Observation of storm rainfall for flash-flood forecasting Volume 2

SATELLITE STRUCTURED ALGORITHM SYSTEM (SAS)

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SUMMARY

This report summarizes the work done by the meteorological team of the TU Dresden within the FLOODsite Task 15 “Radar and satellite observation of storm rainfall”. The aim of this Task was the development of a radar and satellite Structured Algorithm System (SAS) for quantitative precipitation estimation (QPE) at the space and timescales of interest for flash-flood analysis and prediction. Thereby, the part of the TU Dresden was to develop a satellite based SAS for detecting extreme storm rainfall by using highly resolved geostationary satellite data (Meteosat-6, Meteosat-8). This has been done by building up a twofolded SAS, one part based on Meteosat-6 Rapid Scan data (M6/RS-SAS) and the second part based on Meteosat-8 data (MSG-SAS). Both parts include several rainfall estimation techniques. Three heavy precipitation events in orographic distinct and consequently flash flood prone regions (Alto Adige, Cévennes-Vivarais, Saxony) have been examined by applying these techniques with regard to the possibilities of detecting storm rainfalls by using satellite data.

For validation and as a reference radar data of the co-operation partners INPG (Institut National Polytechnique de Grenoble) and UniPad (University of Padua) have been used. The Saxon event has been compared to radar data of the DWD (Deutscher Wetterdienst).

To correct the estimated rain rates concerning the orographic situation, the wind and moisture conditions and the cloud growth rate additional data like MPEF products and radiosondes were included in the M6/RS-SAS. The rain rates resulting from the MSG-SAS were corrected in respect of the moisture conditions of the environment and the growing or decaying of the raining clouds.
ACRONYMS

AE   Auto-Estimator
CAPE  Convective Available Potential Energy
CLA  Cloud Analysis
CMW  Cloud Motion Winds
DEM  Digital Elevation Model
DWD  Deutscher Wetterdienst
ECST  Enhanced Convective Stratiform Technique
EGU  European Geosciences Union
EUMETSAT  European Organisation for the Exploitation of Meteorological Satellites
GMS  Geostationary Meteorological Satellite
GMSRA  GOES Multispectral Rainfall Algorithm
GOES  Geostationary Operational Environmental Satellite
GWT  Griffith-Woodley-Technique
HRV  High Resolution Visible
INPG  Institut National Polytechnique de Grenoble
IR  Infrared
LFC  Level of Free Convection
LUT  Look-Up Table
METEOSAT  Meteorological Satellite
MCS  Mesoscale Convective System
MPEF  Meteorological Product Extraction Facility
MSG  Meteosat Second Generation
MTP  Meteorological Transition Programme
MVIRI  METEOSAT Visible and Infrared Imager
NCEP  National Centres for Environmental Prediction
NIR  Near Infrared
PW  Precipitable Water
RH  Relative Humidity
RTM  Radiative Transfer Modelling
QPE  Quantitative Precipitation Estimation
SAS  Structured Algorithm System
SEVIRI  Spinning Enhanced Visible and Infrared Imager
SSCC  SEVIRI Solar Channel Calibration
SSP  Sub-Satellite Point
TU  Technische Universität
UniPad  University of Padua
UTC  Universal Time Coordonné
UTH  Upper Tropospheric Humidity
VIS  Visible
WV  Water Vapour
## SYMBOLS

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<tr>
<td>θ</td>
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<td>sun zenith angle</td>
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1. Introduction

Flooding – including flash floods - is the most widely distributed of all natural hazards across Europe, causing distress and damage wherever it happen. Events are threatened as floods, whether there is a “temporary covering of land by water as a result of surface waters (still or flowing) escaping from their normal confines or as a result of heavy precipitation” (MUNICH RE, 1997).

Flooding as a vulnerable is released by typical atmospheric conditions like high moisture content and buoyant instability, which are able to produce high convective systems. The tendency for deep convective cells being organized into larger convective systems (referred as mesoscale convective systems- MCS) and their tendency to occur flash floods is given by DOSWELL ET AL. (1996).

As well as the current atmospheric condition the topographic situation of affected area is important. Concerning their roughness the tendency of regions defining as a flash flood prone area differs. FREI & SCHÄR (1998) produced rainfall climatology for the European Alps and the surrounding foreland areas, which shows the enhancement of precipitation along the Alpine foothills. Thus the prediction and analysis of potential flash-flood events occurred by heavy rainfall requires quantitative precipitation estimates (QPE) with high space-time resolution.

Concerning ground based historical rainfall observations with rain gauges only radar measurements are able to observe heavy rainfall events temporal and spatial highly resolved. In Europe numerous physically-based algorithms have been developed in the past two decades and tested for correcting individually the various radar error sources in mountainous areas. Some algorithm development is still required, especially to cope with non uniform properties of the rain fields (DELRIEU, 1999; HANNESSEN, 2000; NICOL, 2006). Despite the increasing density of radar networks covering Europe radar measurements will ever be limited (e.g. in mountain regions, ocean...). Thus satellite data are more and more used to improve rainfall estimations (GRASSOTTI, 1998; LAKSHMANAN, 2006). The problem comparing radar and satellite measurements is founded by the satellite platform itself as well as the technical features of instruments. But as a result of the increasing technical progress in last decades the space borne rainfall measurements were improved (PETTY 1998; LEVIZZANI, 2002; LANG, 2003; EBERT, 2007) and applied to several events (VICENTE, 1998; BENDIX, 2001).

