators of well known temperature that allows to establish directly the relation between radiation and pixel counts. A disadvantage of this method is that the black body radiation does not follow the full optical path of the radiometer. Since the effect of the part of the optical path left out is not known, the black body calibration method cannot be used for an absolute calibration of the radiometer.

Another hindering fact is that the on-board black body mechanism does not work for both Meteosat 4 and 5.

2.7.3 MPEF Absolute Calibration

The second method tries to perform an absolute calibration of the radiometer's IR and WV channel sensors by linearly correlating certain IR and WV mean counts derived from the image segments with theoretical radiances that can be expected to have been measured by the satellite. The theoretical radiances are derived from observed meteorological values which are received from external sources.

For the calibration of the IR channel, the warmest 3*3 IR superpixel mean counts of the segments where mainly sea clusters have been identified by SEG, i.e. the SST product values (in the form of measured IR counts) are used for the correlation calculation. The theoretical IR radiances are derived from collocated NCEP (NMC) SST values contained in the forecast data provided by ECMWF by transforming the measured temperatures into emitted radiances according to Planck's law and the emissivity factor of sea, determining the attenuated radiances exiting the top of the atmosphere in the direction of the satellite by calculating the atmospheric absorption on the basis of the forecast temperature and humidity profiles and convoluting the attenuated radiances with the spectral response function of the IR sensor.

In the case of the WV channel calibration, the theoretical WV radiances are calculated on the basis of the measured temperature and humidity profiles contained in radiosonde observation bulletins received from the GTS. The correlated WV mean counts are the means of the WV image pixels of collocated segments that do not contain classified (by SEG) medium and high cloud clusters.

This vicarious calibration method provides only some sort of absolute calibration of the radiometer. The radiation incident to the radiometer cannot directly be measured and needs to be estimated based on surface temperature data in case of the IR channel radiation and on radiosonde temperature and humidity measurements in case of the WV channel radiation. Therefore, a disadvantage of this method is that not only the radiometer is calibrated but, in addition, also several MPEF algorithms including the Radiation Scheme with its radiation transfer calculations, the SST product generation process and

to some extent also Segment Processing and the previous calibration (see Detailed Algorithm Descriptions). Furthermore, the method is dependent on the quality of the external meteorological observations and the forecasts. There is also the problem of the comparability of MPEF's SST values being sea surface skin temperature and the NCEP (NMC) SST observations being something else (bulk temperature). Also the generally small amount of radiosonde data is problematic, since if even just only a few are of minor quality then this has quite an impact on the WV channel calibration. Nevertheless, the above described absolute calibration method is the one that is routinely used in MPEF.

2.7.4 Calibration of the VIS Channel

A calibration of the VIS channel is not supported by equipment aboard the satellite. A VIS channel calibration might be carried out off-line by comparing the VIS channel information with measurements carried out aboard an aircraft flying at high altitude. Such calibration campaigns were performed for Meteosat 1 and 2 (Koepke 1982, Kriebel 1981) and for Meteosat 4 and 5 by the Deutsche Forschungsanstalt für Luft- und Raumfahrt DLR (Kriebel and Amman, 1990 and 1995). A calibration of the VIS channel of Meteosat 6 is outstanding.

During the above calibration campaigns a vicarious calibration of the Meteosat visible channels was performed by means of an absolutely calibrated radiometer aboard a high altitude aircraft which had a similar spectral sensitivity looking into the same direction as the Meteosat radiometer. Correction for the atmosphere above the aircraft was made prior to the calculation of the linear correlation between the corrected radiance measurements and the VIS channel counts delivered by Meteosat. Since both the corrected VIS radiance measurements and the VIS channel counts reflect the effect of the spectral response functions of the VIS channel sensors of the satellite the determined calibration coefficients relate measured radiance and measured counts as the IR channel calibration coefficients do. Therefore, SCE would need (but currently not done) to convolute the predicted VIS radiance exiting the top of the atmosphere with the VIS channel spectral response function to get the predicted measured radiance before it calibrates it to the predicted count.

The VIS channels calibration coefficients are not dynamically adjusted within MPEF and are fixed as long as they are not updated.

2.8 Verification of Products

The meteorological observations data fulfil a second purpose in the MPEF in addition to the channel calibration, that is the verification of the quality of the MPEF products. Since the observations data arrive hours after their measurement and since the timely collocated MPEF products have already been distributed when the observations data arrive, the retrospective comparison of the data cannot be used for the automatic quality control of the products. Nevertheless, the verification statistics are a good measure of the product quality and might give rise to a start of investigations in the case that the deviations are too big.

2.9 Rectified Image Data Input

The images provided consist of a set of images simultaneously taken by the geostationary satellite in three different spectral ranges called channels:

- 2 images in the visible channel VIS based on the radiation between 0.4 and 1.1 micrometre wavelength
- 1 image in the infrared channel IR based on the radiation between 10.5 and 12.5 micrometre wavelength
- 1 image in the watervapour channel WV based on the radiation between 5.7 and 7.1 micrometre wavelength.

The two VIS images are combined into one VIS image of 5000 * 5000 pixels. The IR and WV images are images of 2500 * 2500 pixels. The spatial resolution of the VIS images is about 2.5 km * 2.5 km at the sub-satellite point (SSP), the resolution of the IR and WV images is about 5.0 km * 5.0 km. The radiometric resolution of the image pixels is 8 bit for all three channels.

The sensors (plus electronics) of the satellite's radiometer integrate the radiation incident on them during short periods of time according to their wavelength dependent response functions. The resulting voltages are transformed by the A/D converter into digital counts, the image pixel values.

The radiation measured by the satellite in the VIS channel is the radiation of the sun in the VIS channel band passing the atmosphere towards the earth, being reflected to some extent by objects (later on in the document called scenes, ie sea, land surface types, clouds at different height levels), passing then the atmosphere towards the satellite, being incident on the VIS sensors and measured according to the sensors' spectral response. High pixel values correspond to high radiance values, ie high brightness, and are usually displayed on an MWS using bright grey levels. Clouds, therefore, appear white. Nevertheless, the MWS allows any colour table to be used.

The radiation measured by the satellite in the IR channel is the radiation emitted by warm bodies (ie scenes) in the IR channel band, attenuated by absorption and re-emission at other wavelengths when passing the atmosphere, being incident on the IR sensor and measured according to the sensor's spectral response. The radiation emitted by a scene is the radiation of an ideal black body of the same temperature corrected by an emissivity factor specific to the scene. Low pixel values correspond to low radiance values, ie low temperature, and are usually displayed on an MWS using bright grey levels to make clouds appear white. Warm surface areas like desert during local day time appear dark.

The radiation measured by the satellite in the WV channel is the radiation emitted by warm bodies in the WV channel band, attenuated by absorption and re-emission at other wavelengths when passing the atmosphere, being incident on the WV sensor and measured according to the sensor's spectral response. The radiation emitted by a scene is the radiation of an ideal black body of the same temperature corrected by an emissivity factor specific to the scene. So far, there is no principal difference to the IR channel. Nevertheless, the information contained in the WV channel data tells something else. Since the infrared radiation with a WV channel wavelength is likely to be absorbed by water vapour in the atmosphere it is not likely that the satellite can see such infrared radiation emitted at the earth's surface as the absolute content of water vapour in the lower atmosphere is too high. What the satellite normally sees is infrared radiation stemming from gas molecules of the atmosphere above about 600 hPA or from medium or high clouds that was not absorbed by water vapour at higher levels. Consequently, high pixel values indicate that the satellite could see the IR radiation emitted by warm (lower) atmosphere levels and that the atmosphere above was relatively dry (in terms of absolute humidity). The WV channel data, therefore, provide information about the water vapour contents in the medium and upper atmosphere. To make medium and high clouds appear white low pixel values are displayed on an MWS using bright grey levels.

The image channel most important to the meteorological product extraction is the IR channel. When the IR channel information is missing it is not possible to classify properly radiating or radiation reflecting scenes on earth. This is obvious for the WV channel images since they normally do not show any details of the earth's surface. But also the VIS images do not provide characteristic enough data for a usable classification; and, most times of the day, parts or the whole imaged earth disc are underilluminated. Nevertheless, the VIS and WV image data are used to improve the classification based on the IR channel data; the WV channel information only indirectly through the correction of the characteristics of semi-transparent clouds.

The images fed into MPEF are pre-processed such that all image pixels are remapped onto a reference image corresponding to an image taken by a Meteosat satellite located at its nominal position over the equator (at the Greenwich meridian) and with nominal attitude, ie with its spin axis parallel to the spin axis of the earth, rotating with 100 rpm and imaging such that the centre of the earth disc is placed in the centre of the image, all image lines being well aligned and the pixels of the different image channels with identical pixel coordinates providing information of the same area of the earth (this is not natural since the different imaging sensors are not exactly pointing into the same direction). This "rectification" pre-processing is performed by the Image Processing System IPS and removes, by and large, all distortions contained in the "raw" images of a "non-nominal" satellite. It is to be noted that the projection of the reference image is that of an imaging Nominal Meteosat satellite and is not to be mixed with a perspective projection or any other one. The IPS does not correct for effects distorting the radiation measurements (eg moon affecting the DC restore signal) apart from an radiometric equalisation of the two VIS channels.

Non rectified images are not processed by MPEF since the derived quantitative values cannot properly be assigned to a geometric location.

2.10 Meteorological Forecast Data Input

The European Centre for Medium-Range Weather Forecasts ECMWF provides twice a day meteorological forecast data via the Global Telecommunication System GTS formatted as GRID bulletins according to the specification FM 47-IX Ext. of the Manual on Codes, WMO - No. 306.

One forecast data set is derived from meteorological synoptic midday observations and arrives about 22:00 UTC at MPEF. It contains 12, 18, 24, 30 and 36 hours forecasts with a base time of 12:00 UTC. The second forecast data set is derived from synoptic midnight observations and arrives about 04:00 UTC containing 6, 12, 18, 24 and 30 hours forecasts with a base time of 00:00 UTC. The validity times of the different forecast data sets are therefore:

midday run:	24:00	06:00	12:00	18:00	24:00		
							UTC
midnight run:		06:00	12:00	18:00	24:00	06:00	
							UTC
midday run:				24:00	06:00	12:00	18:00 24:00

UTC.

The forecast data consist of temperature, humidity and wind profiles defined for several height levels on a 1 degree grid; the surface temperatures of sea being the SST data produced by the National Center of Environmental Prediction NCEP (former NMC) in Washington DC. The forecast bulletins are

decoded at MPEF and the gridded data sets are "segmented" by interpolation onto the centres of the image segments and onto the height levels of the Radiation Scheme model.

Normally every six hours, in the middle between two forecast validity times, the Radiation Scheme derives from the next valid forecast the Atmospheric Absorption Table, the Semi-Transparency Correction Table and the Upper Tropospheric Humidity Table.

2.11 Meteorological Observations Data Input

The MPEF receives from the GTS via the GTS Interface Element following meteorological observations bulletins:

Upper-Air Bulletins:

- WMO TEMP FM 35-IX Ext. : Rawinsonde and radiosonde observations
- WMO TEMP SHIP FM 36-IX Ext. : Rawinsonde and radiosonde observations
- WMO PILOT FM 32-IX : Significant wind information
- WMO AIREP : Wind and temperature information obtained by aircraft

Surface Observation Bulletins:

- WMO SYNOP FM 12-IX Ext : Surface observations
- WMO SHIP FM 13-IX Ext : Surface observations.

The bulletins are provided twice a day with validity times of 12:00 UTC and 24:00 UTC.

These bulletins are decoded by MPEF and are used for the calibration of the WV channel and for the verification of MPEF products.

3. ALGORITHMS DESCRIPTION

In this chapter, an overview is given over the individual algorithms for the generation of MPEF's meteorological products. It was attempted not to clutter the description by too many details making it difficult for a reader to grab the principal ideas. The algorithms are described in detail in the Detailed Algorithm Descriptions chapter.

The reader of this chapter is expected to have read the chapter "Introduction into the Algorithms Subsystem".

3.1 Scenes Prediction (SCE)

3.1.1 Scenes Prediction Output Description

Scenes Prediction provides for each segment of the SEG processing area predictions of characteristics of scenes of the earth's surface (sea, different types of land) known being present in the segment according to the Surface Reflector Map and of clouds at three different standard height levels. The scenes are characterized in terms of means and standard deviations of IR and VIS counts that are expected to be measured by the satellite; WV characteristics of the scenes are not predicted. The predicted VIS counts are normalised.

The predicted scenes characteristics are complemented with indications in which segments containing sea the characteristics are effected by sunglint and which segments are under-illuminated.

3.1.2 General Algorithm Information

3.1.2.1 Algorithm Name

MTP/MPEF Scenes Prediction

3.1.2.2 Outline Algorithm Description

Sufficiently detailed information is provided in the chapters "Prediction of the Characteristics of Scenes", "Scenes Prediction and Segment Processing Feedback" and "Normalisation of VIS Channel Data".

In addition, Scenes Prediction provides the sun and spacecraft azimuth and zenith angles at the centre of each segment for the time when the satellite scans the segment centre. Knowing these angles Scenes Prediction calculates in which segments containing sea sunglint will occur and which segments will be underilluminated according to a threshold. Those segments are flagged accordingly.

3.1.2.3 Spectral Channels

Scenes Prediction concerns itself only with predicting the IR and VIS characteristics of scenes.

3.1.2.4 Domain of Application

Since Scenes Prediction provides input to the Segment Processing its domain of application is normally the same as for Segment Processing.

3.1.2.5 Algorithm Maturity

The algorithm is essentially the same as the one that has been in use for some years in ESOC/MIEC.

3.1.2.6 Origin/History

The algorithm is essentially the same as the one that has been in use for some years in ESOC/MIEC.

3.1.2.7 Evolution from Original Algorithm

The algorithm is essentially the same as the one that has been in use for some years in ESOC/MIEC.

3.1.3 Physical Principles

Scenes Prediction relies on combining knowledge already stored about the presence of different reflector types within a segment with forecast temperature and humidity profiles to predict IR radiances and bi-directional reflectances to predict VIS radiances. These basic predictions are refined using information gained from the analysis of previous extracted scenes.

3.1.4 Assumptions and Limitations

3.1.4.1 Physical Assumptions

- 1) The forecast profiles and static data (e.g. bi-directional reflectances) are assumed to be correct.
- 2) The knowledge about known reflector types in a segment is assumed to be correct.

3.1.4.2 Physical Limitations

- 1) The number of reflector types that may be detected is limited by the global (static) definition of these data.

3.1.4.3 Mathematical Assumptions

None identified.

3.1.4.4 Mathematical Limitations

- 1) VIS radiances are not corrected for atmospheric attenuation.
- 2) The predicted VIS radiances are not convoluted with the VIS spectral response function prior to their calibration to the VIS counts expected to be measured.

3.1.5 Possible Validation Methods

None currently identified

3.1.6 Suggested Quality Indicators

3.1.6.1 Input Data Quality

- 1) Quality/availability of forecast data
- 2) Quality/availability of previous extracted cluster data

3.1.6.2 Internal Processing Quality

- 1) The degree of illumination (possible poor quality near to the day/night boundary).

3.1.7 Potential for Future Improvement

Not yet investigated

3.1.8 References

ESA/MDMD, 1980: Meteorological Products. METEOSAT System Guide, Vol. 5.

Diday, E., 1971: Une nouvelle méthode en classification automatique et reconnaissance des formes. Revue de Statistique Appliquée - Vol XIX No. 2.

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Tomassini, C., 1981: Integrated Processing, ESOC MDMD-MET Technical Note, MDMD T.N.(1).

3.2 Segment Processing (SEG)

3.2.1 Segment Processing Output Description

The output from the Segment Processing task consists of a description of the characteristics of all the clusters that were extracted for each rectified image segment contained in the SEG processing area in terms of the contribution from all three spectral channels (IR, VIS and WV). The cluster characteristics consist of the cluster classifier, the number of the image pixels forming the histogram cluster, the means and the standard deviations per spectral component. Added is the potentially semi-transparency corrected IR mean count. The WV mean count is as well potentially semi-transparency corrected. The cluster characteristics are accompanied with segment specific data like the latitude/longitude coordinates of the segment centre and the sun and spacecraft azimuth and zenith angles.

The extracted clusters are grouped into three classes. Clusters that were identified as produced by the radiation of scenes known (surface reflectors) or predicted (clouds) to be contained in the segments are classified by the type of the scenes (sea, different ground types, clouds at different heights). Clusters that were not identified are marked as unclassified. From the pixels which could not be assigned to the extracted clusters so-called contamination clusters are derived.

3.2.2 General Algorithm Information

3.2.2.1 Algorithm Name

MTP/MPEF Segment Processing

3.2.2.2 Outline Algorithm Description

The main functional structure of Segment Processing can be summarized as :

- Segment Cluster Extraction using Multispectral Histogram Analysis
- Semi-Transparency Correction
- Cluster Classification

Segment Cluster Extraction using Multispectral Histogram Analysis

Multispectral Histogram Analysis is a statistical method for locating and isolating different reflector types that are present in a segment by the creation and analysis of multi-dimensional histograms derived from the image data. A two-dimensional (2-D) histogram derived from the image segment can be regarded as a two-dimensional surface in a three-dimensional space where one dimension is given by the possible IR counts, another by the possible counts of another imaging channel and the third dimension by the frequency of occurrence of pixels with the same pair of IR and the other channel counts. These histograms, which represent the distribution of pixels based on their spectral content, contain peaks which may be interpreted as indicating the presence of discrete reflector types. For example, in the case of the 2-D IR/VIS histogram, pixels in the very cold (IR) and very bright (VIS)

part of the histogram could indicate the presence of high cloud. The actual mechanism for isolating histogram peaks is based on the construction and analysis of the component one-dimensional histograms and is a complex multi-step process that is described in detail in the Detailed Algorithm Descriptions chapter. The significant peaks are used to define histogram clusters that contain a certain part of the surroundings of the peaks. In constructing a cluster, it is assumed that the pixel counts stemming from the radiation of one reflector type are Gaussian distributed around the peak. The clusters are characterized by statistical parameters such as the number of pixels contributing to the cluster, the mean count and the standard deviation per spectral component of the histogram subset forming the cluster.