Analyses have shown that the combined using of satellite and radar data can provide better rain retrievals (ANAGNOSTOU, 2004; BÖHM, 2005). Achieving the best result of rainfall estimation a combination of current knowledge concerning ground based radar and a space born satellite measurement is required.

FLOODsite is the “Integrated Project” on flood risk management and was founded by the first round of the Sixth Framework Programme of the European Commission (2002-2006). The project takes up the fact of combining different knowledge and brings together managers, researchers and practitioners from a range of government, commercial and research organisations within aspect of flood risk management. FLOODsite includes pilot applications in Belgium, the Czech Republic, France, Germany, Hungary, Italy, the Netherlands, Spain, and the UK.

Within the task of risk management – pre flood measures and flood emergency management the TU Dresden is integrated in the FLOODsite Task 15 “Radar and satellite observation of storm rainfall”. The aim of this Task is to develop a radar and satellite Structured Algorithm System (SAS) for quantitative precipitation estimation (QPE) at the space and timescales of interest for flash-flood analysis and prediction. The SAS rely on existing algorithms developed under previous National and EC-funded projects as well as on some more specific algorithms developed under the present project. Thereby, the part of the TU Dresden is to develop a system for detecting extreme storm rainfall by using highly resolved geostationary satellite data (Meteosat-6, Meteosat-8 (Meteosat Second Generation; MSG)). The system consists of two parts: a SAS based on Meteosat-6 Rapid Scan data
(M6/RS-SAS) and a SAS based on Meteosat-8 data (MSG-SAS). The M6/RS-SAS estimates satellite rain rates by using six different estimation techniques and by including additional data like orography, radiosondes and MPEF products. With these additional data the rain rates are corrected concerning the influence of the 3D terrain structure, the influence of the wind (speed and direction), the moisture of the environment and the cloud life cycle. Further the M6/RS-SAS works with radar data for validating the estimated rain rates. The MSG-SAS uses four different algorithms for estimating rain rates. Two algorithms include a moisture and a cloud growth correction by including additional data of radiosondes. The results of both SA-Systems are comparable by user.

Developing two systems based on different satellite input data is caused by the investigated rain events of the co-operation partners (providing validation data) within FLOODsite as well as the limitation of available satellite based rainfall estimation techniques. The investigated rainfall events occurred in 2002 in the region of Cévennes-Vivarais (France), in 2005 in the region of Trentino-Alto Adige (Italy/North Alps) and 2006 in the region of Ore Mountains (Germany/Saxony). Because of the operational data delivery of Meteosat-8 not until the beginning of 2004 former Meteosat data had to be used for the event in 2002. Hence as satellite input Meteosat-6 data and Meteosat-8 are used for the integrated satellite estimation techniques with respect to former analyses of the methods suitability (BERGER, 2003; REUDENBACH, 2003).

The reduced spectral information of Meteosat-6 Rapid Scan (3 channels) in contrast to Meteosat-8 (12 channels) and the better spatial resolution of Meteosat-8 (3km x 3km- Nadir) cause differences in the estimated rain rates. Therefore a comparison of these two satellites is done for the event in 2005 (Italy)

Using temporal highly resolved Meteosat-6 Rapid Scan data (10min) offers a better comparison to MSG data (15min) and the radar measurements (5min). As a result of termination of Meteosat-6 data service at the end of 2006 for afterwards rainfall events the M6/RS-SAS has to be adapted using other satellite input data.

The results of the SA-Systems will be presented in two publications in the JOURNAL OF HYDROLOGY or the European Geosciences Union (EGU) Online-Journal ATMOSPHERIC CHEMISTRY AND PHYSICS (M6/RS-SAS: “Analysing heavy precipitation events over Europe in regions of distinct orography-Using Meteosat-6 Rapid Scan data and weather radar”, MSG-SAS: ”Testing satellite based rainfall estimation techniques concerning their applicability to Meteosat-8 data”).
2. Data background for Quantitative Precipitation Estimation (QPE) with Meteosat-6 Rapid Scan

2.1 Satellite data

The aim of the TU Dresden within Task 15 is to develop an algorithm system for detecting extreme storm rainfall using highly resolved data from different series of the geostationary satellite METEOSAT (Meteosat-6, Meteosat-8). METEOSAT are meteorological satellites operated by the European Organisation of the Exploitation of Meteorological Satellites (EUMETSAT).

2.1.1 Characterization of Meteosat-6 satellite system

Until now there are two generations of Meteosat satellites, “Meteosat First Generation” (MFG) and “Meteosat Second Generation” (MSG). For the M6/RS-SAS the data of Meteosat-6 (MFG-6) are used. MFG-6 carries the MVIRI (METEOSAT Visible and Infrared Imager) instrument which is able to detect the emissions of three spectral wavebands (Table 1).

Table 1: Spectral wavebands detected by Meteosat-6 (EUMETSAT, 2000)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Measuring Range in μm</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIS (visible)</td>
<td>0.45 – 1.0</td>
<td>Reflected light in the VIS part of spectrum</td>
</tr>
<tr>
<td>IR (infrared)</td>
<td>10.5 – 12.5</td>
<td>Emitted radiation in the thermal part of spectrum</td>
</tr>
<tr>
<td>WV (water vapour)</td>
<td>5.7 – 7.1</td>
<td>Radiation of WV absorption bands of spectrum</td>
</tr>
</tbody>
</table>

The data are recorded every 30 minutes for the full earth scan (Full Disk) and every 10 minutes for Europe (Rapid Scan data, available since 01/2002). The Sub-Satellite-Point (SSP) resolution adds up to 5 x 5 km² (WV, IR) and 2.5 x 2.5 km² (VIS) (EUMETSAT, 2003). Since 4th April 2003 all Rapid Scan imagery are rectified to 10° East and all previously imagery were rectified to 0°, because of the changed position of MFG-6 to 10° East. The images are adjusted by EUMETSAT and provided by the EUMETCAST service.