Generally, after the cluster extraction, not all pixels of the histogram could be assigned to the extracted clusters. From the residual set of histogram pixels so-called contamination clusters are extracted and added to the output of SEG. Contamination clusters with mean counts being extremer than the ones of the extracted clusters are assumed to be caused by real radiating objects and are, therefore, assigned to the set of extracted clusters.

Semi - transparency Correction

The Semi-Transparency Correction Table produced by the Radiation Scheme is used by SEG to check whether the IR and WV mean counts of a cluster are characteristic for an opaque reflector or whether a part of the contributing radiation might have originated from surfaces and then passed through thin (semi-transparent) clouds or that have come from an area of sub-pixel scale clouds (see Radiation Model algorithm description). Segment Processing uses the table values to attempt to correct detected radiances for semitransparency and includes the potentially semi-transparency corrected mean IR count in the description of the cluster.

Cluster Classification

For each of the extracted clusters the scenes predicted by SCE are examined for the one which is closest and close enough (according to a threshold) to the cluster. The distance measure used is based on the IR and VIS means of the extracted cluster and the predicted scene and the standard deviations of the predicted scene. The IR mean of the extracted cluster used is the potentially semi-transparency corrected IR mean in order to take into account the potential semi-transparency of clouds and the extracted VIS mean is transformed into a normalised one since the predicted VIS count is normalised. It is to be noted that the WV data is not used for the cluster classification since SCE does not predict WV characteristics. The extracted cluster is classified by the type of the closest predicted scene if the classification criterion is fulfilled. The classification forms an essential output of the Segment Processing algorithm. If a cluster does not fulfil the classification criterion for all predicted scenes of the segment then the cluster is flagged as unclassified.

No attempt is made to classify contamination clusters (see last paragraph of "Segment Cluster Extraction using Multispectral Histogram Analysis" above).

3.2.2.3 Spectral Channels

All three spectral channels (IR, VIS and WV) are normally involved in the identification of scenes. Nevertheless, four processing modes can be distinguished depending on the availability of the spectral channel data:

1. IR only
2. IR and VIS
3. IR and WV
4. IR and WV and VIS

When VIS channel data is available in addition to the IR channel data then the classification of the extracted histogram clusters is, in general, better. Available WV channel data allow the cluster characteristics of clouds to be corrected for semi-transparency resulting in a better height assignment and, consequently, in a better classification. The optimum is, of course, that data from all three channels are available.

If IR channel data is not available then no product can be produced with the exception of the IDS product.

3.2.2.4 Domain of Application

a) Geographical :

Assuming that segmentation of rectified image data uses a segment size of 32*32 pixels then the area of view of each image is contained within a matrix of 80*80 such segments. The areas of the Earth located at the edges of the Earth disk are not normally processed as they are too distorted. The precise area that is processed is the subject of an operational configurable parameter. An overriding consideration is that of the processes that derive quantitative meteorological information from the results of Segment Processing and which limit their processing to an area within a 55° great circle arc of the sub-satellite point.

b) Time / Season :

Segment Processing is performed on every image regardless of date or time.

3.2.2.5 Algorithm Maturity

The algorithm is essentially the same as the one that has been in use for some years in ESOC/MIEC.

3.2.2.6 Origin/History

The algorithm is essentially the same as the one that has been in use for some years in ESOC/MIEC.

3.2.2.7 Evolution from Original Algorithm

The algorithm is essentially the same as the one that has been in use for some years in ESOC/MIEC.

3.2.3 Physical Principles

The presence of discrete reflector types within an image segment is detected by isolating and classifying their 'finger prints' in terms of the contributions made to them by radiances in all three spectral bands. No account is taken of the geographical locations of the reflectors within a segment but simply their presence is detected and all pixels that fall within the defined boundaries for their discrete existence are combined. The classification (physical identification) of the reflectors is performed using a prediction based on what one might expect to see in a segment in the prevailing circumstances (especially with respect to the time of year and time of day) refined by what was observed in the previous slot (i.e. 30 minutes before). Clearly, in the event of missing image data this feedback refinement process does not contribute to the prediction and, therefore, scene extraction is somewhat degraded until continuous image data is restored.

3.2.4 Assumptions and Limitations

3.2.4.1 Physical Assumptions

- 1) Radiating surfaces within an image segment which have similar radiative characteristics are assumed to belong to the same discrete surface even though they may be geographically separated.
- 2) The distribution of the radiance emitted or reflected by a reflector being present in a segment is assumed to be Gaussian.

3.2.4.2 Physical Limitations

- 1) The effective area from which quantitative use may be made of radiance values for the identification of radiating surface is limited to about a 60 degree arc around the sub-satellite point.
- 2) The number of reflector types that may be detected is limited by the global (static) definition of these data.

3.2.4.3 Mathematical Assumptions

None identified

3.2.4.4 Mathematical Limitations

- 1) The use of information extracted from one image to predict the information that may be present in the following image clearly imposes a limitation on the extraction and classification of clusters.
- 2) The multispectral histogram analysis performed as it is in the case of three spectral channels is probably inappropriate in the case of data from more channels being available (e.g. MSG satellite).

3.2.5 Possible Validation Methods

None currently identified

3.2.6 Suggested Quality Indicators

3.2.6.1 Input Data Quality

- 1) The quality of the rectification of the image data could be incorporated, however, since the rectified image segments are received in near real time and the rectification process can compute an overall quality indicator only at the end of the image this quality information is only available a posteriori.
- 2) Availability of spectral channels and underillumination (i.e. VIS data not usable).
- 3) Scenes prediction refinement performed by feedback of cluster extraction results from previous image processing.

3.2.6.2 Internal Processing Quality

- 1) A measure of the emergence of a cluster from its surroundings could be used. This measure could be defined as the number of pixels above the 3σ Gaussian approximation divided by the total number of pixels within the 3σ interval.
- 2) A measure of the contamination of a cluster could be incorporated. This measure could be defined as the number of assigned contamination pixels divided by the sum of the number of pixels covered by the 3σ Gaussian approximation plus the number of contamination pixels.

3.2.7 Potential for Future Improvement

Not yet investigated.

3.2.8 References

ESA/MDMD, 1980: Meteorological Products. METEOSAT System Guide, Vol. 5.

Diday, E., 1971: Une nouvelle méthode en classification automatique et reconnaissance des formes. Revue de Statistique Appliquée - Vol XIX No. 2.

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Tomassini, C., 1981: Integrated Processing, ESOC MDMD-MET Technical Note, MDMD T.N.(1).

3.3 Radiation Scheme (RAD)

3.3.1 Radiation Scheme Output Description

The output from the radiation scheme consists of tables describing the radiative state of the atmosphere under a range of atmospheric conditions and viewing angles. The tables are :

- tables describing the amount of absorption by the atmosphere at 11 μ m
- tables relating tropospheric humidity to the 11 μ m and 6 μ m radiances
- tables relating the effect of opaque cloud at different heights to the 11 μ m and 6 μ m radiances (to allow semi-transparent cloud to be identified and corrected)
- a table relating the measured IR radiances from clouds at different pressure levels to the pressure level and the corresponding height in metres

The tables are specific to each segment and are based on the forecast temperature and humidity profiles allocated to the segment.

3.3.2 General Algorithm Information

3.3.2.1 Algorithm Name

MTP/MPEF Radiation Scheme

3.3.2.2 Outline Algorithm Description

The Radiation Scheme consists of :

- Meteorological Data Preparation
- IR Radiative Transfer Calculations
- WV Radiative Transfer Calculations
- Radiation Table Generation

a) Meteorological Data Preparation

- 1) The forecast meteorological profiles allocated to the segment are used as input to describe the state of the atmosphere. The forecast data are supplemented by data describing the atmospheric composition for the radiatively active gases. Climatological data describing atmospheric aerosols are also used.
- 2) The profiles are interpolated to the atmospheric levels used by the radiation model.

b) IR Radiative Transfer Calculations

- 4) The area of the electromagnetic spectrum covering the spectral range of the Meteosat IR channel is tiled into small spectral intervals which depend on the position and size of absorption lines and of continuum absorption. The radiation exiting from the atmosphere must be calculated in each of these small spectral bands.
- 5) The atmosphere is tiled into a number of shallow homogeneous layers whose mean properties are described using the atmospheric data. The temperature is assumed to vary linearly with optical depth within the layer. The temperatures at the top and bottom of the layer are taken from or interpolated from the atmospheric profiles.
- 6) The radiation emitted by the surface in each spectral interval is calculated using the forecast surface temperature and surface emissivity, the latter depending on surface type.
- 7) In addition to the radiance emitted by the surface, the surface also reflects back downward propagating radiation emitted from the lowest layers of the atmosphere. This is calculated empirically based on the air temperature and humidity near the surface.
- 8) Starting from the lowest level of the atmosphere, the radiation emitted and absorbed in the atmospheric layer in each spectral interval is calculated from the temperature and humidity of the layer. These calculations use the absorption coefficients of the radiatively active gases and aerosols of the appropriate concentration.
- 9) The proportion of the radiation which enters the bottom of a layer and passes through that layer is calculated using the absorption coefficients for the absorbing gases and aerosols being considered. The total amount of radiation leaving the top of an atmospheric layer is the sum of the radiation entering the bottom layer and being transmitted through the layer plus the radiation being emitted by the layer.
- 10) The total amount of radiation exiting from the top of the atmosphere is the net radiation exiting the uppermost layer in the direction of the satellite.
- 11) The theoretical radiance which would have been measured by the IR channel of Meteosat is calculated by convoluting the amount of radiation exiting at each wavelength with the spectral response of the channel.

Note: The convolution of the radiation exiting the top of the atmosphere in the direction of the satellite with the spectral response function of the satellite's IR sensor is implemented such that the radiation emitted by the radiating surface is convoluted and also the radiation emitted by each atmospheric layer but not the radiation from lower layers passing through the layer without absorption.

c) **WV Radiative Transfer Calculations**

- 12) The WV radiances are calculated in an analogous way to the IR radiances, except that the absorption coefficients will be different and that, in the case of radiation at $6\mu\text{m}$, there is a negligible contribution from the surface because of the normally high amount of water vapour molecules in the lower atmosphere absorbing the radiation in the WV channel band.

d) **Radiation Table Generation**

d.1) **Atmospheric Absorption Tables**

- 13) The Atmospheric Absorption Tables represent the amount of absorption at the spectral range of the satellite's IR sensor. These tables are based entirely on the IR channel radiation results. Since it is not known in advance whether there will be cloud in the segment and since the surface temperature may be in error, the tables are computed for a cloud-free situation and for opaque cloud at any of the standard levels. In the cloud-free situation the results are produced for the surface temperature and a temperature being the surface temperature increased by a

fixed temperature increment. There is one table for each segment, i.e. for specific viewing angles and atmospheric conditions.

- 14) In their final form the Atmospheric Absorption Tables list the Planck radiance of any of these surfaces (and thus the corresponding surface temperature) as a function of satellite-measured IR radiances.

d.2) Semi-Transparency Correction Tables

- 15) The Semi-Transparency Correction Tables are computed to express the combination of IR and WV radiances which would be measured for opaque cloud at one of the standard atmospheric levels. These tables therefore require both WV and IR radiative transfer results. The tables express the WV radiance as a function of IR radiance for opaque cloud and for the cloud-free scene at each of the standard meteorological levels. The temperature and humidity profiles used are the forecast profiles.

d.3) Upper Tropospheric Humidity Generation Tables

- 16) The Upper Tropospheric Humidity Tables provide measured IR and WV radiances (i.e. the radiances that are likely to be measured by the satellite according to its spectral response function) for several atmospheric conditions as clear sky and clouds at 850 hPa and 700 hPa (as well as for clouds at 500, 300 and 200 hPa, but this part of the tables is not relevant since the UTH product generation process excludes their usage for classified medium and high cloud and contamination clusters). The measured radiances are calculated by performing radiation transfer calculations taking into account the effect of the spectral response function of the satellite's IR and WV channel sensors. The radiation transfer calculations make certain assumptions concerning the atmospheric profiles. At heights from surface up to 600 hPa the forecasted temperature and humidity profiles are used. Above 600 hPa, the temperature profile used is the forecasted one, whereas the forecasted humidity profile is not used. Instead, the transfer calculations are made for a set of mean humidities of 1 %, 5 %, 10 %, 20 %, 40 % and 100 % taken as constant in the range of 600 hPa to 400 hPa and decreasing linearly to 0 % between 400 hPa and 100 hPa. The value of 400 hPa was chosen since it led to the best UTH product results as a study investigating several "lid" values showed.

For each of the processing segments, the Upper Tropospheric Humidity Tables provide for each of the constant humidity profiles the theoretical measured IR and WV radiances for clear sky and clouds at 850 hPa and 700 hPa. The WV radiances corresponding to a completely dry atmosphere and to a completely saturated atmosphere are computed to represent maximum and minimum radiance thresholds. These tables therefore allow the actual humidity between 600 and 400 hPa to be estimated from the measured IR and WV radiances. Although these tables are being 2 dimensional, they are not completely filled since only certain combinations of IR and WV radiance are possible when allowing for variation in the humidity between 600 and 400 hPa.

d.4) Radiance/Pressure Table

- (17) The table provides, for each segment, the theoretical IR radiances expected to be measured by the satellite according to the spectral response function of the IR sensor for a set of opaque clouds at different pressure levels. The theoretical measured IR radiances are related to the corresponding pressure levels for which also their heights in metre are provided. The theoretical IR radiances are estimated by means of IR channel radiation transfer calculations

which are based on the forecasted temperature and humidity profiles. The heights are determined by calculating the thickness of the pressure layers due to the barometric equation and summing up, for each layer, the thickness of the layers underneath.

3.3.2.3 Spectral Channels

The Radiation Transfer Model does not use any Meteosat spectral channels, however, it uses the spectral response functions of the IR and WV channels to simulate not only the radiances which would have exited from the top of the atmosphere in the direction of the satellite under the atmospheric conditions described but also the radiances that would have been measured by the satellite sensors.

3.3.2.4 Domain of Application

a) Geographical :

There are no geographical restrictions on the use of the radiative transfer model, although the results are likely to be more accurate at temperate latitudes where the atmosphere contains less water vapour.

b) Time / Season :

There are no time based restrictions on the use of the radiative transfer model.

3.3.2.5 Algorithm Maturity

The radiative transfer model proposed for use in MPEF is based on the model currently in use in the MIEC. This model has been in operational use in substantially the same form since 1986.

3.3.2.6 Origin / History

The first radiative transfer used in the MIEC was computationally too slow to be used routinely. Therefore all the radiation tables were pre-computed on the basis of a set of model atmospheres. These model atmospheres were originally derived from a large set of actual radiosonde profiles chosen to represent a wide range of meteorological conditions. All the MIEC radiation tables were computed from the model atmospheres. At each MIEC segment, the forecast atmospheric profiles received each day were used to select the model atmosphere which was most similar in radiative terms using a measure of similarity. The radiative tables appropriate to the most similar model atmosphere at that segment were then used for routine product generation.

In 1986 the original MIEC radiative transfer model was replaced by a computationally fast radiative transfer model which could be used routinely to compute the appropriate radiative tables directly from the forecast atmospheric profiles. It is essentially this model which is used in the MPEF.

3.3.2.7 Evolution from Original Algorithm

The radiative model used within the MIEC is used in a largely unchanged form within the MPEF.

3.3.3 Physical Principles

The radiative transfer model is based on the principle that the land / sea surface radiates an amount of radiation in each direction and at each wavelength which depends only on the temperature of the surface and its emissivity. The relationship between temperature, radiance and wavelength is expressed by the well known Planck's law :

$$B_{\lambda}(T) = \frac{c_1}{\lambda^5 (\exp(\frac{c_2}{\lambda T}) - 1)}$$

where λ is the wavelength, T is the temperature and c_1 and c_2 are the standard radiative constants. $B_{\lambda}(T)$ is the Planck radiance at wavelength λ and temperature T.

For the sea surface, the sea radiates almost as a black body, i.e. it has an emissivity close to 1. Black bodies are efficient radiators and absorbers of radiation. The amount of absorption and radiation can be calculated using Planck's law. A small amount of radiation reaching the sea surface is reflected back towards space. The reflectivity of the sea surface varies with the angle of incidence of the radiation.

Land surfaces typically do not behave as black bodies and have an emissivity which is less than 1 and which varies with the surface type. They therefore radiate (and absorb) an amount of radiation which is less than the theoretical maximum indicated by Planck's law.

Similarly the atmosphere radiates in all directions according to its temperature, but in addition it may absorb some of the radiation reaching it from elsewhere. The amount of atmospheric absorption depends on the composition of the atmosphere, but is influenced most strongly by atmospheric water vapour. Other atmospheric gases absorb radiation, however, unlike water vapour their concentrations in the atmosphere do not vary significantly. The absorption of a gas is defined by its absorption coefficient, κ . The amount of radiation which the gas allows to pass unabsorbed is known as the transmissivity, τ , and is :

$$\tau = \exp \{ - \kappa \cdot x \} \quad \text{where } x \text{ is path length}$$

If the state of the atmosphere and of the surface are known in terms of their temperature structure and composition and if the absorption coefficients are known, it is possible to estimate the radiation at each wavelength which will be emitted by, absorbed by and be transmitted through the atmosphere and hence will eventually exit from the top. By stating these principles in mathematical form, the well known radiative transfer equation for a non-scattering and horizontally homogeneous atmosphere, which is in local thermodynamic equilibrium, is obtained :

$$L(p', \theta) = L_{SFC} + \int_p^{p_{SFC}} B[T(p)] \frac{\partial \tau}{\partial p} dp$$

$$L(p', \theta) = L_{SFC} \tau(p', \theta) + \int_p^{p_{SFC}} B[T(p)] \frac{\partial \tau}{\partial p} dp$$

where $L(p', \theta)$ is the upward radiance at the pressure level p' , L_{SFC} is the radiance emitted from the surface, τ is the atmospheric transmittance between the surface and the level p' , θ is the satellite viewing (zenith) angle relative to the surface of the segment, B is the Planck function depending on the temperature $T(p)$ at pressure p . The integration goes from the bottom of the atmosphere to the top.