2.1.2 Meteosat-6 data calibration

The vicarious calibration of Meteosat-6 IR, WV and VIS channel is given by EUMETSAT.

The calibration of IR channel for each image is based on the converting of sea surface temperatures data sets from the National Centres for Environmental Prediction, USA (NCEP). Taking the impact of the intervening atmosphere into account the temperatures are converted to radiances. The expected radiances are correlated with the observed counts of pixels which have been identified as sea surface
scenes. The instantaneous calibration coefficients are the relation between the expected radiances and the observed count. If the new average of calibration coefficient differs more than a fixed value from the calibration coefficient that was operational at the moment, the IR calibration coefficient will be updated (EUMETSAT, 2007, [b]).

The calibration of WV channel uses radiosonde observations as external references. The expected radiance at the top of atmosphere is determined by use of temperature and humidity profile. Under the conditions that the radiosonde station must be located within the 550 great circle arc around the SSP and that the segment must be free of clouds above 700hPa the expected radiances are related to the mean WV count in the same segment, in which the radiosonde is located. The instantaneous calibration coefficient is derived twice a day from the collocations of the expected radiances and the observed counts. If the new average of calibration coefficient differs more than a fixed value from the calibration coefficient that was operational at the moment, the WV calibration coefficient will be updated (EUMETSAT, 2007, [b]).

The calibration of VIS channel relies on the SEVIRI Solar Channel Calibration (SSCC) algorithm. Therefore the spectral response is accounted by a radiative transfer simulation over bright desert and sea targets. A large number of images under different illumination conditions are processed to reduce and estimate the calibration error (typically: corresponding to 5 to 10 days of daylight data). Normally the calibration of the VIS channel is done eight times per year (EUMETSAT, 2007, [c]).

The calibration coefficients are calculated as the slope of the line connecting the centre of gravity of the collocation data and the so-called space count (the radiometric reading when the satellite is viewing space) (EUMETSAT, 2007, [b]).

The calibration relation is given by (EUMETSAT, 2005):

$$R = \alpha(C_n - C_0) \quad (3.1)$$

- $R$ .......... Radiance (W m$^{-2}$ sr$^{-1}$)
- $\alpha$ .......... Calibration Coefficient
- $C_n$ .......... Digital Meteosat Count
- $C_0$ .......... Space Count

The conversion from radiance to temperature for the WV and IR channel is expressed as follows (EUMETSAT, 2005):

$$R(T) = \exp(A + B/T) \quad (3.2)$$

- $R$ .......... radiance (W m$^{-2}$ sr$^{-1}$)
- $T$ .......... temperature (K)
- $A$ .......... regression coefficient (-)
- $B$ .......... regression coefficient (K)

The regression coefficients are shown in Table 2:

<p>| Table 2: Regression coefficients for Meteosat-6 (EUMETSAT, 2005) |
|-----------------|-----|-----|</p>
<table>
<thead>
<tr>
<th>Channel</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>6.7615</td>
<td>-1267.2000</td>
</tr>
<tr>
<td>WV</td>
<td>9.1124</td>
<td>-2264.9000</td>
</tr>
</tbody>
</table>
The calculation of the effective radiance based on VIS channel information is given by (EUMETSAT, 2005):

\[ L_f = C_f (DC - DC_0) \] (3.3)

- \( L_f \) effective radiance (W m\(^{-2}\) sr\(^{-1}\))
- \( C_f \) calibration coefficient (W m\(^{-2}\) sr\(^{-1}\))
- \( DC \) observed digital count (digital count unit)
- \( DC_0 \) offset (digital count unit)

The application of equation 1, 2 and 3 to derive the temperature values from the count values for the IR- and WV- channel and from the radiance for the VIS- channel of Meteosat-6 is done in the M6/RS-SAS by using look-up-tables (LUT).

### 2.1.3 Additional Meteorological Products

At regular intervals many meteorological products (e.g. Meteorological Products Extraction Facility - MPEF) are generated from the Meteosat image data (EUMETSAT, 1996). The spatial resolution of MPEF products depends on the distribution per segments. One segment consists of 32x32 infrared pixels and a matrix of 80x80 segments covers the complete Meteosat-6 field of view.

The following MPEF-products are integrated in the developed algorithm system:

- Cloud Analysis (CLA)
- Cloud Motion Winds (CMW);
- Upper Tropospheric Humidity (UTH).

The CLA product allows differentiating three cloud layers in a segment. A further estimation product of CLA is the cloud top temperature. For the current version of M6/RS-SAS the CLA product is integrated but not yet used (EUMETSAT, 2003).

The CMW is a product of applying correlation algorithms to three consecutive images. The number of images allows the tracking of the movement of cloud masses. From these tracking the wind direction, wind speed, the temperature and pressure level of the forecasted wind are derived (EUMETSAT, 1996). In the M6/RS-SAS the wind direction, wind speed and the estimated pressure level are used to define influence of orographic effects and to assess a coefficient for increase or reduction of satellite derived rain rates. The temporal resolution of M6/RS-SAS integrated CMW products amounts to 30 minutes.