This equation is solved by treating the atmosphere as a number of shallow layers of uniform composition and state. The amount of radiation which will reach the layer from below, how much will pass through the layer and how much will be emitted by the layer is evaluated for each layer. By integrating each small layer up through the atmosphere the total radiance exiting from the top of the atmosphere can be calculated.

Atmospheric absorption normally occurs at very specific, sharply defined wavelengths which are related to atomic transitions within the gas molecules. This is known as line absorption. In the case of water vapour, however, there is also absorption which occurs due to weak chemical bonds between water vapour molecules. These cause vibrational effects which occur over a wide waveband and is known as continuum absorption.

3.3.4 Assumptions and Limitations

3.3.4.1 Physical Assumptions

- 1) That only the following gases contribute to the radiative properties of the atmosphere :
 - water vapour (line and continuum absorption)
 - carbon dioxide
 - oxides of nitrogen
 - ozone
 - methane

The effects of atmospheric dust are also taken into account.

- 2) That also aerosols contribute to the radiative properties of the atmosphere.

3.3.4.2 Physical Limitations

- 1) The results are likely to be less accurate in areas of high water vapour concentration.
- 2) The model can only be used for wavelengths where scattering by atmospheric particles is negligible, i.e. the model does not consider scattering processes.

3.3.4.3 Mathematical Assumptions

- 1) That the atmosphere can be represented with sufficient accuracy as discrete, shallow layers.
- 2) The meteorological data used in the radiation predictions are unbiased.

- 3) There is negligible atmospheric scattering at the wavelengths of interest.

3.3.4.4 Mathematical Limitations

- 1) Radiative transfer calculations are computationally intensive. Improvements in the fidelity of the model or an increase in the resolution of the model may only be achieved by significantly increasing the computational load.

3.3.5 Possible Validation Methods

One possible validation method would be to compare the results obtained from MPEF radiation transfer model with other models using the same input data and comparing the results. The comparison could be against one of the more complete models and any areas of difference investigated. Unfortunately it is not usually possible to say with certainty which set of results is the more accurate. The LOWTRAN transmission model is often seen as the standard model and could therefore be used in a comparison.

Another method would be to compare the radiances calculated with the model with radiances obtained from another well calibrated satellite with similar spectral channels to Meteosat. The atmospheric structure could be obtained from actual radiosonde ascents collocated in space and time with the raw radiances obtained from the other satellite.

3.3.6 Suggested Quality Indicators

3.3.6.1 Input Data Quality

- 1) The age of the forecast atmospheric profiles.
- 2) Whether the concentrations of the other absorbing gases e.g. ozone and carbon dioxide were based on climatology or some form of observational data.

3.3.6.2 Internal Processing Quality

- 1) An indication of the amount of water vapour in the atmosphere which will influence the accuracy of the results.
- 2) The resolution of the atmosphere into layers and the number of spectral intervals used in the model.

3.3.7 Potential for Future Improvement

- 1) It may be possible to improve the accuracy of the model by increasing the number of atmospheric levels or the resolution of the spectral intervals. This will probably require a trade-off against an increasing computational load.
- 2) The atmospheric composition profiles which are climatologically based could be replaced with observational data, particularly with ozone whose composition varies and is currently estimated from satellite observation. A similar procedure may also be applicable to aerosols.
- 3) The atmospheric turbidity could be estimated from Meteosat VIS imagery.

3.3.8 References

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3.4 Calibration of IR Channel

3.4.1 IR Calibration Output Description

The IR calibration output consists of the IR calibration coefficient α_{IR} and the IR space count. It also includes associated timing information and quality indices based on the success of the IR calibration extraction process.

3.4.2 General Algorithm Information

3.4.2.1 Algorithm Name

Within MPEF, the calibration of the IR channel is influenced by three different information sources. The algorithms involved are :

- MTP/MPEF IR Calibration Update due to IR Channel Gain Changes
- MTP/MPEF Absolute IR Calibration Derivation Using Sea Surface Temperature Data
- MTP/MPEF Relative IR Calibration Derivation Using Black Body Data

3.4.2.2 Outline Algorithm Description

The general purpose and the different methods of the calibration of the IR channel have already been described in the chapter "Calibration of the Imaging Channels" and its subchapters. This chapter describes briefly the implementation of the different calibration algorithms.

a) Calibration Update due to Gain Changes

Changes in the gain (sensitivity) of the IR channel are invoked by telecommands usually uplinked during the radiometer's retrace phase. A gain change becomes therefore effective already during the retrace, and the new gain level value is reported to MPEF in the header records of the image of the next slot. Relevant to MPEF is that a gain change does not happen during the forward scan, since MPEF would not be able to compensate the jump in the pixel values in the middle of an image.

When a gain change is indicated in the image header records, MPEF immediately modifies the current operational IR channel calibration coefficient by 20 % per gain level step. MPEF uses the updated IR calibration coefficient already in the current slot.

b) Absolute Calibration Using Sea Surface Temperature

The absolute calibration of the WV channel is performed in two steps. First, instantaneous calibration coefficients are calculated and, from these in a second step, the operational calibration coefficient is derived. The instantaneous coefficients are not directly used by the MPEF product generation processes and are not distributed to the end users (via the HRI dissemination). The calculation strategy is dependent upon whether it is eclipse season or not.

Every half an hour an instantaneous calibration coefficient is calculated. Twice a day, in slots 16 and 40, a selection of the latest instantaneous calibration coefficients is averaged.

Outside the eclipse season: The mean is calculated from the latest 24 instantaneous calibration coefficients.

During the eclipse season: The mean is calculated from the latest 6 instantaneous calibration coefficients of the slot in question, i.e. slot 16 or 40.

If the mean deviates by more than a configurable value (± 0.0002) from the current operational calibration coefficient the mean becomes the new operational calibration coefficient.

The steps in the derivation of the instantaneous IR calibration coefficient are :

- 1) The MPEF SST product is defined by the warmest 3x3 IR sea pixel mean in segments where sea clusters have been classified by SEG. The segments where an MPEF SST has been defined and where the cloud amount is less than a particular percentage (currently 25%) are selected.
- 2) At those segments, the nearest atmospheric temperature and humidity profiles obtained from the forecasts are assembled and supplemented by a sea surface temperature taken from the NCEP (NMC) SST analysis.
- 3) Using the Temperature/Radiance Table and the Atmospheric IR Radiation Absorption Table provided by RAD, the radiation emitted by the sea surface according to its temperature and the attenuation of the radiation through its way through the (forecasted) atmosphere towards the satellite are calculated. Since both tables take account of the IR channel spectral response function, the calculated theoretical IR channel radiance is the radiance that the satellite is expected to have measured.
- 4) A quality check is applied by using the current IR calibration coefficient to convert the theoretical measured IR radiance into the corresponding engineering count and comparing this with the measured 3*3 IR pixel mean count which corresponds to the MPEF SST at those collocations. The measured count should be close to the count estimated from the theoretical radiance and the current calibration factor. Those segments where this quality check fails are removed from further processing.
- 5) Over the remaining segments, the mean C of the warmest 3*3 IR pixel mean counts and the mean L of the theoretical measured IR radiances are calculated.
- 6) From these means, the IR calibration coefficient, α_{IR} , is computed using :

$$\alpha_{IR} = \frac{L}{C - C_0} 4$$

where C_0 is the space count when the radiometer is viewing space in the area of the image surrounding the Earth's disc. The corresponding space radiance L_0 is regarded to be 0.

Note: The space count C_0 is not derived from the space pixels in the image. It is put into the algorithm as an algorithm parameter.

Note that this is not a standard least squares linear regression process since the calibration slope is the line which joins the space point to the mean sea cluster point.

c) **Relative Calibration Using Black Body Data**

The relative calibration processing is designed to compensate for small changes in the radiometer response. The procedure is based on data from the 2 on-board black bodies. The temperatures of the 2 black bodies are telemetered along with the count difference when viewing them. The cold black body acts as the zero reference point. The relative calibration factor is used to compensate for any small changes in detector response which may occur after the absolute IR calibration factor has been derived. This adjustment will only be required if the absolute IR calibration factor cannot be derived for some reason. In this case the relative calibration factor would be used to make small adjustments to the most recently calculated absolute IR calibration factor.

The steps in the derivation of the IR relative calibration factor are :

The precise method has not yet been defined.

3.4.2.3 Spectral Channels

The IR Calibration is entirely based on IR channel data.

3.4.2.4 Domain of Application

a) Geographical :

The domain of application of the IR calibration extraction is limited by the coverage of the SST product (currently 55° around the SSP). The coefficient can be computed over any sea area where the sea clusters satisfy the specified quality checks.

b) Time / Season :

There may be a seasonal dependence on the quality of the IR calibration coefficient due to the effects of satellite eclipse. The quality of the coefficient is also likely to be better during the day than during the night when the segment processing may not discriminate as well between low cloud and the sea surface without the use of VIS data. The quality may also be lower when the IR detector is affected by contamination and therefore operating at a higher gain. At higher gain settings, the IR noise increases.

3.4.2.5 Algorithm Maturity

The implemented MPEF IR absolute calibration technique using SST is based on the MIEC techniques. A relative calibration technique called the Fine Adjustment of Gain was used until 1988. The new relative calibration method using the 2 on-board black-bodies will be a new method, but one based on well defined principles.

3.4.2.6 Origin / History

Initially there was no formal IR operational calibration technique within the MIEC. A value for the IR calibration was simply chosen so that the MIEC SST based on it was climatologically unbiased.

A relative calibration technique known as the Fine Adjustment of Gain (FAG) was implemented in 1979 to reduce short-term variations in the MIEC calibration coefficient.

In the early 1980s a formal MIEC calibration method was introduced which minimised the bias between the MIEC SST and collocated ship temperature observations. The radiation processing was indirect and used the model atmospheres which were derived using the MIEC radiation model in operation at that time. This method was upgraded in 1986 when the new direct radiation model of Schmetz was introduced and when the ship temperature measurements were replaced by an NCEP (NMC) temperature analysis.

Because of a mechanical malfunction of the spacecraft (Meteosat 4 + 5), the relative calibration technique using the 2 on-board black bodies has not yet been implemented.

3.4.2.7 Evolution from Original Algorithm

The MPEF calibration method using SST is basically the same as the MIEC calibration method. The relative calibration method using the 2 on-board black bodies is new.

3.4.3 Physical Principles

The calibration principle depends on deriving the calibration coefficient which represents how the radiometer's sensor, electronics and A/D converter respond to incident radiation. The calibration coefficient is simply the factor of proportion between the input radiance measured according to the IR channel sensor's response and the output voltage counts.

The technique assumes that the detector system responds linearly to changes in radiance input. This relationship is established before launch by laboratory test.

The on-board black body is an object which radiates an amount of radiation which depends only on its temperature T . The amount of radiation emitted with a wavelength λ can be obtained using Planck's law.

$$B_{\lambda}(T) = \frac{c_1}{\lambda^5 (\exp(\frac{c_2}{\lambda T}) - 1)} 5$$

where λ is the wavelength, T is the temperature and c_1 and c_2 are the standard radiative constants. $B_{\lambda}(T)$ is the Planck radiance at wavelength λ and temperature T .

This equation is the basis of the calibration technique using the on-board black bodies. In principle a knowledge of the black body temperatures allows the radiance emitted within the waveband to which the radiometer is sensitive to be computed.

While it would be convenient to use the on-board black bodies for calibration, absolute calibration is not possible because the optical path for the on-board calibration is different from the path through which radiation originating from the Earth reaches the radiometer. Part of the optical chain cannot be monitored by the on-board calibration technique and so the on-board black bodies can only be used to indicate relative changes in radiometer sensitivity.

The absolute calibration method uses a knowledge of the actual sea surface temperature and the atmospheric temperature and humidity profiles at that position to compute the 11 μm radiation which would theoretically reach the satellite's radiometer, and to equate this radiation with the radiometer voltage count actually measured. This is the current MPEF calibration method.

Unfortunately the use of MPEF products and models within the calibration process actually calibrates the total computational chain as well as the radiometer. Any transient biases in either the meteorological data used in the calculation or in the radiative transfer model itself are calibrated out in this process.

3.4.4 Assumptions and Limitations

3.4.4.1 Physical Assumptions

- 1) The IR channel radiometer responds linearly to changes in radiative input.
- 2) The on-board black body is a true black body.
- 3) The spectral response of the IR radiometer remains fixed and as measured in the laboratory.

3.4.4.2 Physical Limitations

- 1) The linearity of the radiometer.
- 2) The presence of cloud contamination in the sea cluster, especially thin cirrus which could reduce the count attributed to the sea.

3.4.4.3 Mathematical Assumptions

- 1) The meteorological data used in the radiation predictions are unbiased.
- 2) The radiative transfer model is unbiased.

3.4.4.4 Mathematical Limitations

- 1) The accuracy of the forecast atmospheric profiles and the sea surface temperature analysis.
- 2) The accuracy of the radiation model.
- 3) The presence of undetected cloud contamination in the sea segments.

3.4.5 Possible Validation Methods

The calibration coefficient can be validated either through the effect it has on the products derived using it, or it can be validated directly by other methods. Sea surface temperature is the most appropriate product for an indirect evaluation because it is completely temperature based. Any differences between the MPEF SST and another independent SST measurement such as the NCEP (NMC) SST analysis or against observational data could indicate an error in the IR calibration coefficient. However these differences could also arise from other sources including:

- biases in SST due to deficiencies in the extraction method such as cloud contamination etc

- errors in the product being used as the validation standard, especially if also derived from satellite data
- errors in observational data due to different parameters being measured, for instance a bulk temperature instead of a skin temperature or due to differences in spatial scale.

Some possible validation methods could be :

- 1) Calibration using the moon as the target [Gay et al, 1978]. Because it has no atmosphere the moon should make an ideal calibration target. Previous studies, however, have not been able to achieve stable results.
- 2) Cross-calibration using other satellites with more accurate on-board calibration.

3.4.6 Suggested Quality Indicators

3.4.6.1 Input Data Quality

Some possible indicators of IR calibration quality would be :

- 1) The age of the forecast profiles used.
- 2) The IR channel noise level.
- 3) An indication of whether VIS data were used to detect sea clusters.
- 4) Whether the calibration was derived from a 'cold' or 'warm start'.
- 5) An indication of the number of 'contamination' pixels identified by the histogram analysis process.

3.4.6.2 Internal Processing Quality

- 1) The gain of the IR channel.
- 2) The total number of sea segments used.
- 3) The variability of the coefficient as estimated by each individual collocated pair of theoretical radiance and measured count.

3.4.7 Potential for Future Improvement

In the case of calibration using the SST, many of the potential improvements to the IR calibration would arise from improvements to the cluster extraction and identification and the radiation model. Other improvements could be to implement one of the other methods described in the section on validation. Some possible improvements are :

- 1) Make more use of either the WV data or UTH products to indicate regions of potential cirrus cloud affecting the sea cluster.
- 2) Select only those segments where the amount of classified sea pixels exceeds 75% of the segment's pixels (like MIEC did) to minimise the risk of contamination by thin clouds.

3.4.8 References

Gärtner, V., 1988 : MIEC IR Calibration Derived from Cloud-free Sea Pixels. Proc. of the 7th Meteosat Scientific Users' Meeting, Madrid, September 1988, EUMP04.

Köpke, P., 1980 : Absolute Calibration of the METEOSAT VIS and IR Channel by Ground Measurements. Proc. of the 2nd Meteosat Scientific Users' Meeting, London, EUMP.

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3.5 Calibration of VIS Channel

3.5.1 VIS Calibration Output Description

The VIS calibration output consists of a single parameter, α_{VIS} , the VIS calibration coefficient. It also includes associated timing information and quality indices based on the success of the VIS calibration extraction process. Note that the VIS calibration coefficient will only be calculated on an occasional basis using data obtained during special calibration campaigns. The VIS calibration factor will probably not be calculated in the MPEF but will be obtained from external researchers. The value obtained by researchers will be used operationally within the MPEF.

3.5.2 General Algorithm Information

3.5.2.1 Algorithm Name

MTP/MPEF VIS Calibration Generation

(There will be no internally implemented MPEF VIS Calibration routine. An externally calculated VIS calibration value will simply be entered into the MPEF system.)

3.5.2.2 Outline Algorithm Description

There will be no internal VIS calibration algorithm.

3.5.2.3 Spectral Channels

The VIS Calibration is entirely based on VIS channel data.

3.5.2.4 Domain of Application

a) Geographical :

The coefficient can be computed over any geographical region.

b) Time / Season :

There is no seasonal dependence on the derivation of the VIS calibration coefficient.

3.5.2.5 Algorithm Maturity

There is currently no VIS calibration method, either operational or under development in the MIEC. The VIS calibration coefficients in operational use have been derived externally by Köpke [1980] and Kriebel [1980]. The techniques of Köpke and Kriebel have been in use at least since the late 1970s.

3.5.2.6 Origin / History

There is currently no VIS calibration method, either operational or under development in the MPEF.

3.5.2.7 Evolution from Original Algorithm

There is currently no VIS calibration method in the MPEF.

3.5.3 Physical Principles

The VIS calibration principle is the same as for the IR and WV channels, however, there are significant additional difficulties.

As with IR and WV calibration, the VIS calibration technique depends on deriving the calibration coefficient which represents how the radiometer responds to radiation measured according to the VIS channel sensor's spectral response and what voltage output (count) it gives for a given radiance input. The calibration coefficient is simply the factor of proportion between input radiance and output counts. The technique assumes that the detector system responds linearly to changes in radiance input, which is established before launch by laboratory test.