The UTH product contains a measurement of clear sky water vapour radiance (no medium or high clouds are present) and an estimate of the level of water vapour in the troposphere. From these values the upper tropospheric humidity is derived (EUMETSAT, 1996). During the environment moisture correction the estimated humidity is used to assess a critical value, which defines a dry or moist environment. The temporal resolution of M6/RS-SAS integrated UTH products amounts to one hour.

### 2.2 Pilot sites and validation data

According to the pilot sites of the cooperation-partners (Task 15) two different areas under investigation were analysed. All regions are often affected by heavy rainfall conditions partial released by topographic effects. The analysed events were observed by radar and the data are used to validate
satellite estimations. The radar data were adjusted by surface measurements by the cooperation-partners.

The pilot site of Cévennes-Vivarais (Figure 1) is covered by the S-band radar stations Bollène and Nîmes located in the Rhone Valley in the south-east of France. The region is affected by the Massif Central and foothills of the French Alps and corresponds to a medium-elevation mountainous area (DELRIEU, 2006). The area is prone to intense rain events often as a result of a Mesoscale Convective System (MCS). The MCS mostly occurs due to the passage of cold fronts within westerly meteorological conditions and also within warm sectors of southerly Mediterranean perturbations (DELRIEU, 2004; NICOL, 2004). The analysed event of September 2002 was affected by such a MCS. Thus radar data from the station Bollène and Nîmes with a temporal resolution of 5 minutes for the time period 8th - 9th September 2002 were used to validate satellite data. The spatial resolution of radar data is 1km².

The Italian pilot site is located in the Trentino-Alto Adige region in the north-eastern Italian Alps (Figure 3). The data used were collected by the C-band radar station Monte Macaion. The region covered by radar ranges enfolded the areas from 200 m a.s.l to 3900 m a.s.l., corresponding to the highest mountains in north-eastern Italy (TONELLI, 2003). The region is classifiable as an Alpine high-mountainous area (DELRIEU, 2006). The radar data used from the Monte Macaion station have a temporal resolution of 5 minutes and were referred to 18th and 25th July 2005 for the event of Val Pusteria within the Trentino-Alto-Adige pilot site. The spatial resolution of data is similar to the French data.

![Figure 1: Topography of the Cévennes-Vivarais region, showing the radar at Bollène and Nîmes (OHMCV, 2007, [d])](image1)

![Figure 2: Pilot site Cévennes-Vivarais, scan region of Bollène radar- Slope values](image2)
2.3 Additional data

Some satellite based rainfall estimation techniques include a moisture correction of environment. The moisture correction factor in these methods is a product of precipitable water (PW) and relative humidity (RH). This PWRH factor is defined between the surface and the 500-mb level (VICENTE, 1998; BA & GRUBER, 2001). To determine the PWRH factor the PW for entire sounding and the UTH value for the corresponding time step and region are used.

Further used radiosonde values are Convective Available Potential Energy (CAPE), level of free convection (LFC), temperature of the lifted condensation level and pressure of the lifted condensation level. These values enable the user of M6/RS-SAS to define the actual condition of atmosphere for investigation areas.

Normally radiosonde measurements are done at 12:00 UTC. If available also radiosonde data of intervals of 6 hours are integrated in the M6/RS-SAS.
3. **Meteosat-6 structured algorithm system (M6/RS-SAS)**

3.1 **Overview**

Since the beginning of the FLOODsite project the satellite meteorology team of TU Dresden is developing an algorithm, which is able to detect extreme storm rainfall using highly resolved Meteosat-6 and MSG data. The structure of the satellite based M6/RS-SAS is shown in Figure 5.

The M6/RS-SAS allows the user to work with several satellite and radar based input data, which are highlighted green. The four main modules are highlighted brown.

The M6/RS-SAS input format of satellite data is related to the format supplied via EUMETSAT (Open-MTP format). The radar data input is separated into ASCII (additional information about radar data) and binary (rain rates) file format.

The **DATA IMPORT MODULE** masters the task to import the current satellite data. The module stores important information and converts counts to radiance or rather to temperature values via according look up tables of current input channel.

The **VALIDATION MODULE** provides the radar rain rates and additional radar meta-data (geographic position, topographic data and station information) for further calculations.

The **RAINFALL ESTIMATION MODULE** uses several satellite based rainfall estimation techniques to derive rain rates from temperature values.

Beside the cloud life cycle and statistical analysis the task of the **APPLICATION MODULE** is to analyse the spatial structure of topography. Based on the analyses of topography and using several meta-data (wind direction and wind speed from CMW) a rain multiplier is defined to intensify or reduce the derived rain rates.
3.2 Methods implemented and/or developed

The included satellite data are based on MFG-6 Rapid Scan. To simplify matters first analyses were made by using Rapid Scan data because of their reduced spectral information of three channels (infrared, water vapour, visible) in comparison to MSG-1 data and their spectral information of 12 channels. To derive rain rates from the satellite input data the following methods for rainfall estimation are included:

- Griffith-Woodley Technique (NEGRI, 1984; NEGRI, 1993)
- Auto-Estimator Technique (VICENTE, 1998)
- GOES Multispectral Rainfall Algorithm (BA & GRUBER, 2001; BERGER, 2003)
- Technique after GROSE (GROSE, 2002; BERGER 2003)
- Enhanced Convective Stratiform Technique (REUDENBACH, 2003; BENDIX, 2001)
- Combined Method

3.2.1 Basics of established methods

In Table 3 the differences of the established satellite based estimation techniques are described. The development areas of the algorithms differ more or less from each other. Therefore, it is necessary to test the application of the techniques for the application area addressing the precipitation systems and the topography.