While the principle remains the same, there are significant problems in calculating the VIS channel coefficient, namely :

- 1) The VIS channel measures reflected solar radiation, not radiation emitted by the body governed by well defined physical laws as in the case of infra-red radiation.
- 2) Different reflecting bodies reflect different proportions of the incident solar radiation. The reflecting properties of the surface may also vary with the angle of the incident radiation and the viewing angle of the satellite.
- 3) The reflecting characteristics of each body change with the wavelength of radiation within the broad spectral waveband covered by the VIS channel.
- 4) The effects of the atmosphere on the incoming and reflected radiation varies with wavelength within the VIS waveband.
- 5) The calculation of the VIS radiation requires a scattering model rather than a radiative transfer model.

Fortunately the VIS calibration remains fairly constant, and so any value derived will remain appropriate for a long period of time. There is also relatively little requirement to know the VIS calibration accurately for the current generation of MPEF products. None of the MPEF products depends on a knowledge of the absolute amount of VIS radiation reflected. It is sufficient that relative changes can be detected. While the computation of the bidirectional reflectance tables, which are used to predict the radiances reflected by specific surfaces, depends on a knowledge of the VIS calibration factor, a feedback loop in Segment Processing compensates for small errors in the VIS calibration factor.

3.5.4 Assumptions and Limitations

3.5.4.1 Physical Assumptions

- 1) The radiometer responds linearly to changes in radiative input.
- 2) The spectral response of the VIS radiometer remains fixed and as measured in the laboratory.

3.5.4.2 Physical Limitations

- 1) The interaction of the surfaces with the incident radiation is described empirically rather than by modelling the physical processes at work.

3.5.4.3 Mathematical Assumptions

- 1) The scattering model is unbiased.

3.5.4.4 Mathematical Limitations

- 1) The reflection model is empirical rather than physical.

3.5.5 Possible Validation Methods

Some possible validation methods could be :

- 1) Cross-calibration using other satellites with accurate on-board calibration.

3.5.6 Suggested Quality Indicators

3.5.6.1 Input Data Quality

- 1) The range of conditions over which the empirical relations are determined.
- 2) The number of different reflecting surfaces from which the calibration value can be derived.

3.5.6.2 Internal Processing Quality

There will be no internal VIS calibration algorithm. The quality indicators will be those supplied by the agency which derives the VIS calibration coefficient.

3.5.7 Potential for Future Improvement

- 1) Obtain the Köpke or Kriebel scattering model and implement as part of the MPEF.

3.5.8 References

Kriebel, K., 1980 : Calibration of the METEOSAT VIS Channel. Proc. 2nd METEOSAT Scientific Users' Meeting, London, EUMP

Köpke, P., 1980 : Absolute Calibration of the METEOSAT VIS and IR Channel by Ground Measurements. Proc. of the 2nd Meteosat Scientific Users' Meeting, London, EUMP.

3.6 Calibration of WV Channel

3.6.1 WV Calibration Output Description

The WV calibration output consists of the WV calibration coefficient α_{WV} and the WV space count. It also includes associated timing information and quality indices based on the success of the WV calibration extraction process.

3.6.2 General Algorithm Information

3.6.2.1 Algorithm Name

Within MPEF, the calibration of the WV channel is influenced by three different information sources. The algorithms involved are :

- MTP/MPEF WV Calibration Update due to WV Channel Gain Changes
- MTP/MPEF Absolute WV Calibration Derivation Using Tropospheric Humidity Data.
- MTP/MPEF Relative WV Calibration Derivation Using On-Board Black Body Data

3.6.2.2 Outline Algorithm Description

The general purpose and the different methods of the calibration of the WV channel have already been described in the chapter "Calibration of the Imaging Channels" and its subchapters. This chapter describes briefly the implementation of the different calibration algorithms.

a) Calibration Update due to Gain Changes

Changes in the gain (sensitivity) of the WV channel are invoked by telecommands usually uplinked during the radiometer's retrace phase. A gain change becomes therefore effective already during the retrace, and the new gain level value is reported to MPEF in the header records of the image of the next slot. Relevant to MPEF is that a gain change does not happen during the forward scan, since MPEF would not be able to compensate the jump in the pixel values in the middle of an image.

When a gain change is indicated in the image header records, MPEF immediately modifies the current operational WV channel calibration coefficient by 20 % per gain level step. MPEF uses the updated WV calibration coefficient already in the current slot.

b) Absolute Calibration Using Tropospheric Humidity from Radiosonde Ascents

The absolute calibration of the WV channel is performed in two steps. First, instantaneous calibration coefficients are calculated and, from these in a second step, the operational calibration coefficient is derived. The instantaneous coefficients are not directly used by the MPEF product generation processes and are not distributed to the end users (via the HRI dissemination). The calculation strategy is dependent upon whether it is eclipse season or not.

Outside the eclipse season: Twice a day, in slots 16 and 40, an instantaneous calibration coefficient is calculated using information derived from the image of slot 48 respectively 24. From the 6 most recent instantaneous calibration coefficients, i.e. usually from the last 3 days, an averaged coefficient is derived in the following way. The mean and the standard deviation of the 6 values are calculated. Since the instantaneous values vary much, the outliers that deviate by more than 1 standard deviation from the mean are discarded and, from the remaining ones, a final mean is calculated. This final mean is a candidate for an update.

During the eclipse season: The process for the calculation of the instantaneous calibration coefficient that runs in slot 16 uses the information derived from the image of slot 46 instead of 48.

If the final mean deviates by more than a configurable value ($\pm 1\%$) from the current operational calibration coefficient the mean becomes the new operational calibration coefficient.

The steps in the derivation of the instantaneous WV calibration coefficient are :

- 1) Segments where no high level or medium level cloud have been detected are selected.
- 2) At those segments where a collocation is possible, atmospheric temperature and humidity profiles obtained from actual radiosonde ascents are assembled.
- 3) The atmospheric profiles are interpolated in height to the levels used by the Radiation Model and are input into the MPEF Radiation Model to calculate the amount of radiation emitted by the different levels of the atmosphere and the effect of the atmospheric absorption in the WV channel band. The Radiation Model must be used directly in this process since no tables are available which have used the radiosonde humidity profiles. (This is not the case for IR calibration for which appropriate tables already exist). Since the radiation transfer calculations take also account of the WV channel spectral response function, the calculated theoretical WV channel radiance is the radiance that the satellite is expected to have measured.
- 4) All those collocations are excluded from the calculation of the instantaneous WV calibration coefficient where the mean measured WV count deviates by more than a given threshold from the theoretical count which is derived from the theoretical radiance by calibrating it using the current operational WV calibration coefficient.
- 5) From the remaining collocations, the mean measured WV count (over all collocations), C , and the mean theoretical measured radiance (L) are computed.
- 6) From these means, the WV calibration coefficient, α_{WV} , is computed :

$$\alpha_{WV} = L / (C - C_0),$$

where C_0 is the space count when the radiometer is viewing space in the area of the image surrounding the Earth's disc. The corresponding space radiance L_0 is regarded to be 0.

Note: The space count C_0 is not derived from the space pixels in the image. It is put into the algorithm as an algorithm parameter.

Note that this is not a standard least squares linear regression process since the calibration slope is the line which joins the space point to the mean cluster point.

c) **Relative Calibration**

The relative calibration processing is designed to compensate for small changes in the radiometer response. The procedure is based on data from the 2 on-board black bodies. The temperatures of the 2 black bodies are telemetered along with the count difference when viewing them. The cold black body

acts as the zero reference point. The relative calibration factor is used to compensate for any small changes in detector response which may occur after the absolute WV calibration factor has been derived. This adjustment is required because the absolute WV calibration factor is only derived twice daily.

The steps in the derivation of the WV relative calibration factor are :

The precise method has not yet been defined.

3.6.2.3 Spectral Channels

The WV calibration method is entirely based on WV (6 μ m) channel data.

3.6.2.4 Domain of Application

a) Geographical :

The coefficient can be computed over any geographic region free from high or medium cloud close to a radiosonde station.

b) Time / Season :

There may be a seasonal dependence on the quality of the WV calibration coefficient due to the effects of satellite eclipse. The quality may be lower when the WV detector is affected by contamination and therefore operating at a higher gain. At higher gain settings, the WV noise increases.

3.6.2.5 Algorithm Maturity

The implemented MPEF WV absolute calibration technique using tropospheric humidity data is based on the operational MIEC techniques which have been in operational use since about 1985. The relative calibration method using the on-board black-body data would be a new technique, but one based on well defined principles.

3.6.2.6 Origin / History

Initially there was no formal WV calibration technique operational within the MIEC. The WV calibration coefficient was simply chosen so that the MIEC UTH extracted was climatologically reasonable.

In the early 1980s, a formal MIEC calibration method was introduced based on minimising the bias between the MIEC UTH product and collocated radiosonde humidity profiles. The radiative transfer processing was indirect and used the model atmospheres which were derived using the MIEC radiation model which was in operation at that time. This method was replaced in 1986 when the new direct radiation transfer calculation using measurements made during radiosonde ascents was introduced.

The relative calibration method using the 2 on-board black bodies can only be adopted when the black body scanning mechanism can be used. The system has been in place since Meteosat 4, but has not been used because of a mechanical malfunction.

3.6.2.7 Evolution from Original Algorithm

The MPEF calibration method using temperature and humidity profiles is basically the same as the MIEC calibration method. The relative calibration method using the 2 on-board black bodies will be new however.

3.6.3 Physical Principles

The calibration principle depends on deriving the calibration coefficient which represents how the radiometer's sensor, electronics and A/D converter respond to incident radiation. The calibration coefficient is simply the factor of proportion between the input radiance measured according to the WV channel sensor's response and the voltage counts output by the WV detector. The technique assumes that the detector system responds linearly to changes in radiance input. This relationship is established before launch by laboratory test.

The on-board black body is an object which radiates an amount of radiation which depends only on its temperature T. The amount of radiation emitted with a wavelength λ can be obtained using Planck's law.

$$B_{\lambda}(T) = \frac{c_1}{\lambda^5 (\exp(\frac{c_2}{\lambda T}) - 1)} 6$$

where λ is the wavelength, T is the temperature and c_1 and c_2 are the standard radiative constants. $B_{\lambda}(T)$ is the Planck radiance at wavelength λ and temperature T.

This equation is the basis of the calibration technique using the on-board black bodies. In principle a knowledge of the black body temperatures allows the radiance emitted within the waveband to which the radiometer is sensitive to be computed.

While it would be convenient to use the on-board black bodies for calibration, absolute calibration is not possible because the optical path for the on-board calibration is different from the path through which radiation originating from the Earth reaches the radiometer. Part of the optical chain cannot be monitored by the on-board calibration technique and so the on-board black bodies can only be used to indicate relative changes in radiometer sensitivity. With early Meteosats it was not possible for the WV radiometer to monitor the black bodies at all.

Because of the limitations of black body calibration, an alternative absolute calibration method was developed. This calibration method used a knowledge of the actual atmospheric temperature and humidity profiles to compute the 6.3 μm radiation which should reach the satellite's radiometer and equate this with the corresponding WV radiometer voltage count. This is the current MPEF calibration method.

Unfortunately the use of MPEF products and models within the calibration process actually calibrates the total computational chain as well as the radiometer. Any transient biases in either the

meteorological data used in the calculation or in the radiative transfer model itself are calibrated out in this process.

3.6.4 Assumptions and Limitations

3.6.4.1 Physical

- 1) The WV channel radiometer responds linearly to changes in radiative input.
- 2) The on-board black body is a true black body.
- 3) The spectral response of the radiometer remains fixed and as measured in the laboratory.
- 4) If an absolute WV calibration scheme using the on board black bodies is to be defined, some way may need to be devised to estimate the effect of the part of the optical system not monitored during the black body view.

3.6.4.2 Mathematical

- 1) The meteorological data used in the radiation predictions are unbiased.
- 2) The radiative transfer model is unbiased.

3.6.5 Possible Validation Methods

The WV calibration coefficient can either be validated through the effect it has on the products derived or it can be validated directly by other methods. The Upper Tropospheric Humidity product is the most appropriate product for an indirect evaluation because it is highly dependent on the WV calibration. Any differences between the MPEF UTH and another independent humidity measurement could indicate an error in the WV calibration coefficient. The independent humidity measurements would need to be integrated over a fairly deep atmospheric layer to mimic the contribution function of the WV channel, i.e. the degree to which each vertical level in the atmosphere contributes to the eventual WV radiance exiting from the top of the atmosphere. Such differences could arise from other sources including :

- biases in UTH extraction due to deficiencies in the extraction method such as contamination from high level cloud, especially cirrus
- errors in the product being used as the validation standard. Humidity observations are notoriously variable
- errors in observational data due to different parameters being measured, or errors in the contribution function used or due to differences in spatial scale.

Some possible validation methods could be :

- 1) Calibration using the moon as the target [Gay et al, 1978]. Because it has no atmosphere the moon should make an ideal calibration target. Previous studies, however, have not been able to achieve stable results.
- 2) Cross-calibration using other satellites with accurate on-board calibration.

3.6.6 Suggested Quality Indicators

3.6.6.1 Input Data Quality

- 1) The WV channel noise level.
- 2) An indication of whether VIS data were used to extract the clusters used in the mean WV count.
- 3) Whether the calibration was derived from a 'cold' or 'warm start'.
- 4) The accuracy of the humidity data.
- 5) The accuracy of the observed atmospheric profiles.
- 6) The accuracy of the radiation model.
- 7) The linearity of the radiometer.

3.6.6.2 Internal Processing Quality

- 1) An indication of the number of 'contamination' pixels identified.
- 2) The presence of high cloud contamination, especially thin cirrus.
- 3) The accuracy of the Radiation Model.

3.6.7 Potential for Future Improvement

Many of the potential improvements to the WV calibration would arise from improvements to the cluster extraction and identification and the radiation model. Other improvements could be to implement one of the other methods described in the section on validation. Some possible improvements are :

- 1) Make more use of either the WV data or the UTH product on pixel or superpixel level to indicate regions of potential cirrus cloud which would affect the measured WV radiance.
- 2) In the calculation of the WV mean count over the collocated segments, use only the means of classified clusters such as leaving out contamination and unclassified clusters.

3.6.8 References

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3.7 Cloud Motion Wind (CMW) Product

3.7.1 Product Description

The global observation of the atmospheric winds is an important goal for atmospheric and oceanic climatological studies and for operational forecasting. Satellite wind speed and direction are a valuable input in numerical weather prediction. The CMW product from ESOC/MIEC was used on a routine basis in the data assimilation process of numerical forecast models with a widely recognized quality. In order to provide the users with some more information, additional effort is put in developing CMW quality estimates which will be included in future MPEF products.

The MPEF CMW product is a segmented product. It is computed by trying to identify and to localize, for each segment of the CMW processing area, the same cloud pattern in the previous and the succeeding image. The present MPEF CMW algorithm derives winds from all three spectral channels data. Automatic Quality Control (AQC) is performed on all the IR, the WV and the VIS winds. The "best" one from each segment is put into the final CMW product which can be scheduled for Manual Quality Control (MQC).

The CMW product consists, per segment of the CMW processing area, of the following parameters of the "best" wind, if such one was found there:

- Wind location
- Wind speed in m/s
- Wind direction in tens of degrees (in degrees is foreseen)
- Temperature in K
- Pressure level in tens of hPa

Main synoptic hour delivery

The CMW product is distributed after a full quality control (AQC and MQC) four times per day at the main synoptic hours 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC.

Intermediate fast delivery

The remaining 12 intermediate CMW products which only undergo AQC, but not MQC, could principally also be distributed to the end user, but this is currently not done.

Note: During eclipse periods the times of some deliveries may have to be modified depending on the satellite capability.

3.7.2 General Algorithm Information

3.7.2.1 Algorithm Name

MTP/MPEF Cloud Motion Winds (CMW) Generation

3.7.2.2 Outline Algorithm Description

The MPEF CMW algorithm measures the displacement of cloud patterns between currently 3 slots of images and through this displacement computes the wind vectors. The algorithm structure is based on a single-slot wind extraction (between two subsequent slots) and a combination concept which allows full flexibility and optimal realtime processing. It foresees extraction of the winds in all three METEOSAT image channels, the VIS channel data currently being subsampled to IR channel data resolution. An algorithm to derive wind vectors from the full resolution VIS data is available but not operationally used yet..

In MPEF, it is possible to extract single-slot winds every half hour, for a geographical domain of a 55° circle around the sub-satellite point. The extraction process can run in two different modes. In the backward correlation mode, it is tried to localize cloud patterns (tracers) found in the segments of a target image also in the previous image, the search image, and to derive from the displacement of the patterns in the two images the wind speed and direction parameters. In the forward correlation mode, the same analysis is performed using the succeeding image as the search image. Currently, in MPEF, the winds of a backward correlation are combined with the winds of a forward correlation using the same slot as target in the two correlation processes. The target slot is therefore the central slot of a consecutive triplet of images. Since the same target slot is used, there is no problem in identifying "half-winds" belonging together, perform a consistency check on them with respect to speed and direction, and combine them into one wind. The quality of the individual spectral winds is characterized by a set of quality indicators which are amalgamated into a quality mark. The "best" wind out of the combined IR, WV and VIS winds of a target image segment is put into the final MPEF CMW product. The CMW product generation is scheduled such that the image triplets are not overlapping and following each other without a gap causing every one and a half hour a CMW product to be generated.

The present algorithm description will first describe the procedure for the extraction of the single-slot winds, then the way these are combined to form the raw CMW product and finally the Quality Control concept. The fully detailed description of the algorithm can be found in the Detailed Algorithm Description.

a.) The single-slot wind component extraction

The derivation of single-slot wind vectors from the three spectral image data sets is performed by separate independent processes, each being specialised for a spectral channel. Their general structure is similar, also in terms of the forward and backward correlation, such that there is no need to describe them separately. Nevertheless, differences are mentioned if appropriate to the current level of detail. Since the algorithms operate on the images repeatedly segment by segment, it is sufficient to describe the processing steps performed on a segment.