Table 3: Features about the established satellite techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Development area</th>
<th>Input</th>
<th>Threshold</th>
<th>Calibration</th>
<th>Stratiform/ convective rain</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRIFFITH-WOODLEY TECHNIQUE (GWT)</td>
<td>south Florida, USA</td>
<td>T IR</td>
<td>T IR &lt; 253K</td>
<td>Gauge and radar rain rates</td>
<td>Only by temperature level, weighting rain to T10% of the coldest pixels, T40% next warmest pixel, T50% to the warmest pixel</td>
</tr>
<tr>
<td>AUTO-ESTIMATOR TECHNIQUE (AE)</td>
<td>GOES, USA</td>
<td>T IR</td>
<td>195K ≤ T IR ≤ 260 K</td>
<td>Radar rain rates</td>
<td>Growth rate, gradient correction for locating heavy precipitation cores</td>
</tr>
<tr>
<td>GOES MULTISPECTRAL RAINFALL ALGORITHM (GMSRA)</td>
<td>GOES, USA</td>
<td>T IR, T WV, R VIS</td>
<td>T IR &lt; 250K (day), T IR &lt; 230K (night)</td>
<td>Radar rain rates</td>
<td>Temperature gradient, Slope for each local minimum; large gradient → convective cloud, weak gradient → cirrus cloud, gradient less than slope → nonraining clouds; difference between IR-WV channel for defining raining clouds (before: failed in cirrus screening)</td>
</tr>
<tr>
<td>IR-Technique after GROSE (GROSE)</td>
<td>GOES, USA, GMS, Japan</td>
<td>T IR</td>
<td>190K ≤ T IR ≤ 240 K</td>
<td>SSM/I derived rain rates</td>
<td>Rain/ no rain threshold established by raw histogram matching (RHM), for ocean: 233.5K, for land: 228.5K</td>
</tr>
<tr>
<td>ENHANCED CONVECTIVE STRATIFORM TECHNIQUE (ECST)</td>
<td>Meteosat-6, mid-latitudes, Europe</td>
<td>T IR, T WV</td>
<td>T IR &lt; 253K</td>
<td>Radar rain rates</td>
<td>Discrimination of stratiform / convective rain, redux convection</td>
</tr>
<tr>
<td>COMBINED METHOD after JATHO (CM)</td>
<td>T IR</td>
<td>190K ≤ T IR ≤ 260 K</td>
<td></td>
<td>Includes the features of techniques AE, GMSRA, Grose, ECST</td>
<td></td>
</tr>
</tbody>
</table>
3.2.2 Integration of satellite techniques into M6/RS-SAS

Concerning the marginal spectral information of MFG-6 data and the complexity of each estimation technique the integration of methods is limited. To improve the satellite derived rain rate additional MPEF-products and radiosonde data were included. The products are the cloud motion winds (CMW), the upper tropospheric humidity (UTH) and precipitable water from radiosonde measurements.

The features of currently integrated techniques are described in Table 3.

The Griffith-Woodley Technique (GWT) based on the proposed simplifications of Negri (1984). The input consists of data from infrared (IR) channel. All pixels with a temperature lower than 253 K are clustered by an algorithm (JATHO, 2004). The minimum number of pixels in a cloud is currently limited to 10. The detected area is weighting depending on their temperatures. Thus the 50% coldest area (T50%), the coldest 10% area (T10%) and T40% are defining and assigned with adequate rain rates.

The derivation of rain rates by the Auto-Estimator Technique (AE) contains the application of a regression function to all IR-temperatures between 190K and 260K. The method is implemented in two ways. First as simplification, the regression function between temperature and rain rate is used. Secondly, the correction concerning the cloud growth rate, cloud-top temperature gradient as well as atmospheric humidity is fully integrated in the method.

The GOES Multispectral Rainfall Algorithm (GMSRA) is implemented in two ways, too. The most simplified method (BERGER, 2003) uses only IR input data in the range of 190 K ≤ T ≤ 260K. The original orientated method uses additional spectral information from visible (VIS) channel and includes the correction concerning the cloud growth rate, cloud-top temperature gradient and atmospheric humidity.

The Technique after Grose uses the IR-temperatures between 190 K ≤ T ≤ 260K to derive rain rates. At the moment the method doesn’t consider the now casting system components and is therefore used as proposed by BERGER (2003).

The Enhanced Convective Stratiform Technique (ECST) uses the temperatures of the IR- and WV-channel. The method includes the discrimination between convective and stratiform clouds. The determination of areas as clouds is done by a cluster algorithm (JATHO, 2004). In addition to the original orientated method a Modified ECST is integrated in M6/RS-SAS. The implementation of additional data (DEM) allows first conclusions about the influence of topography (windward, lee) on the algorithm derived rain rates. An adjustment to the atmospheric humidity with a 1D cloud model or 3D cloud model (ARPS) is not realised.

In addition to the methods described above a new method was developed and integrated in the M6/RS-SAS. This method combines the simplified regression functions of the methods AE (VICENTE, 1998) valid to temperatures >212K, GMSRA (BA & GRUBER, 2001; BERGER, 2003), the technique after Grose (GROSE, 2002; BERGER, 2003) and the ECST (REUDENBACH, 2003; BENDIX, 2001) a new method was developed and integrated in the M6/RS-SAS. The so called Combined Method (CM) is an empirical function (Figure 6).
Figure 6: Deriving the Combined Method by combining the methods Auto-Estimator, Grose, GMSRA and ECST being integrated in the M6/RS-SAS

The regression function describing the new developed method COMBINED METHOD is given by

\[ RR = 659.57 - 5.24 \cdot T + 0.01 \cdot T^2, \]  

(3.1)

where RR corresponds to the derived rain rate and T corresponds to the IR cloud top temperature from satellite.