The first operation performed by the algorithm is the selection, specific to the spectral channel, of the cloud tracer in the target image segment. This tracer is used for the extraction of the backward and forward correlation single-slot winds. This selection is done, in the case of the IR_CMW process, by taking the coldest (highest according to the potentially semi-transparency corrected IR mean count) cluster classified by SEG as cloud. For the VIS channel, in segments with low level clouds but no medium and high level clouds, one currently simply selects the cloud cluster with the highest entropy. In case of the WV channel, that one of the medium and high level cloud clusters is chosen which has the coldest (lowest) WV mean count. The height assignment is also performed during this step. For IR

tracers, this is done by calibrating the potentially semi-transparent IR mean count of the tracer to the measured IR radiance, calculating by an inverse application of the spectral response function of the IR sensor the incident radiance, deriving from it the emitted radiance by an inverse atmospheric absorption calculation, converting the emitted radiance to a temperature according to Planck's law, and finally the cloud top temperature to a pressure level via forecast temperature-to-pressure profiles. For VIS tracers, the height is determined according to the tracer's IR mean count. Inverse atmospheric absorption correction is performed; semi-transparency correction does not play a role since only low level cloud clusters are processed. The determination of the height of WV image tracers is similarly performed but based on the potentially semi-transparency corrected WV mean count. It is to be noted that an inverse atmospheric absorption correction is not carried out, which might be a deficiency.

The second basic step in the extraction algorithm is the definition of the target area and the search area, according to the selected tracers. These areas are the parts of the images on which the cross-correlation is applied. Currently the target area is a complete segment taken from the central image of the three slots used to compute the CMW product. The search area consists of a square of 9 segments of the search image (the previous one in case of backward correlation, the succeeding one in case of forward correlation) with its central segment being on the same position as the target segment. The sizes and locations that are used in the operational system are, therefore, 32*32 pixels for the target area and 96*96 pixels for the search area. The full VIS resolution CMW algorithm applies the same figures since the area corresponding to a 32*32 IR pixels is divided into four full resolution VIS image segments containing 32*32 VIS pixels each.

The third step is the enhancement procedure. This enhancement is applied in the same way to the target and search areas prior to the correlation being performed, but currently only by the IR wind vector extraction process. The enhancement method is dependent on the number of cloud clusters classified in the segment. If only one cluster was classified as cloud then all pixels with IR counts outside the cloud cluster's IR bounds are masked. If two cloud clusters were classified then all pixels are masked that are warmer than the IR mean count of the warmer cloud and, additionally, a contrast enhancement function is applied to the IR counts of the pixels of the segment. If three or more cloud clusters were classified then the Spatial Coherence Filtering is applied and a contrast enhancement based on partial cloud cover for multilayered scenes (clouds, surface) which are further described in the Detailed Algorithm Description.

The core of the processing is the cross-correlation process which also includes the masking function. The full correlation surface will be computed. Two schemes are implemented, based on the same mathematical correlation function. The first one is using the time/space domain computation of the full surface (but with reduced resolution in a first step), the second using a two dimensional Fast Fourier Transform which computes the full surface with full resolution. A total a four correlation algorithms is implemented which can be selected by the user using a correlation mode parameter:

- Full resolution FFT implementation
- Reduced resolution time-domain
- Full resolution time domain
- SSADM (Euclidian distance) correlation

Note: The operational baseline is the second implementation (reduced time-domain), the full time resolution can be used in non-realtime for reference purposes, and SSADM is to be compared with the FFT implementation for efficiency and quality.

On the resulting correlation surface a peak search is made, allowing up to three (configurable) candidate peaks to be defined for every tracer. Information from forecasts can be used to speed up the

search, without having any limiting aspect. These peaks are converted to geographical displacement and then to wind speed and direction. This defines the single-slot wind.

b.) Combining the single-slot winds to form the raw CMW product

The following part of the process combines, per target segment, the backward and forward correlation single-slot winds from subsequent slots in order to form the raw CMW product. If more than one relevant peak was found in the correlation surface, then the best matching single-slot winds are combined to form the most coherent extracted raw CMW product. The combined single-slot winds are of course based on the same tracer.

c.) The quality marks concept and the Automatic Quality Check

At every step of the processing, the quality of the result of an operation is derived and provides a quality mark. For example, the tracer quality is assessed after tracer selection, the correlation quality is assessed through the peak value and shape, and so on.

Once the raw CMW product has been computed, a battery of consistency checks is performed such as temporal consistency, spatial consistency, slot-to-slot height consistency, comparison with forecasts. These tests also provide quality marks which are then linearly combined with the previous ones to give a final quality index for the product prior to passing it to the manual quality control.

3.7.2.3 Spectral Channels

The MPEF CMW extracts winds from all three spectral images of METEOSAT: WV, IR and VIS. It has to be noted that VIS is used with a reduced spatial resolution making it comparable with the other channels, so that the segment sizes and coverages on earth are identical for all three channels. Additionally, a Full_VIS_CMW product is generated but currently not distributed to the end users.

3.7.2.4 Domain of Application

a) Geographical :

The CMW product is extracted in a geographical domain currently contained in a 55° circle centred at the sub-satellite point. This domain can be made different for each channel.

b) Time / Season :

No influences/variation identified so far.

3.7.2.5 Algorithm Maturity

The MPEF CMW algorithm stems directly from the MIEC CMW algorithm developed and validated at ESOC over many years. The quality of the CMW Product generated by this algorithm has been recognized worldwide. In its baseline configuration, the MPEF CMW is identical to the status of the

MIEC algorithm as in 1992. However, it incorporates numerous improvements and ideas that have already been tested at ESOC/MIEC but not yet implemented.

3.7.2.6 Origin/History

The MPEF CMW algorithm has been defined and specified for the MTP meteorological processing. It is the result of numerous discussions with ESOC/MIEC experts and of the analysis of the ESOC/MIEC algorithm, together with a certain number of structural improvements.

3.7.2.7 Evolution from Original Algorithm

As defined earlier, the baseline configuration of the algorithm is identical to the MIEC CMW algorithm, but a complete re-thinking of the algorithm structure allows a strong potential for evolution, especially the following points:

- The single-slot wind combination structure allows optimized realtime processing and eases a posteriori decisions (best matching peaks from different slots). It also allows full flexibility in combining the single-slot winds, or in using more than three consecutive slots for product generation. It allows also more flexibility in the product distribution schedule. This schedule is limited physically by the slot rate.
- The tracer selection and height assignment processes are foreseen for all three channels.
- The areas used for the correlation, called the search and the target areas, are defined in a flexible way. The baseline is 32*32 pixels for the target area and 96*96 pixels for the search area, both centred on the current segment position.
- The enhancement of the IR target and search areas is based on the use of masking functions and of Spatial Coherency analysis. The masking function is used to tell the correlation to ignore given samples, so that they do not appear in the statistics. The Spatial Coherency Method is applied to the enhancement of IR scenes containing three clusters. This method has been applied and validated at ESOC by J.Hoffman (Hoffman, 1989).
- The cross-correlation will be performed in the full surface (the baseline for the correlation surface is 65*65 original pixels = 32 pixel displacements in each direction of the target segment in the search area plus the target position itself), allowing the extraction of winds in a way independent of the forecast. This large surface also enables more sophisticated peak search processes to be performed. The size of the resulting correlation surface is also well suited to a Fast Fourier Transform implementation.
- The peak search is performed on the whole correlation surface. For increased speed, the forecast information can be used to start the peak search, but without limiting the search to a restricted area. The algorithm structure enables the evolution towards the definition of multiple relevant peaks within the correlation surface. The best candidate peak can be selected by consistency with the next slot wind.
- Finally, the whole algorithm is so defined that it is able to process one segment of image after another, in realtime, providing the CMW product information on the same segment by segment basis. This is important because a very fast product delivery can be achieved, together with an better processing load distribution (no load peaks).

3.7.3 Physical Principles

The CMW product is based on the measurement of clouds or cloud structure displacements between two or more consecutive METEOSAT images. This displacement is measured, down to a fraction of a pixel by means of a cross-correlation between the target area, containing the template (the tracer) and the search area and an interpolation in the cross-correlation surface.

The speed and direction of the wind is computed from this displacement. To do this, the displacement in pixel units is converted into earth-related location differences and finally in m/s and orientation in degrees.

The height at which the wind is measured is defined by the temperature of the tracer and converted to a pressure level via the forecast temperature-to-pressure profile of the atmosphere. The semitransparency correction is performed in the Segment Processing, so that the already corrected count value is used in the CMW algorithm. This potentially semi-transparency corrected count is calibrated into a measured radiance, converted then into an emitted radiance by taking inversely the spectral response function and the atmospheric absorption into account and deriving a temperature according to Planck's law.

3.7.4 Assumptions and Limitations

3.7.4.1 Physical Assumptions

- 1) The clouds and cloud structures move at wind speed (i.e. passive tracers). Note: this corresponds to the displacement of the upper part (not the top) of the clouds.
- 2) Clouds can be considered as black bodies (for temperature measurement).
- 3) The temperature corresponding to the characteristic count of the tracer cluster corresponds to the atmospheric temperature at tracer altitude as provided by the forecast.
- 4) The wind in a given segment does not vary fast between consecutive slots, so that the symmetry check is not restraining the CMW product.
- 5) The slot-to-slot pixel displacement of the rectified image is negligible.
- 6) The pixels of the rectified images are mapped to given geographical locations.

3.7.4.2 Physical Limitations

- 1) The slot-to-slot pixel displacement of the rectified image is limiting the CMW accuracy.
- 2) Beyond the 55° great arc circle the conversion from pixel displacement to wind speed and direction degrades the CMW accuracy.

3.7.4.3 Mathematical Assumptions

None identified.

3.7.4.4 Mathematical Limitations

- 1) The sizes of the search and target area limit the wind speed.
- 2) Singularity in pixel to Earth coordinates mapping near the Earth Horizon (about 88°).

3.7.5 Possible Validation Methods

In the MPEF system, a product verification is performed routinely, in an a posteriori mode, based on the comparison of the MARF encoded CMW product with reliable external data. It is performed against radiosonde or airplane data and forecast wind fields provided by NWP centres, for all retrieval times where a Manual Quality Control is performed. It is desirable to use the first guess of the NWP model assimilation scheme or the analysis rather than forecast fields.

Different groups of statistics can be provided by using the NWP verification data for the CMW product:

- Speed, direction or vector difference
- Speed bias versus speed class
- Coverage charts

These routine verification data should be available on a daily basis and on a monthly basis in terms of monthly sums or averages.

The routine verification enables first the validation of the initial configuration of the algorithm. It then enables fine tuning and optimization the parameters of the MPEF CMW algorithm and is a basis for measuring the correlation between the quality indicator generated by the Automatic Quality control and the "real" quality of the product. This is a valuable tool for optimizing the AQC and speed-up or even suppress the lengthy manual quality control. This verification tool and the validations are also the only way for the quality checking of experimental CMW as produced by modified algorithms.

For validation over shorter periods of time, detailed data may be obtained from case studies, the so-called "wind campaigns". These results can be compared in an a posteriori way with either the archived products or with the results of off-line processing of the data with modified algorithms for investigation purposes. However, it has to be kept in mind that in such cases the results are statistically only representative of a short period and therefore do not always produce reliable results.

3.7.6 Suggested Quality Indicators

3.7.6.1 Input Data Quality

The following information is used to define the quality of the input data:

- The cluster quality is inferred by the cluster classification (suspect, semitransparent, etc).
- The geometrical image quality provided by the image rectification. As this information is only available at the end of a rectified image, it will not be used in the CMW AQC, but a posteriori, prior to distribution.

3.7.6.2 Internal Processing Quality

The following information is used during CMW extraction and AQC to quantify the CMW quality:

- Tracer entropy in the target area
- Tracer size in the target area

- Tracer entropy in the search area
- Tracer size in the search area
- Correlation peak value
- Correlation peak (number of pixels used in the correlation)
- Correlation peak (means for search and target areas)
- Correlation peak (Standard deviation in neighbourhood)
- Correlation peak (Min and Max of local gradients)
- Wind direction consistency between slots
- Wind speed consistency between slots
- Correlation coefficients consistency between slots
- Height consistency between slots
- Temporal consistency with previous CMW product
- Spatial consistency with neighbouring CMW products
- Consistency of CMW product with Forecast

Out of these quality marks the final quality indicator for AQC is derived as a weighted sum of the above marks. The details about the computation of these marks can be found in the Detailed Algorithm Description.

3.7.7 Potential for Future Improvement

Several improvements are already built into the algorithm structure. These improvements are not those towards the ESOC/MIEC algorithms, but that could occur after the validation and operational use of MPEF.

- Fully flexible single slot combination, possibility of combining more single slot winds, in a different order, or using the same image for the extraction of two subsequent CMW products.
- VIS channel height assignment.
- Flexible segment size, search area size and target area size. If the FFT scheme is used for the correlation, search area sizes up to 128*128 are possible without processing load increase.
- Variable position of the target area within the segment.
- VIS and WV enhancement.
- Optimized peak search in the correlation surface (full surface available).
- More sophisticated AQC, tending to speed up or suppress the lengthy MQC.

3.7.8 References

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3.8 Sea Surface Temperature (SST) Product

3.8.1 Product Description

The Sea Surface Temperature (SST) product consists of a set of temperatures with associated locations. The temperatures (reported to the nearest 0.1°C) are derived estimates of the mean temperature for the sea surface within the image segments of the SST processing area and are taken to be representative of the whole segments. The associated locations are the centres of the image segments concerned. The measured quantity on which the product is based is the ocean 'skin' temperature but, because of the use made of conventionally observed sea surface temperature data in the processing of the SST product, the eventual product is more closely related to ocean 'bulk' temperatures.

The SST product is a direct interpretation of the output from the IR radiometer which means that persistent and significant changes in the SST values with respect to independent measurements of sea surface temperature may be interpreted as changes in the behaviour of the IR radiometer. For this reason the comparison of the SST product with independent measurements plays an important role in the monitoring of the performance of the IR radiometer. Furthermore, the results from these comparisons contribute to decisions taken regarding changes to the IR calibration coefficient, changes to the on-board gain settings in the associated electronics and even the initiation of a decontamination of the spacecraft.

Despite being extracted from every slot as an intermediate product (and, additionally, in order to supply the IR calibration process with data of maximum frequency) only the final SST products, being a weighted average of the intermediate SST products of the last 12 hours, are disseminated to the user community. The final SST products are generated twice a day and correspond to the main synoptic hours of 0000 and 1200 UTC.

3.8.2 General Algorithm Information

3.8.2.1 Algorithm Name

MTP/MPEF Sea Surface Temperature (SST) Generation

3.8.2.2 Outline Algorithm Description

The results from the analysis of image segments contain information about extracted scenes and these provide a major input to the algorithm. Particular use is made of the classification of the scenes. For those segments that are classified as containing an area of sea, a representative sea surface temperature for the segment is derived by defining an IR count value representative of the sea surface in the segment. This SST count is calibrated to a measured radiance ($\text{Wm}^{-2}\text{sr}^{-1}$), the measured radiance is transformed into an emitted radiance by taken into account the spectral response function of the IR sensor and performing an inverse atmospheric attenuation calculation (this is done by just applying the Atmospheric Absorption Table produced by RAD) and, thence, the emitted radiance into a temperature. The representative IR count is found by searching for the highest one (i.e. warmest temperature) of the IR means of the 3*3 sea pixel areas wholly contained within the segment. Each

temperature so derived is then subjected to an automatic quality control process which examines it for consistency with a collocated value from a background field of sea surface temperatures. This background field contains normally data received from the National Center of Environmental Prediction NCEP (the former NMC) in Washington DC. As a result of this comparison a quality mark is attributed to each temperature which will be used to decide whether the temperature should be included in the intermediate SST product. The final SST product, which is a weighted mean of all those temperatures derived over the most recent twelve hour period, is the algorithm output.

3.8.2.3 Spectral Channels

Essentially the SST product is derived directly from the IR(11 μ m) channel data. However it is sensitive to data received from the other channels (WV and VIS) as well since they contribute to the scenes identification process.

3.8.2.4 Domain of Application

a) Geographical :

Clearly the overriding limitation to the extraction of the SST product from a segment is that the segment lies over an area of sea and that the surface of the sea is not obscured by intervening cloud. The SST product may be derived for all segments whose centre lies within a specified extraction area for the product (this is currently a 55° great circle arc of the sub-satellite point and is currently defined in common for all quantitative meteorological products).

b) Time / Season :

Although the product is based directly on the output of the IR channel and therefore may be derived at any time it does display some variability in quality from night to day owing to the influence of data from the VIS channel upon segment scenes identification.

3.8.2.5 Algorithm Maturity

The method for extracting SST data from the output of satellite-born radiometers has remained essentially unchanged since the deployment of the first suitably equipped meteorological satellites around 1970. Since it is the inherent property of radiation with wavelengths around 11 μ m that its intensity is related to the temperature of its source then no significant development of a basic extraction algorithm was ever needed. Around 1982 an automatic quality control scheme was introduced to eliminate those temperatures grossly different from comparative measurements (like NCEP data).

3.8.2.6 Origin/History

As explained above the evolution of the algorithm for extracting sea surface temperature from IR radiances does not relate back to predecessor work.

3.8.2.7 Evolution from Original Algorithm

The only sense in which the algorithm described here has evolved is in respect of the way in which a final SST product is refined. Clearly the choice of the way in which the SSTs are to be combined into a weighted mean could be the subject of tuning. From the algorithm previously used at MIEC to the one implemented in MPEF a change from 36-hour running mean to a 12-hour running mean is incorporated. This reflects the increased frequency of the SST extraction but has the effect of producing a product which is able to reveal temporal changes on a shorter time scale than previously.