3.3 The identification and correction of the effects related to the 3D structure of terrain

For enabling conclusions concerning the effects of the 3D structure of the terrain (e.g. windward-lee-effects) the user of M6/RS-SAS is able to choose whether to apply a rainfall multiplier to the integrated methods or not (except the MODIFIED ECST). The effect of multiplier enables to intense or reduce the derived rain rates caused by the combination of additional topographic information (like DEM data) and current atmospheric conditions (like wind direction).

To derive the rain multiplier based on the interaction between the wind vector, the local terrain height gradient (in the direction of the current wind vector) as well as the wind speed three steps have to be differentiated:

a). Determination of windward or lee situation of the investigation area
The first step to determine the windward or lee situation of an area implies the using of elevations of the tested area. Thereby the accuracy is defining by the number of surrounding pixels. An area consisting of 7x7 pixels provides less information than an area of 3x3 pixels. Currently, a 3x3 pixel environment is used to define the normal vector of the area (Figure 7).
Figure 7: 3x3 pixel environment of “F” to define the normal vector

Regarding to figure 7 the east-west gradient from the environment of pixel “F” is defined by satellite. The gradient in x-direction is defined by

$$\Delta x = \sum \left( (x_3 - x_2) + (x_2 - x_1) / 2 \right), \quad (3.2)$$

considering \(x_1\) as mean of the values from C to K, \(x_2\) as mean of the values from B to J and \(x_3\) as mean of the values from A to I.

The north-south gradient and the gradient in y-direction, respectively from the tested area is defined by

$$\Delta y = \sum \left( (y_3 - y_2) + (y_2 - y_1) / 2 \right), \quad (3.3)$$

considering \(y_1\) as mean of the values from C to A, \(y_2\) as mean of the values from G to E and \(y_3\) as mean of the values from K to I.

The normal vector \(\vec{n}\) for sloping plane around “F” in the 3-dimensional space results from

$$\vec{n} = \begin{bmatrix} 1 \\ 0 \\ \Delta x \end{bmatrix} \times \begin{bmatrix} 0 \\ 1 \\ \Delta y \end{bmatrix}. \quad (3.4)$$

A further step is the calculation of the wind vector \(\vec{w}\) based on MPEF cloud motion winds. From the CMW product the wind direction \(w_{\text{direc}}\) is used to define the vector by

$$\vec{w} = \begin{bmatrix} -\sin(w_{\text{direc}}) \\ -\cos(w_{\text{direc}}) \\ 0 \end{bmatrix}. \quad (3.5)$$

Caused by the 2-dimensional wind vector describing via x- and y-direction, \(z = 0\).

To define the windward or lee situation it is possible to define the angle between \(\vec{n}\) (4.4) and \(\vec{w}\) (3.5). The function is given by

$$\angle(\vec{n}, \vec{w}) = \arccos \left( \frac{\vec{n} \cdot \vec{w}}{||\vec{n}|| \cdot ||\vec{w}||} \right) \begin{cases} \text{Lee if } & \leq 90^\circ \\ \text{Windward if } & > 90^\circ \end{cases}. \quad (3.6)$$
Whether the result is greater than 90° the tested area presents a windward situation. If not the wind situation is considered as lee. Due to this fact it is possible to have a look at the angle of wind direction and the tested area.

b) Determination of angle between wind direction vector and plain

To define the intensity of impact of the current wind situation within the observed area it is necessary to assess the angle between wind direction vector and plain. The function is given by

\[ S_w = \angle(\vec{n}, (-\vec{w})) = 90 - \arccos \frac{\vec{n} \cdot (-\vec{w})}{\|\vec{n}\| \|\vec{w}\|} \]  

(3.7)

c) Determination of rainfall multiplier to define intensification or reduction of derived rain rate

Taking into account of formula 3.6 and 3.7 as well as the wind speed it is possible to determine a rainfall multiplier, which is able to intesne or reduce the satellite derived rain. The formula is given by

\[
M = 1 + \left\{ \begin{array}{ll}
\sin(S_w) \cdot u & F = -40.8 \text{ if Lee} \\
F_{\text{Windward/Lee}} & F = 3.08 \text{ if Windward}
\end{array} \right.
\]  

(3.8)

The multiplier \( M \) is the result of the angle of intersection (\( S_w \)), the wind speed (\( u \)) and a factor concerning current windward or lee situation (\( F_{\text{Windward/Lee}} \). \( M \) ranges between 0.2 and 3.5 based on the research of VICEUENT (2002). To define the factor \( F_{\text{Windward/Lee}} \) for \( M = 0.2 \) and \( M = 3.5 \) the maximum wind speed \( u > 32.7 \text{m/s} \) from the beaufort scale (DWD, 2007, [a]) as well as the maximum \( S_w \) of 90° are used. The current scaling to calculate \( M \) is based on empirical values fixed to the beaufort scale and is modifiable.

The defining of the multiplier to reduce or intesne the derived rain rates excludes the MODIFIED ECS-TECHNIQUE because of giving an impression of the effect of applying special empirical functions to the ORIGINAL ECST. Hence only windward or lee situation (given by formula 3.6) and no additional wind speed information is used. The empirical functions to derive rain rates from IR temperatures were empirical developed by BENDIX (2001) for a windward (Payern/ Swiss) and a lee (Udine/ Italy) situation. The empirical function for a lee situation is described as

\[
RR = -0.49 \cdot T + 116.74
\]  

(3.9)

and for a windward situation as

\[
RR = -0.956 \cdot T + 235.44
\]  

(3.10)

The derived rain rate is given by RR and the IR cloud top temperature by T.

For future analyses and improvements of derived rain rates life cycle analyses could be carried out providing a better localisation of clouds and appreciation of the cloud state (life cycle).
4. Case studies for QPE with Meteosat-6 Rapid Scan

Currently six different satellite rainfall estimation techniques based on input data from Meteosat-6 IR, WV and VIS channel are integrated in the satellite based M6/RS-SAS. Additional satellite data (MPEF) and radiosonde data enable the user to improve the derived rain rates (Chapter 2). According to the aim of Task 15 within the FLOODsite project the satellite based M6/RS-SAS was applied to two different pilot sites of the co-operation partners (Chapter 2.2). The validation data have a temporal resolution of 5 minutes and a spatial resolution of 1x1km². To investigate data pixel by pixel the radar data were up-scaled to the spatial resolution of the satellite data. This was done by defining the mean value of highly resolved radar data enclosed to the current satellite data pixel. The resolution of one satellite pixel represents for the French pilot site an area of about 5km x 7km and for the Italian pilot site an area of about 5km x 8km.

4.1 Cévennes-Vivarais, France, 8-9th September 2002

The catastrophic flash-flood event occurs during the 8-9th September 2002 in the Gard region caused by a major Mesoscale Convective System (DELRIEU, 2004). Rain accumulations about 600mm in 24h were measured by radar as well as by rain gauges (NICOL, 2004). The flash flood event was distinguished into three phases. During the first the convective part of a Mesoscale Convective System (MCS) produces total amounts greater than 200 mm in 5-6 hours. The second phase characterised the stationary of MCS at the Cévennes mountain limit ridge by producing sustained rain. During the third phase the cold front passes. Due to that the MCS was sweep out of the region and high rain rates were observed (DELRIEU, 2004).

The flash flood event is analysed from 12:00 to 15:00 UTC of 8th September 2002, the first phase of the event. During this time the passage of MCS with a SW/NE direction as published by DELRIEU (2004) is well comprehensible with the derived satellite data.

To compare radar measurements with satellite derived rain the AUTO-ESTIMATOR TECHNIQUE (VICENTE, 1998) as a simple way to derive rain from cloud top temperature, the ECST developed for Europe (REUDENBACH, 2003), a modified ECST-Version (BENDIX, 2001) as well as the new developed COMBINED METHOD as a combination of features of integrated methods (Chapter 3.2.2) are used. Therefore the region of Bollène radar station for 15:00 UTC is used exemplarily. Exemplarily the results of other implemented techniques are given in the Appendix.

Additional information concerning the atmospheric and wind conditions of the tested time step is given in Table 4. There the number of CMW segments providing information for the investigated area defines the number of 2-dimensional values given in Table 4.

### Table 4: Current atmospheric and wind condition, 8th September 2002, 15:00UTC

<table>
<thead>
<tr>
<th>Atmospheric data measured by radiosonde</th>
<th>2-dimensional information for investigated area from MPEF products</th>
<th>CMW</th>
<th>UTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>236.1</td>
<td>39.3</td>
<td>1.0</td>
<td>154.4</td>
</tr>
<tr>
<td>1.1</td>
<td>297.1</td>
<td>288.9</td>
<td>893.2</td>
</tr>
</tbody>
</table>
Figure 8 shows the comparison between the radar data from Bollène station and the satellite derived rain rates as well as the differences. The comparison is done for the time step using the satellite data of 15:00 UTC (mm/h) and the radar data measured between 14:55 UTC and 15:00 UTC (mm/h).

It is shown that the areas of satellite derived rain have greater dimensions than the area of radar measurements, particular in the north-east. In comparison to radar the methods determining satellite rain rates seem to underestimate precipitation. Beside the latent underestimation the satellite data are not able to represent the high radar values at higher altitudes (mountain region) but indicating regions at lower altitudes with highest precipitation. Between the detected areas a spatial offset is recognised. This is maybe caused by a relocation of satellite derived rainfall at the cloud top and ground measured rain.

Caused by the complexity of the satellite methods themselves the laminar and local assignments of rain as well as the range of derived values differ. The method ECST uses more spectral input information (IR and WV) than the Auto-Estimator and COMBINED METHOD. The ECST derived rain rate bases on several channel information and therefore is more exact than the other methods using marginal IR information.

As described in Chapter 3.4 the effect of orography to the satellite derived rain rates is tested. This is done only for MODIFIED ECST by using information about the windward and lee situation, the current wind direction and the application of special windward or lee functions (formula 3.9 and 3.10) to the IR cloud top temperatures. Further the satellite derived rain rates of implemented methods (except MODIFIED ECST) are modified using a rain multiplier (formula 3.8), which is able to reduce or intensify the rain rate but does not have a consequence to the extension of derived rain area.
The differences between rainfall estimation for the ORIGINAL ECST, without considering the orography and the MODIFIED ECST, considering the orographic influence (formula 3.9 and 3.10) is shown in the following Figures.

A comparison between Figure 9 and Figure 10 demonstrates that the impact of the derived rain rates affected by special windward and lee functions caused a marginal modified rain area. The height of derived rain rates differ less.