3.8.3 Physical Principles

The intensity of the radiation in the (thermal) IR part of the electromagnetic spectrum emitted from a body varies with the temperature of the body. Meteosat contains a radiometer sensitive to radiation around 11 μ m which scans the Earth's surface and so the output of this instrument provides an indication of the temperature of the radiating surface. However radiation at these wavelengths is affected by its passage through the Earth's atmosphere, particularly due to the presence of water vapour, and so, in order to determine the actual temperature at the Earth's surface, the measured radiation has to be corrected for the effect of the spectral response of the IR sensor and the likely effects of absorption by the atmosphere. This correction is achieved by using the output of an atmospheric radiative transfer model which creates a table of atmospheric corrections with entries for each of the image segments prior to the derivation of the SST product. Then the corrected radiance is related to the temperature of the radiating surface first by taking into account the emissivity of sea and then Planck's law.

Note: In the implementation of the algorithms, the spectral response function is not applied where it is physically effective, i.e. at the level of the satellite's sensor where the measured radiance is absorbed from the attenuated (incident) radiance, but to the emitted radiance at the surface of the scene. Therefore the Planck function is convoluted with the spectral response function resulting in following formula:

$$L(T) = \int_{\lambda_1}^{\lambda_2} B(\lambda, T) \Phi(\lambda) d\lambda$$

where

T	=	temperature of the scene's surface
L	=	black body radiance corresponding to T convoluted with the spectral response function
λ	=	radiation wavelength
B	=	Planck's function
Φ	=	spectral response function of the spectral channel
λ_1, λ_2	=	spectral range of the spectral channel

This relation of radiances and black body temperatures is pre-calculated and made available in form of radiance/temperature conversion tables. If the radiance value calculated by calibrating a count value falls between two radiance values of the conversion table linear interpolation is applied.

3.8.4 Assumptions and Limitations

3.8.4.1 Physical Assumptions

- 1) The sea behaves like a black body.
- 2) The warmest 3*3 pixel area consists of only sea pixels.
- 3) The SST chosen in a segment is representative of the whole segment.
- 4) The land/sea mask has previously designated as land any pixel that is actually part land and part sea.

3.8.4.2 Physical Limitations

- 1) The presence of undetected thin cloud overlaying sea pixels would cause a false classification of the underlying surface.
- 2) The occurrence of warm sea surface spots during periods of high solar heating combined with calm winds, which restricts mixing of top ocean layers with lower layers, will cause consequent heating of the lowest layer of the atmosphere where the effect of atmospheric absorption is greatest. However this warming of the atmosphere is almost certainly not likely to be found in the upper air data used for determining the corrections to be applied due to atmospheric absorption. Tests have shown that, as a consequence of this deficiency, the derived SST in these conditions may overestimate the true value by (in the worst case) up to 3.9°C. Calm seas also reduce vertical mixing so that ocean skin temperatures may be significantly higher than bulk temperatures.
- 3) The absence of data from the VIS channel at night sometimes causes the segment analysis scheme to fail to discriminate properly between sea surface and low cloud.

3.8.4.3 Mathematical Assumptions

None identified.

3.8.4.4 Mathematical Limitations

- 1) The 8-bit digitisation of the IR channel data leads to roughly 0.5°C jumps in temperature.
- 2) The parameterisation of the boundary conditions for the reflection of downward thermal radiation at the surface (as embodied in the radiation scheme) gives SST differences to an 'exact' solution between -0.2°C and 0.1°C.
- 3) Standard atmospheric aerosol profiles are used in the interpretation of image data and in the event of extreme aerosol conditions (e.g. after a Saharan dust outbreak or a volcanic eruption) this may lead to an underestimate by the SST of 1-2°C.

3.8.5 Possible Validation Methods

Verification of satellite derived sea surface temperatures is a notoriously difficult task mainly due to the lack of equivalent independent data. Measurements coming from ship reports are traditionally made using a bucket or water intake method both of which are essentially bulk temperatures and both are made by direct contact between water and a thermometer element. Also the spatial and temporal characteristics of satellite derived measurements are often significantly different from those from ships.

For this reason, comparison with the analyzed surface temperature field forms the basis of the product verification. If surface temperature fields from forecast models become available and prove to be reliable then they could also be considered. The use of carefully screened and selected ship and buoy data (with emphasis placed upon achieving good collocation in time and position) may also be valuable. The external meteorological data are compared with the MARF encoded SST product data.

3.8.6 Suggested Quality Indicators

3.8.6.1 Input Data Quality

- 1) Quality of segment scene(s) - passed from Segment Processing
- 2) Choice of data for SST background field (i.e. availability of NCEP (NMC) analysis)
- 3) Quality of image rectification

3.8.6.2 Internal Processing Quality

- 1) Results from tests of cluster properties against thresholds
- 2) Standard deviation of IR counts in warmest 3*3 area
- 3) AQC mark - extent below or above NCEP (NMC) comparison threshold

3.8.7 Potential for Future Improvement

Currently the reported position of the SST is the centre of the segment from which it was extracted which means that the combination of SSTs gathered over a period into a weighted mean is straightforward. However, since the locating of the warmest 3*3 pixel area involves a search of the segmented rectified image a more precise definition of the location of the SST is available. Moreover, currently only one SST is generated per segment whereas, if this more precise location were assigned to each SST then more than one per segment would be possible. A method would be needed then to limit the extent of the search for more than one SST per segment since no account is currently taken of the presence of cloud in the segment i.e. it is assumed that the warmest 3*3 area is bound to be sea rather than cloud. It would also not be easy to refine these results by taking into account previously extracted temperatures as at present. So the user would be presented with a product which certainly would contain more data points (and therefore could be of use in revealing quite small horizontal temperature gradients) but which would almost certainly exhibit a large amount of temporal variability.

The current algorithm definition, as illustrated in the logical model and process specifications, has foreseen this possible future change by already isolating all 3*3 pixel non-land areas and separating the process of the selection of the warmest value(s) in the segment.

Currently all available SSTs in the 12-hour period prior to each slot are combined into a weighted mean with the weights being pre-defined and unaffected by the quality of the results that are combined. It would be desirable to take such considerations into account and thereby to adjust the standard set of weights in accordance with the quality of the results.

3.8.8 References

ESA, 1987; MIEC Processing, ESOC, Meteosat Exploitation Project, ESA STR-224.

Gärtner, V., 1988; Operational Calibration of the Meteosat IR Channel Using Sea Surface Temperature Observations. Proceedings of the 7th Meteosat Scientific Users' Conference, Madrid, J14-J16.

3.9 Cloud Analysis (CLA) Product

3.9.1 Product Description

The Cloud Analysis product is defined on a segment basis and consists of the cloud amount expressed as a percentage and its cloud top temperature and pressure for up to 3 cloud layers per segment. Beside several auxiliary data it also includes quality indices based on the success of the CLA extraction process.

3.9.2 General Algorithm Information

3.9.2.1 Algorithm Name

MTP/MPEF Cloud Analysis (CLA) Generation

3.9.2.2 Outline Algorithm Description

a) Basic CLA Extraction Algorithm

- 1) All clusters within a segment which have previously been identified by Segment Processing as cloud are selected.
- 2) For each classified cloud cluster in a segment, a temperature plausibility check is performed. Clusters failing this check do not account for the cloud coverage of the segment.
- 3) If more than 3 cloud clusters have been identified and have passed the temperature check then they are reduced to 3 by merging clusters. Clusters are merged starting with cloud at the lowest levels in the atmosphere. Cloud clusters are merged only within the three standard cloud layers. Merging of clusters is achieved by summing pixels and forming weighted means of the mean counts.
- 4) The contamination cluster pixels are proportionally distributed among the cloud clusters having passed the temperature check and the ones not having passed the check, not having been classified at all or having been classified as surface scene.
- 5) For each of the maximal three contaminated merged cloud clusters in a segment, the cloud coverage as ratio of the number of the cluster pixels to the total number of pixels in the segment, the cloud top temperature and the cloud top pressure are calculated.

b) CLA Temperature Consistency Check

- 1)The temperature quality check is applied to ensure that the cloud top temperature lies within reasonable limits. This quality check is designed to ensure that cloud has been successfully discriminated from the land / sea surface. The limits, which are based on the estimated land /

sea surface temperature, depend on whether cluster extraction has used both IR and VIS data or IR only.

Where both IR and VIS data are available a fixed temperature limit of 22 ° C is used. If IR data only have been used the check is based on :

$$T_{limit} = T_{surf} - T_{diff} \quad 8$$

where the surface temperature is estimated from the forecast surface temperature allocated to the segment.

c) **Clear Sky AQC**

Segment Processing is not always able to identify clouds that are clearly visible in the image. In order to take the burden from the MQC operator to mark all segments classified as cloud-free but, nevertheless, containing clouds, the Clear Sky AQC algorithm has been implemented to do that for him as fully as possible.

The Clear Sky AQC algorithm applies the CMW cross-correlation algorithm to try to determine cloud motion vectors in segments where no cloud was classified. All segments, except desert segments as they are excluded from the check since they might cause the derivation of false vectors due to rapid temperature changes in the IR channel data from one slot to the next, where cross-correlation vectors could be derived are flagged as non cloud-free when the vector speed is higher than a threshold. The threshold is dependent on whether the surface being sea or land.

3.9.2.3 Spectral Channels

The CLA extraction algorithm uses clusters classified as cloud as the basic input. The IR and VIS channels therefore contribute to the clustering during daylight hours and the IR channel only at night. The IR radiance corrected for both atmospheric absorption and semi-transparency is used, and so the WV channel also contributes indirectly to the results.

3.9.2.4 Domain of Application

a) Geographical :

The CLA product can be successfully extracted in all regions up to 55° g.c.a. from the sub-satellite point. Beyond this limit the obliqueness of the viewing angle will cause the cloud amount to be substantially over-estimated, especially with deep cloud.

b) Time / Season :

Since this product is based on clusters identified as cloud, there is likely to be a difference in quality during the day when VIS data are available compared with during the night. The problem is worst over

desert regions where the land surface temperature can fall during night-time hours to values normally associated with cloud tops.

3.9.2.5 Algorithm Maturity

The proposed MPEF technique for the extraction of the CLA product has been operational at the MIEC using substantially the same techniques since the start of Meteosat 1 operations in 1977. The quality of the MIEC CLA product was substantially improved once the feedback loop in the cluster prediction component of the histogram analysis process was upgraded and after plausibility limits on cloud top temperature were introduced.

3.9.2.6 Origin / History

The proposed MPEF CLA extraction technique is substantially the same as that used in the MIEC. This technique has been supplemented by a consistency check to provide an automatic quality check on the raw CLA fields extracted.

3.9.2.7 Evolution from Original Algorithm

The MPEF CLA extraction algorithm is basically the same as the MIEC algorithm. However the basic CLA extraction algorithm has been supplemented by a consistency check against surface temperature which provides an automatic quality check on the raw extracted CLA product.

3.9.3 Physical Principles

The CLA product is based on the fact that clouds will have a distinctive radiative signature, and so cloud radiance clusters can be separated from radiance clusters originating from other surfaces. Once the clusters have been extracted it is possible to identify that cloud has been their source by knowing their probable temperature and brightness.

If a cloud is sufficiently opaque it will radiate as a black body. The satellite measures IR radiation exiting from the top of the atmosphere, and so, if the amount of absorption by the atmosphere can be estimated, it is possible to estimate the cloud top temperature. (The estimation of the absorption by the atmosphere is described in the section on the Radiation Model.)

Since cloud may not be opaque (e.g. cirrus cloud) or may not completely fill the field of view of a segment pixel, in these circumstances, the IR radiation reaching the satellite will be the sum of the radiation emitted by the cloud, plus a contribution from the background (normally by the land / sea surface or from cloud at a lower altitude) transmitted through the cloud. Since these background surfaces are normally warmer than the cloud, the measured IR radiation associated with transparent cloud will tend to over-estimate the cloud temperature and hence under-estimate the cloud top height. It is possible to use the combination of the IR and WV radiances first to detect that the cloud is in fact semi-transparent (or does not fill the field of view) and secondly to correct for the semi-transparency to give the equivalent IR radiance which would be measured if the cloud were opaque. (The semi-transparency correction is described in the section on the Segment Processing.) This correction allows a temperature to be calculated which represents the true cloud top height of a semi-transparent cloud.

3.9.4 Assumptions and Limitations

3.9.4.1 Physical Assumptions

- 1) Clouds give rise to a distinctive radiative signature, and so cloud within a segment can be identified by analysing a histogram of radiance counts.
- 2) Thick clouds composed of water droplets radiate as black bodies.
- 3) Semi-transparent cirrus (composed of ice crystals) or sub-pixel cloud can be detected using the combination of the measured IR and WV radiance counts.

3.9.4.2 Physical Limitations

- 1) High level cloud obscures low level cloud so that the amount of lower level cloud will be underestimated.
- 2) Fog will be classified as cloud.
- 3) The level of noise in the WV channel may affect the accuracy of the cloud top temperature if the semi-transparency correction is used.
- 4) There may be rare occasions where snow cover is wrongly identified as cloud.
- 5) The presence of VIS data will improve the ability of cloudy pixels to be distinguished from land pixels. Without the VIS data low cloud may not be successfully discriminated from the land / sea surface.
- 6) Sub-pixel scale cloud may be wrongly identified.
- 7) Towards the borders of the 55° g.c.a. region, the cloud amount will be over-estimated. This will be especially true with deep cloud.

3.9.4.3 Mathematical Assumptions

None identified.

3.9.4.4 Mathematical Limitations

- 1) The accuracy of the forecast data will affect the reasonableness checks which help to separate low cloud from a cold land surface at night.
- 2) The accuracy of the radiation scheme will affect the accuracy of the cloud top temperature estimate.
- 3) The accuracy of the semi-transparency correction will affect the accuracy of the cloud top temperature estimate.
- 4) The presence of 'contamination' pixels in the segment may affect the estimate of the amount of cloud within the segment.
- 5) Cloud is identified in 3 atmospheric layers only.

3.9.5 Possible Validation Methods

There is no obvious source of regular observational data against which the CLA product can be validated. It will therefore probably be necessary to validate CLA against other MPEF products or other derived products. Some possibilities are :

- 1) The CLA product should be consistent with the CTH product (see above) and so cross-checks will be possible.
- 2) It may be possible to check CLA for consistency with NWP analysis fields. This could be a regular automated process.
- 3) Probably the best validation of the CLA algorithms will be indicated by the number of deletions made by the MPEF meteorological operators.
- 4) It may be possible to run specific campaigns using either LIDAR data or data obtained from aircraft.

3.9.6 Suggested Quality Indicators

3.9.6.1 Input Data Quality

Some possible indicators of CLA quality would be :

- 1) Age of the forecast data used in the reasonableness checks.
- 2) WV noise level.
- 3) An indication of which channels were used.
- 4) Whether the CLA product was derived from a 'cold' or 'warm start'.
- 5) An indication of the amount of 'contamination' pixels identified.

3.9.6.2 Internal Processing Quality

- 1) An indication of the obliqueness of the viewing angle.
- 2) The level of contamination in the clusters.
- 3) The amount of merging of clusters which has occurred.

3.9.7 Potential for Future Improvement

Some of the potential improvements to the CLA product will lie elsewhere in the MPEF system, however, they are described below for completeness. Some possible improvements are :

a) Internal Processing Measures

- 1) Make more use of either the WV data or UTH products to indicate regions of cloud, especially at night-time.
- 2) Maintain a dynamically updated snow cover map to help discriminate cloud from snow.
- 3) Make the fixed temperature limit used in the consistency check when both IR and VIS data have been used variable to include positional and seasonal changes.

b) Data Input Measures

- 1) Use measures of cloud texture to improve the cloud cluster extraction and identification. Possible measures could be the local standard deviation, autocorrelation etc. The measures

could be made into pseudo-images which can be processed using the current histogram processing techniques. Such measures may help distinguish cloud from land surfaces at night when no VIS data are available.

- 2) Supplement the standard clustering technique with edge detection methods.
- 3) Improve the estimate of surface temperature, especially over desert regions where large diurnal cycles occur. This should help to discriminate low cloud from a cold land surface.
- 4) It would be desirable to keep all cloud clusters extracted as separate cloud clusters instead of merging them into 3 separate layers.

3.9.8 References

Hoffman, J., 1988 : Analysis of Cloud Fields Adapted to the Evaluation of Cloud Motion Winds. Proc. of the 7th Meteosat Scientific Users' Meeting, Madrid, September 1988, 98-92.

Kriebel, K.T., 1990 : Wolkenanalyse mit Satellitendaten. *Promet*, Nr. 3/4, 86-91.

McGuffie K., R.G. Barry, J. Newell, A. Schweiger, and D.A. Robinson 1988 : Intercomparison of Satellite-Derived Cloud Analyses for the Arctic Ocean in Spring and Summer. *Int. J. Remote Sensing*, 9, No. 3, 447-467.

3.10 Upper Tropospheric Humidity (UTH) Product

3.10.1 Product Description

The Upper Tropospheric Humidity (UTH) product is an estimate of the mean relative humidity of the atmosphere between approximately 600 hPa and 400 hPa.

3.10.2 General Algorithm Information

3.10.2.1 Algorithm Name

MTP/MPEF Upper Tropospheric Humidity (UTH) Generation

3.10.2.2 Outline Algorithm Description

The generation of the UTH product is directly based on the IR and WV image pixel counts and on the output of SEG and the Upper Tropospheric Humidity Table provided by RAD. The IR and WV image pixels of each segment not belonging to contamination and medium and high cloud clusters are averaged by calculating the weighted mean of the IR and WV mean counts (semi-transparency does not play a role since medium and high clouds are excluded) of the surface and low cloud clusters (if there are any, otherwise no UTH value is derived for such a segment). These segment IR and WV mean counts are calibrated to measured radiances which are used to derive an upper tropospheric relative humidity by interpolating entries of the Upper Tropospheric Humidity Table that are close to the mean IR and WV radiances of the segment.

3.10.2.3 Spectral Channels

The UTH extraction algorithm is based on the Meteosat IR and WV channel information.

3.10.2.4 Domain of Application

a) Geographical :

The UTH product is extracted in an area up to 55° within the great circle arc from the sub-satellite point (SSP).

b) Time / Season :

The UTH product is completely based on infrared (IR and WV) channel data therefore the extraction of this product is independent of the time of day.

3.10.2.5 Algorithm Maturity

The UTH product was developed in 1982 and has been used operationally since that time.

3.10.2.6 Origin/History

The UTH algorithm was originally developed by ESOC/MIEC.

3.10.2.7 Evolution from Origin Algorithm

The UTH extraction method used is essentially the same method as that employed in the MIEC. The introduction of a consistency check as part of an automatic quality control scheme is foreseen but has not yet been defined.

In May 1987 the algorithm was modified to extract the UTH product only if the atmosphere is free from medium and high level cloud.

In MPEF, UTH values are derived also for segments with clusters classified as medium and high clouds, but only the pixels of clusters classified as surface or low cloud are used in the processing.

The range of the constant humidity values of 600 hPa to 400 hPa in the calculation of the Upper Tropospheric Humidity Tables was several times subject of tuning. In MPEF, the upper "lid" of 400 hPa (different from MIEC) was chosen since investigations showed that this value led to best UTH product results in the MPEF implementation.

3.10.3 Physical Principles

The UTH product extraction is in principle the calculation of single-column values for the upper tropospheric humidity. The physics involved is the quantitative description of the transfer of the IR and WV channel radiation from the radiation emitting surface through the atmosphere towards the satellite as calculated by RAD. The transfer calculations are performed for a set of different constant humidity values for the upper tropospheric atmosphere as described in the chapter "Radiation Scheme" and result in the Upper Tropospheric Humidity Generation Tables. These tables can be used to derive from the IR and WV radiation measured by the satellite to estimate an average of the upper tropospheric humidity that caused the emitted radiation to be attenuated to the values measured.

In MPEF, UTH product values are derived, with certain restrictions, also for segments containing medium or high cloud clusters. Only the pixels of surface and low cloud clusters are used, excluding the pixels of contamination and medium and high cloud clusters from the processing. Principally, a UTH value could be derived for the atmosphere above medium or high clouds, but the uncertainty of a contribution of the cloud top height resulting in a too high humidity estimate is too big.

3.10.4 Assumptions and Limitations

3.10.4.1 Physical Assumptions

- 1) It is assumed that an adequate knowledge of the temperature structure of the atmosphere can be obtained from the forecast data.

- 2) Only a negligible amount of the outgoing radiance is emitted from layers beneath 600 hPa. The atmosphere above 400 hPa is represented by decreasing the relative humidity to 0% at 100 hPa which seems to be a reasonable assumption consistent with the structure of standard profiles and observations (see Takayama).
- 3) A constant humidity value is assumed to be valid between 600 and 400 hPa which is not very realistic.
- 4) The reason for using forecast profiles at lower levels as input to the radiation model is that these levels contribute very little to the outgoing radiance.

3.10.4.2 Physical Limitations

- 1) In case that the forecast profile allocated to a particular segment does not accurately represent the state of the atmosphere at that point the measured radiance may be outside the range of the allowed radiances (those corresponding to a completely dry or a completely saturated atmosphere) and no UTH value is derived.

3.10.4.3 Mathematical Assumptions

None identified.

3.10.4.4 Mathematical Limitations

The most important factors influencing the UTH product accuracy are listed below:

- 1) the accuracy of the forecast profiles used in the radiation model
- 2) the accuracy of the radiation model

3.10.5 Possible Validation Methods

To use the UTH product as input for NWP models, it is useful to validate the satellite based UTH against humidities from the radiosondes.

A more regularly validation is based on the comparison of the UTH product with a mean radiosonde humidity between 600 and 400 hPa. Each derived UTH value is compared with any radiosonde within the same segment within a certain time period (MIEC: 12 h) of the extraction time.

Because the extracted UTH product is dependent on the WV calibration, these UTH/radiosonde comparisons provide a method of checking the actual WV calibration coefficients. The calibration of the WV channel is done analogous to the SST/ship comparisons for the IR channel.

3.10.6 Suggested Quality Indicators

3.10.6.1 Input Data Quality

- 1) quality information of relevant segment cluster classification
- 2) quality of image rectification

- 3) age of forecast data
- 4) information on water vapour noise level
- 5) information on the amount of contaminated pixels

3.10.6.2 Internal Processing Quality

- 1) indication of existing low clouds or cloud free areas

3.10.7 Potential for Future Improvement

The humidity derived by using the method described in this chapter applies to a deep layer of the atmosphere reaching from 600 to 400 hPa. The UTH product is simply defined to be the mean humidity for this layer, however, the location and contribution of each level within the layer varies with the state of the atmosphere. In order to improve the UTH product, the seasonal and geographical contribution function profile may be taken into account.

In the radiation scheme applied for the WV channel, water vapour is the only absorber considered. The inclusion of additional absorbers like CH₄, N₂O, CO₂, and O₂ would have an influence on the calculated radiance in the water vapour channel (Poc et al., 1980; Fischer et al., 1981).

The introduction of a local consistency check (especially in cloud free areas) could be a useful part of an automatic quality control scheme.

3.10.8 References

Fischer, H., N. Eigenwillig, and H. Müller, 1981: Information Content of METEOSAT and Nimbus/THIR Water Vapor Channel Data: Altitude Association of Observed Phenomena. *J. Appl. Meteor.*, 20, 1344-1352.

Poc, M., M. Rolleau, N.A. Scott, and A. Chedin, 1980: Quantitative Studies of METEOSAT Water Vapor Channel Data. *J. Appl. Meteor.*, 19, 868-876.

Schmetz, J., and O.M. Turpeinen, 1988: Estimation of the Upper Tropospheric Relative Humidity Field from METEOSAT Water Vapour Image Data. *J. Appl. Meteor.*, 27, No. 8, 889-899.

Takayama, Y., 1992: Accuracy of in-flight calibration of the water-vapour channel of a satellite radiometer by radiance calculations. *Int. J. Remote Sens.*, 13, 1537-1548.

Turpeinen, O.M., and J. Schmetz, 1989: Validation of the Upper Tropospheric Relative Humidity Determined from METEOSAT Data. *J. Atmos. Oc. Tech.*, 6, No. 2, 359-364.

3.11 Cloud Top Height (CTH) Product

3.11.1 Product Description

The Cloud Top Height product is defined on a 3x3 pixel 'superpixel' basis and consists of a pseudo image of 8 grey levels where the grey level represents the cloud top height within one of the following height classes :

<u>Grey Level</u>	<u>Cloud Height Band</u>
0 (black)	< 3 km (or no cloud)
1	3 km to 4.5 km
2	4.5 km to 6 km
3	6 km to 7.5 km
4	7.5 km to 9 km
5	9 km to 10.5 km
6	10.5 km to 12 km
7 (white)	> 12 km

It also includes associated timing information and quality indices based on the success of the CTH extraction process.

The CTH product is distributed in WEFAX image format.

3.11.2 General Algorithm Information

3.11.2.1 Algorithm Name

MTP/MPEF Cloud Top Height (CTH) Generation

3.11.2.2 Outline Algorithm Description

Since the CTH product represents the cloud top height values as grey levels in a WEFAX formatted image of 800 * 800 pixels, the resolution of the original image of 2500 * 2500 pixels had to be reduced. A reduction by a factor of 3 allows to represent the whole processing area of 55° around the subsatellite point in the WEFAX image and have still some space left for the annotation which indicates the satellite used, time and date of the image slot and a grey scale describing the height classes.

The reduction of the resolution of the image is performed by forming so-called superpixels out of areas of 3*3 pixels. For each superpixel, it is tried to determine a height if it is reasonable to assume that it belongs to a cloud. For the height determination, information provided by SEG is used. Since the segment size of 32*32 pixels is not dividable without rest by the superpixel size, the pixels of a superpixel might stem from four different segments. "Multi-segment" superpixels are treated as if they lay completely in the segment that contains their central pixel.

The assignment of an height to a superpixel is performed in the following way:

- 1) The height class bounds in metre of the CTH product are converted into IR counts by means of the Radiance/Pressure Table produced by RAD. The table delivers for heights in metre the theoretical measured IR radiances that stem from opaque clouds at the given heights. These radiances are inversely calibrated to IR counts representing the bounds in unit of counts.
- 2) The measured IR and WV counts of the warmest IR cluster of the segment that contains the central pixel of the superpixel are taken as representative for the background that might radiate through semi-transparent clouds.
- 3) The IR and WV means of the pixels of the superpixel are calculated.
- 4) A semi-transparency correction of the superpixel IR mean is performed if appropriate.
- 5) The CTH pixel count is defined as the minimum of following two values:
 - minimum measured IR count of the pixels of the superpixel
 - semi-transparency corrected superpixel IR mean.
- 6) The CTH pixel count is compared with the CTH height class bounds in counts, and the identifier of the class to which the CTH pixel belongs is assigned to the CTH pixel. The CTH pixel is encoded with the grey level that represents the height class.

3.11.2.3 Spectral Channels

The CTH product generation algorithm is based on the IR channel information. In order to allow for the correction of the semi-transparency effect also the WV channel data is required.

3.11.2.4 Domain of Application

- a) Geographical :

The CTH product can be successfully extracted in all regions up to 55° g.c.a. from the sub-satellite point. Beyond this limit the obliqueness of the viewing angle will cause the cloud amount to be over-estimated. (The CTH product is already an over-estimate of the cloud amount since it indicates cloud if any is present in any pixel within the 3x3 superpixel.)

- b) Time / Season :

Since this product is based almost completely on data provided by the two infra-red channels (IR and WV), there is a negligible difference in quality between the CTH extracted during the day and the CTH extracted during the night.

3.11.2.5 Algorithm Maturity

The implemented MPEF CTH extraction technique is substantially the same, apart from slight modifications, as the one that had been in operational use at the MIEC since the start of Meteosat 1 operations in 1977.

3.11.2.6 Origin / History

The implemented MPEF CTH extraction technique is substantially the same as that used in the MIEC.

3.11.2.7 Evolution from Original Algorithm

The implemented MPEF CTH extraction algorithm is basically the same as the MIEC algorithm. A change has been introduced in MPEF with the definition of the superpixel size of 3*3 pixels rather than 4*4 pixels as in MIEC where an occasional repetition of superpixel rows and columns was necessary to enlarge the CTH image such that it fitted the WEFAX format.

3.11.3 Physical Principles

The CTH product is based on the fact that cloud tops reach an equilibrium temperature with their environment. Hence, in principle, it is possible to infer the height of the cloud from its temperature if the vertical temperature structure of the atmosphere is known. This presupposes that the presence of cloud will not change the ambient temperature structure of the atmosphere, which is true to a reasonable approximation. Cloud above 3 kilometres, which is the base level for the CTH product, can be easily discriminated within the image since cloud is almost always colder than any land surface.

If a cloud is sufficiently opaque it will radiate as a black body. The satellite measures IR radiation exiting from the top of the atmosphere, and so, if the amount of absorption by the atmosphere can be estimated, it is possible to estimate the cloud top temperature and hence cloud top height. (The estimation of the absorption by the atmosphere is described in the section on the Radiation Model.)

Since cloud may not be opaque (e.g. cirrus cloud) or may not completely fill the field of view of a pixel, in these circumstances, the IR radiation reaching the satellite will be the sum of the radiation emitted by the cloud, plus a contribution from the background (normally from the land / sea surface or from cloud at a lower altitude) transmitted through the cloud. Since these background surfaces are normally warmer than the cloud, the measured IR radiation associated with transparent cloud will tend to over-estimate the cloud temperature and hence under-estimate the cloud top height. It is possible to use the combination of the IR and WV radiances first to detect that the cloud is in fact semi-transparent (or does not fill the field of view), and secondly to correct for the semi-transparency to give the equivalent IR radiance which would be measured if the cloud were opaque. (The semi-transparency correction is described in the section on Segment Processing.) This correction allows a temperature to be calculated which represents the true cloud top height of a semi-transparent cloud.

3.11.4 Assumptions and Limitations

3.11.4.1 Physical Assumptions

- 1) Cloud top temperatures are in equilibrium with their environment.
- 2) Clouds do not change the ambient temperature structure of the atmosphere.
- 3) Thick clouds composed of water droplets radiate as black bodies.
- 4) Semi-transparent cirrus cloud (composed of ice crystals) or sub-pixel cloud can be detected using the combination of the measured IR and WV radiances.
- 5) Cloud above 3 kilometres is always colder than its neighbouring land / sea surface temperature.

3.11.4.2 Physical Limitations

- 1) The level of noise in the WV channel will affect the accuracy of the height assignment.
- 2) There may be rare occasions where snow cover reaches sufficiently low temperatures to be wrongly identified as cloud.
- 3) Since high cloud will obscure lower cloud, multiple cloud heights at a given location will not be detected. In any case even if separate cloud layers were to be detected only one would be reported since the minimum pixel radiance is used.

3.11.4.3 Mathematical Assumptions

None identified.

3.11.4.4 Mathematical Limitations

- 1) The accuracy of the forecast data will affect the accuracy of the height assignment.
- 2) The accuracy of the radiation scheme will affect the accuracy of the height assignment.
- 3) The accuracy of the semi-transparency correction will affect the accuracy of the height assignment.
- 4) Errors in the estimation of cloud top temperature will give rise to larger height assignment errors where the temperature lapse rate is low.
- 5) The accuracy may degrade with cloud of a small spatial scale since it will only partly fill the field of view and hence trigger the semi-transparency correction more frequently.
- 6) CTH images in general overestimate the cloud amount since the product shows superpixels with any cloud cover. The degree of overestimation will increase with the more oblique viewing angles which occur towards the edge of the 55 ° g.c.a. processing area.

3.11.5 Possible Validation Methods

There is no obvious source of regular observational data against which the CTH product can be validated. It will therefore probably be necessary to validate CTH against other MPEF products or other derived products. Some possibilities are :

- 1) The CTH product should be consistent with the CLA product, and so cross-checks should be possible.
- 2) It may be possible to check CTH for consistency with NWP analyses of cloud fields. This could be a regular automated process.
- 3) The height assignment in CTH could be compared with cloud top heights derived from stereo satellite imagery. This could probably only be performed occasionally on specific validation campaigns.
- 4) Probably the best validation of the CTH algorithms will be indicated by the number of deletions made by the MPEF meteorological operators.

3.11.6 Suggested Quality Indicators

3.11.6.1 Input Data Quality

Some possible indicators of CTH quality would be :

- 1) Age of the forecast data used to derive the height assignment information.
- 2) WV noise level.

3.11.6.2 Internal Processing Quality

- 1) Whether or not the semi-transparency correction was triggered. (The fact that it was triggered could imply a reduction in accuracy, however, the semi-transparency correction not being triggered could imply a processing error.)
- 2) The number of cloudy pixels within the superpixel.

3.11.7 Potential for Future Improvement

The product is already of good quality so that improvements are likely to be slight. Some possibilities are :

- 1) Additional checks for the presence of snow could be investigated.

3.11.8 References

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Smith, W.L., and C.M.R. Platt, 1978 : Comparison of Satellite Deduced Cloud Heights with indications from Radiosonde and Ground Based Laser Measurements. *J. Appl. Meteor.*, 17, 1796-1802.

3.12 Precipitation Index (PI) Product

3.12.1 Product Description

The Precipitation Index (PI) product is primarily generated to support the Global Precipitation Climatology Project (GPCP). In the framework of this project the supporting centre (MPEF) is acting as a "Geostationary Satellite Data Processing Centre (GSDPC)".

The Precipitation Index (PI) product provides estimates of the accumulated convective precipitation in the tropical regions covering the area within latitudes 40°N and 40°S and longitudes 50°E and 50°W over a period of five days (pentad). The estimate is made per segment of the PI processing area by assigning the IR pixels of the segment to temperature classes (16 ones in total) according to the black body temperature EBBT that is equivalent to their corresponding attenuated radiance. The EBBT of a pixel is equivalent to its so-called brightness temperature. This processing is performed every sixth slot close to the intermediate synoptic hours (i.e. 0000, 0300, 0600 1800, 2100 UTC). The number of pixels per temperature class and per segment are gathered over the five days of a PI pentad. Sums are build per PI processing slot time in order to provide a time series of eight times over the day. These eight data sets are further summed up into one data set covering the whole pentad.

Additionally, the PI product provides, for each segment, the average (over all processing slots of the pentad) of the means and the variances (per processing slot) of the EBBT values of the IR pixels of the segment.

Nine further data sets are derived which combine the amount of IR pixels assigned to temperature classes (3 ones in total) with the values of the UTH product derived for the same PI processing slot. For that purpose, three UTH range classes are defined covering 0 - 40 %, 40 - 75 % and 75 - 100 % relative humidity. The amount of pixels in a temperature class are summed up, disregarding the UTH range classes, to three data sets covering for the three temperature classes the UTH range from 0 % to 100 %.

The PI product is not disseminated in real time. The non-real-time distribution on magnetic tapes is done in accordance to the World Meteorological Organization (WMO)/ICSU Global Precipitation Centre Project (GPCP) rules.

3.12.2 General Algorithm Information

3.12.2.1 Algorithm Name

MTP/MPEF Precipitation Index (PI) Generation

3.12.2.2 Outline Algorithm Description

Intermediate PI product values are generated for all segments with their segment centre lying within 40°N and 40°S and 50°E and 50°W of the sub-satellite point for every three hours of the day.

The intermediate PI product values of the normally 40 processing slots of the processing period of five days (so-called pentad) are merged, in the course of their derivation, into the final PI product covering finally the whole pentad. The pentads of a year cover fixed periods of times: Pentad 1 begins on 1 January and Pentad 73 ends 31 December. In a leap year, Pentad 12 includes 29 February and consists, by definition, of 6 days.

The intermediate PI product values are derived from the IR pixel counts of each segment. The IR pixel counts are calibrated to measured radiances which are converted into brightness temperatures taking into account the effect of the spectral response function of the IR sensor and applying Planck's law to the attenuated radiances. For each segment of the PI processing area, a histogram of the distribution of the brightness temperatures of the image pixels of the segment is calculated by assigning the pixels correspondingly to the following brightness temperature classes. The histogram frequency values are normalised by dividing them by the total number of pixels of a segment (1024). Note, that the effects of semi-transparent or sub-pixel seized clouds are not taken into account.

Class	Temperature Limits (K)
1	> 271
2	266 - 270
3	261 - 265
4	256 - 260
5	251 - 255
6	246 - 250
7	241 - 245
8	236 - 240
9	231 - 235
10	226 - 230
11	221 - 225
12	216 - 220
13	211 - 215
14	201 - 210
15	191 - 200
16	< 190

Additionally, the pixels are distributed into three other brightness temperature classes ($EBBT < 220$ K; 220 K \leq $EBBT < 235$ K; 235 K \leq $EBBT < 255$ K) and within the temperature classes into four subclasses according to the UTH value derived for the segment by a special run (for the PI product generation) of the UTH product generation process. The subclasses are defined for UTH value ranges of 0 - 40 %, 40 - 75 %, 75 - 100 % and 0 - 100 % relative upper tropospheric humidity. The distribution frequency values are normalised by dividing them by the total number of pixels in a

segment (1024). Note, that if no UTH value is available for a segment the pixels are put into the subclasses 75 - 100 % and 0 - 100 %.

Finally, the EBBT mean and variance of all segment pixels are calculated for all segments of the PI processing area.

The final PI product aggregates the intermediate PI product values over all PI processing slots of a pentad. The normalised UTH subclass frequencies are just summed up without further normalisation. The normalised EBBT histogram frequencies are summed up (without further normalisation) firstly taking into account the values from all processing slots and secondly only the values from slots with the same slot number resulting in eight data sets containing 16 temperature classes each. The EBBT mean and variance values are simply averaged. Note, that the arithmetic mean of the variances is not the variance of the brightness temperature over the whole pentad.

3.12.2.3 Spectral Channels

The PI extraction is based on the Meteosat IR channel data. Since the results from an UTH product generation run are essentially required, the PI product generation is also dependent on the availability of the WV channel data.

3.12.2.4 Domain of Application

a) Geographical :

The PI product is derived for each segment in an area bounded by 50°W, 50°E, 40°N and 40°S because within the north/south boundaries precipitation is usually of convective nature.

b) Time / Season :

The PI product is independent of the time of the day because it is based on infrared data and WV channel data but not on the VIS channel data.

3.12.2.5 Algorithm Maturity

The PI algorithm has been developed for estimation of spatial and time averaged precipitation using GOES data in the IR channel in 1979. The algorithm is used for estimation of global precipitation in the framework of the Global Precipitation Climatology Project (GPCP). Within the GPCP data from all geostationary satellites are used.

The PI algorithm has been operational since September 1986. It was experimentally tested from September 1985 until September 1986.

3.12.2.6 Origin/History

The PI algorithm is mainly based on the one originally developed by Arkin in 1979 and slightly modified by Richards and Arkin in 1981. It is based on the simple relation between fractional cloud

cover with an equivalent black body temperature (EBBT) of less than a threshold assumed to be 235 K. This scheme is adopted by the WCRP to provide data to the GPCP.

3.12.2.7 Evolution from Original Algorithm

The original algorithm was slightly modified for MIEC operations and is used in MPEF in essentially this modified form.

3.12.3 Physical Principles

The main reason for estimating precipitation is because of its important role in the earth's weather and climate. The formulation of precipitation processes in climate and weather prediction models is very simple compared with the complex microphysical behaviour of rain clouds.

Generally used parameterisation schemes assume that condensation takes place when the air becomes supersaturated with respect to a certain threshold which constitutes an adjustable coefficient and is usually taken to be slightly less than 100% relative humidity.

Looking for a simple relationship between cloud cover and precipitation, Arkin et al. (1979, 1981) found that a high percentage of the variance in spatial averaged rainfall accumulations can be expressed as a linear function of the mean fraction of the area. It was assumed that these areas are covered by clouds having effective black body temperatures less than certain thresholds (T_{EBB}) ranging from 220 K to 250 K.

The spatial averaging was performed for areas of 2.5° latitude by 2.5° longitude. This relation was affected partly by spatial and partly by time averaging. As a result it was found that the PI product can be simply expressed by the following relation:

P I: Precipitation Index

α : constant factor

C_F : fractional cloud coverage having temperatures less than the threshold T_{EBB} .

t: averaging period in hours

3.12.4 Assumptions and Limitations

3.12.4.1 Physical Assumptions

- 1) Normally, convective rain is more strongly correlated with visible radiation than infrared radiation, however, since rainfall observations are required the whole day, only infrared images are used to compute the PI product.
- 2) The PI algorithm is based on the probability and extent of rainfall in the case when the temperature of a pixel is below a certain threshold.
- 3) Following Arkin (1979) it is assumed that the fractional cloud cover colder than a certain temperature threshold is proportional to the accumulated precipitation.

3.12.4.2 Physical Limitations

- 1) Since temperature is the only input to the extraction method, the PI estimates are useful only in the tropics and in parts of the warm extra-tropics where the majority of rainfall is convective and where the temperatures at the earth's surface are relatively warm. When restricted to the tropics, however, the technique will erroneously depict rainfall in regions of persistent, non-precipitating cirrus (outflow regions of squall lines, Mesoscale Cloud Clusters (MCC's), etc) since these clouds are usually colder than the threshold values assumed.
- 2) The cloud top temperature is the only parameter considered, although two clouds with the same temperature can result in varying precipitation accumulations depending on the orography, wind shear and moisture conditions.

3.12.4.3 Mathematical Assumptions

- 1) The statistical relationship only fits well if averaged over a large area and over a long time period (several hours).

3.12.4.4 Mathematical Limitations

- 1) During leap year, Pentad 12 will include 29 February and consist of 6 days.
- 2) In addition, the accuracy of the PI algorithm is certainly affected by orographical effects.

3.12.5 Possible Validation Methods

The PI algorithm is being validated in the Global Precipitation Climatology Centres (GPCC) being part of the GPCP. This is done by using observed precipitation in different climatic regions on a seasonal basis for a long time period. The threshold temperatures T_{EBB} as well as the constant factor α should be determined by using observed rainfall.

In addition, models can be used in the evaluation of satellite estimates of rainfall but they cannot serve as unequivocal ground truth due to uncertainties in the estimates of rainfall contained in them. But models do reflect the fact that rainfall is a product of numerous interactions between thermodynamic and dynamic processes in the atmosphere that generate precipitation. Thus models can be used to interpret satellite estimates of rainfall from a broader perspective than simply as tools for estimating their validity.

Models provide the means to carry out sensitivity tests of satellite rainfall estimates placing bounds on them. The differences between model and satellite estimates may not always be resolvable but may be useful to get further insight into the estimation technique.

Validation of the PI product can be performed by converting the fractional cloud cover into rainfall, and by finding out whether the precipitation can be estimated with an identical method, independently of the area considered.

3.12.6 Suggested Quality Indicators

3.12.6.1 Input Data Quality

- 1) quality of rectified image data
- 2) quality of calibration

3.12.6.2 Internal Processing Quality

- 1) detection of missing data
- 2) persistence

3.12.7 Potential for Future Improvement

Ground measurements are needed to establish the required relation between the PI product and the rainfall rate.

To fit the requirements of the GPCP, it would be of some advantage to provide in addition to the sums of the histogram classes also averages of the means and averages of the variances.

It was found by Turpeinen et al. (1987) that the upper tropospheric humidity over areas having only low clouds improves the relationship.

It could be of some benefit provide the PI product not on a segmented basis which correspond to approximately $1.5^{\circ} \times 1.5^{\circ}$ geographical resolution but in the same resolution as requested within the framework of GPCP being $2.5^{\circ} \times 2.5^{\circ}$.

3.12.8 References

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3.13 Climate Data Set (CDS) Product

3.13.1 Product Description

The Climate Data Set product as sent by MPEF to the MARF for archiving contains statistical information of one image which characterises the image histogram clusters classified by Segment Processing in the image segments of the CDS product processing area. The characterisation consists of the cluster classification number, the number of pixels, the mean pixel count and the standard deviation of the counts in all three spectral channels and an IR mean count corrected for the atmospheric absorption and semi-transparency (if appropriate) effects of each classified cluster within each segment. To allow for conversion of the pixel counts into temperatures calibration tables for all three spectral channels are provided. The segments themselves are described by their coordinates within the rectified image and the latitude and longitude of their centres (in terms of pixels). In addition, for each segment, the solar zenith angle, the spacecraft zenith angle, the difference of the sun and spacecraft azimuth angles and a sunglint indication flag are given.

The characterisation of the clusters is a direct output of Segment Processing. As Segment Processing of the MPEF keeps all extracted reflector clusters and also the contamination clusters separate a merging of clusters has to be performed in order to match the format and the contents of the previous CDS product of MIEC/ESOC which provided up to five classified scenes per segment which are contaminated by the distribution of all unclassified pixels among them.

It is to be noted that the final formatting of the CDS product sent to the end-users is done by the MARF.

3.13.2 General Algorithm Information

As no genuine algorithm is involved in the extraction of the CDS product some of the following subchapters are not applicable. The merging of clusters, the distribution of the contamination and the calculation of the calibration tables are described in the Detailed Algorithm Description.

3.13.2.1 Algorithm Name

MTP/MPEF Climate Data Set (CDS) Generation

3.13.2.2 Outline Algorithm Description

The merging of clusters, the distribution of the contamination and the calculation of the calibration tables are described in the Detailed Algorithm Description.

3.13.2.3 Spectral Channels

The information of all spectral channels (IR, WV, VIS) is used.

3.13.2.4 Domain of Application

Defined by Segment Processing and the CDS product processing area.

3.13.2.5 Algorithm Maturity

The algorithm was operational at MIEC for many years.

3.13.2.6 Origin / History

The algorithm was developed at MIEC.

3.13.2.7 Evolution from Original Algorithm

Implemented as at MIEC.

3.13.3 Physical Principles

See Segment Processing.

3.13.4 Assumptions and Limitations

The distribution of the pixels of the unclassified and of the contamination clusters among the classified clusters causes a deterioration of the accuracy of the characteristics data of the classified scenes provided by the CDS product.

- When adding contamination pixels to a classified cluster only the number of pixels of the cluster is updated but not the mean value and not the standard deviation. The effect is that the contamination pixels are distributed to the classified cluster according to its Gaussian distribution curve which means that 68.3 % of the contamination pixels are put into the 1σ interval of the classified cluster where they definitely do not belong to.
- The distributed portions of a contamination cluster do not reflect the different ranges of the 'hills' (different standard deviations) of the classified clusters; just the Euclidian distances between the projection point of the barycentre of the contamination cluster on the connection line of the barycentres of the pair of chosen classified clusters and the barycentres of the two classified clusters are taken into account. A consequence of that contamination distribution strategy is that the contamination pixels might be distributed in a rather biased manner.

The merging of classified clusters in order to reduce their number not to exceed five

- reduces of course the resolution of the classified cluster information

- makes due to the non-linearity of the semitransparency effect the corrected IR mean count suspect.

3.13.5 Possible Validation Methods

See Segment Processing.

3.13.6 Suggested Quality Indicators

3.13.6.1 Input Data Quality

See Segment Processing.

3.13.6.2 Internal Processing Quality

- 1) Number of clusters merged into one.
- 2) Amount of contamination assigned to a cluster.

3.13.7 Potential for Future Improvement

- 1) Separation of classified and contamination clusters

The current structure of the format of the CDS product does not limit the number of clusters to five. Therefore it would be easily possible to keep the contamination clusters separate from the identified clusters and to avoid reducing of the number of identified clusters to five if exceeded. This more detailed and more specific information would probably be of a better use to climatological researchers.

This modification can only be implemented after agreement with the end-users.

3.13.8 References

ESA/ESOC/MEP, 1992 : METEOSAT System Guide Volume 12, Description of Magnetic Tapes and Files

ESA STR-224, 1987 : MIEC Processing

ESA/ESOC/MDMD, 1981 : METEOSAT System Guide Vol 5, Meteorological Products

3.14 ISCCP Data Set (IDS) Product

3.14.1 Product Description

The ISCCP Data Set (IDS) product provides three types of data to the International Satellite Cloud Climatology Project (ISCCP) of the World Climate Research Programme (WRCP) of the World Meteorological Organisation (WMO), i.e. the AC data set, the B1 data set and the B2 data set. These data sets contain mainly satellite images partially subsampled to different resolution or showing only a certain part of the earth's disc.

The B1 and B2 IDS products are produced every three hours at 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 UTC, although the 2100, 0000 and 0300 UTC images do not contain useful visible image data. The AC IDS product is produced only occasionally about five times a month on request of the Satellite Calibration Centre (SCC) of the ISCCP.

The AC, B1 and B2 IDS products are sent as files to the MARF. The combining of IDS products of several days and their formatting to the data set delivered to the end user is the responsibility of the MARF.

3.14.2 General Algorithm Information

3.14.2.1 Algorithm Name

MTP/MPEF ISCCP Data Set (IDS) Generation

consisting of : AC Data Set Extraction
 B1 Data Set Extraction
 B2 Data Set Extraction

3.14.2.2 Outline Algorithm Description

The ISCCP defines three data stages of data to be provided differentiating primarily between

- full resolution image radiance data (stage A data)
- reduced volume radiance data (stage B data)
- and derived cloud parameters (stage C data).

Stage A data are full resolution radiometer image data including certain satellite orbital parameters (navigation) and calibration parameters. The stage A data are subdivided into AC data used for satellite intercalibration (provided by MPEF) and into AS data used for local climatological studies (not provided by MPEF).

Stage B data are radiometric image data which have been reduced in volume by means of averaging and sampling techniques. The stage B data contain five subcategories of data which are B1 data and B2 data (provided by MPEF), and B3 data, BC data and BS data (not provided by MPEF).

Stage C data are cloud parameters obtained from the B3 data set and correlative data (not provided by MPEF).

The rectified image data are used as input to the processing algorithms without applying any calibration factors to the infrared and water vapour data.

The visible pixel data are averaged to 5 km x 5 km resolution to match the infrared and water vapour data resolution.

MPEF does not produce all ISCCP data sets but the following three ones:

- the AC data set containing data for satellite intercalibration. The data are full resolution image data, with navigation and calibration parameters appended.
- the B1 data set containing radiometric image data which have been reduced in volume to half of the original IR data resolution through a process of averaging and sampling.
- the B2 data set consisting of further compressed data, produced by further sampling the matched resolution B1 data radiance pixels to a nominal 30 km spacing (every third pixel and every third line of the B1 data).

To derive the AC data set from the rectified image, a predefined area on the earth's disk is selected for which the infrared, water vapour and the averaged visible data are extracted.

The B1 data set is derived by sampling every second line and every second pixel along a scan line for the IR and WV images resulting in a 1250 pixels by 1250 pixels size for every image. Because the VIS image data are in a higher resolution, these data are first averaged to match the IR and WV pixel resolution. Then, well-defined header information is appended to the data set. All three channel data are processed in this way resulting in three images of 1250 lines of 1250 pixels.

The B2 data set is a further reduced B1 data set with the spatial resolution further reduced compared with the B1 data set. The B2 data set is generated by taking every third B1 line and every third B1 pixel from the B1 data set. In addition, the header information is updated. This procedure results in images of 416 x 416 pixels in size.

3.14.2.3 Spectral Channels

The IDS product consists of data from all three spectral channels (IR, WV, VIS).

3.14.2.4 Domain of Application

For each of the three data sets, there are different geographical and time domains for which the algorithms are defined.

a) Geographical :

The AC data set is generated for geographical areas of about 2000 km x 2000 km consisting of 400 pixels times 400 pixels.

The B1 data set and the B2 data set are provided for the full Meteosat area.

b) Time / Season :

To get the required number of 60 of the 2000 km x 2000 km areas for the AC data set, the corresponding data has to be collected four or five times a month.

The times for collection of the AC data set are set by the end user who ensures that they coincident with overpasses of polar orbiting satellites to allow inter-satellite calibration.

3.14.2.5 Algorithm Maturity

The IDS product has been operational since 1985.

3.14.2.6 Origin/History

The IDS extraction method used is the same method as employed in the MIEC.

3.14.2.7 Evolution from Original Algorithm

The IDS extraction method used is the same method as employed in the MIEC.

3.14.3 Physical Principals

There is no physical principle because the aim of generating the IDS product is to support and contribute to the ISCCP. The primary scientific objective of the ISCCP is to produce a global, reduced-resolution, infrared and visible, calibrated radiance set. This radiance set contains the basic information on the radiative properties of the atmosphere which can be used for derivation of cloud parameters.

The AC data are collected at times coincident with overpasses of polar orbiting satellites.

3.14.4 Assumptions and Limitations

3.14.4.1 Physical Assumptions

None identified.

3.14.4.2 Physical Limitations

There are no useful visible data available at 2100, 0000 and 0300 UTC. During the eclipse period the 0000 UTC data is replaced by the 2300 UTC data.

3.14.4.3 Mathematical Assumptions

None identified.

3.14.4.4 Mathematical Limitations

None identified.

3.14.5 Possible Validation Methods

None identified.

3.14.6 Suggested Quality Indicators

3.14.6.1 Input Data Quality

- 1) quality of image rectification
- 2) quality of calibration coefficients

3.14.6.2 Internal Processing Quality

Not Applicable

3.14.7 Potential for Future Improvement

Not applicable

3.14.8 References

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