Considering the orographic effect as well as the current wind situation the integrated satellite methods, except the MODIFIED ECST, are supplemented by a rain multiplier (formula 3.8). The following Figures show the comparison between the derived rain rates being modified by the rain multiplier or not.
The impact of application of the rain multiplier to the derived rain rates is shown exemplary for AUTO-ESTIMATOR and COMBINED METHOD. Figure 11 a) and 11 c) represents the rain rates without using multiplier and Figure 11 b) and 11 d) by using rain multiplier. The method ECST is given in the Appendix and not presented, because the results using the rain multiplier or not do not differ. A comparison between Figure 11a) and 11b) as well as 11c) and 11d) distinguished only less differences. That is maybe caused by the multiplier itself. Regarding formula 3.8 the multiplier depends on the current wind speed. As shown in Table the wind speed for the investigated time step is less with 1.0 to 1.1m/s. Thus the effect of multiplier to intensify or reduce the derived rain rates is marginal.

Analysing the amount of precipitation input to a flash flood prone region the input of satellite derived and radar measured rain are compared for the area under investigation. In the process the radar data are used as reference. Concerning BAUMGARTNER & LIEBSCHER (1996) the threshold to define heavy rainfall is about 10mm/h. This value is used to differentiate between radar measured rain considered as flash flood relevant or not. The analyses between satellite and radar data are done for a single time step (15:00 UTC) and a time period (12:00 UTC-14:50 UTC) for the event of 8th September 2002. The time period is separated into three parts 12:00-12:50 UTC, 13:00-13:50 UTC and 14:00-14:50 UTC. The analyses are done exemplarily for SIMPLE AUTO-ESTIMATOR, ECST, MODIFIED ECST and COMBINED METHOD.

Firstly the single time step 15:00 UTC for the French pilot site is tested. Therefore all radar rain rates >= 10mm/h and their appropriate satellite rain rate are used to generate a difference between satellite and radar for each grid cell. Figure 12 shows the mean differences of satellite and radar for the investigated area. The satellite derived rain rates are used with and without a rainfall correction by a rain multiplier as well as using special empirical windward and lee functions (MODIFIED ECST).

A comparison between the determined differences in figure 12 emphasises for the investigated time step the underestimation of satellite derived rain in comparison to radar measurements. To analyse a potential tendency of satellite data to underestimate radar measurements further investigations for the period of 12:00-14:50 UTC are done. In the process the statistical values of difference between satellite and radar rain like minimum value (Min), maximum value (Max), mean value (Mean), standard derivation (SD) and standard error of the mean (SE) are defined. Exemplarily for the period of 14:00 to 14:50 UTC the statistic is given by Table 5.
Table 5: Cévennes Vivarais - Statistic of 8th September 2002, 14:00-14:50 UTC - satellite input to the region covered by radar (radar rain rate >=10mm/h)

<table>
<thead>
<tr>
<th></th>
<th>AE (simple)</th>
<th>ECST (modified)</th>
<th>Combined Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not corrected</td>
<td>Corrected</td>
<td>Not corrected</td>
</tr>
<tr>
<td><strong>Min [mm/h]</strong></td>
<td>-64.28</td>
<td>-64.31</td>
<td>-67.31</td>
</tr>
<tr>
<td><strong>Max [mm/h]</strong></td>
<td>12.26</td>
<td>12.45</td>
<td>18</td>
</tr>
<tr>
<td><strong>Mean (abs) [mm/h]</strong></td>
<td>-10.6</td>
<td>-10.58</td>
<td>-10.27</td>
</tr>
<tr>
<td><strong>SD [mm/h]</strong></td>
<td>18.85</td>
<td>18.88</td>
<td>20.27</td>
</tr>
<tr>
<td><strong>SE [mm/h]</strong></td>
<td>2.45</td>
<td>2.46</td>
<td>2.64</td>
</tr>
</tbody>
</table>

The analyses of the mean values (absolute, relative) for AUTO-ESTIMATOR, ECST, MODIFIED ECST and COMBINED METHOD (with and without rainfall correction) for the time period between 12:00 UTC and 14:50 UTC and exemplarily for the time step of 15:00 UTC reveal the further tendency of satellite data to underestimate the radar measurements. This is based on the dependency of rain multiplier of marginal wind speed (during the investigated time periods of about 0.54 to 1.5 m/s) as well as the absence of wind speed and direction due to missing CMW information. A comparison between the mean values of time step 15:00 UTC and the time periods between 12:00-14:50 UTC is done to analyse whether a tested method tends to underestimate radar measurements more than the others. The results clarify that for the period between 12:00 UTC and 14:50 UTC the simple implemented AUTO-ESTIMATOR TECHNIQUE underestimates the radar measurements (with and without correction by a rain multiplier) most. The new developed COMBINED METHOD tends to underestimate radar fewest.

To demonstrate the difference between satellite and radar rain (>=10mm/h) considered as an amount of precipitation input to the area covered by radar the mean values of 12:00-14:50 UTC are analysed again. Exemplary for the time span of 14:00-14:50 UTC the percent entry of satellite derived rain into the region of the French pilot site in comparison to radar (considered as 100% input) is given in Table 6.

Concerning Table 6 the SIMPLE AUTO-ESTIMATOR TECHNIQUE accounts for less precipitation amount to the investigated area followed by the ECST. More precipitation input is given by the MODIFIED ECST. The highest rain values are derived by the COMBINED METHOD but represents still an underestimation of radar measured rain of about >12.41%. The analysis represents that in case of marginal wind speed an orographic correction by a rain multiplier has only less effects in rising up the satellite derived rain rates.
Table 6: Cévennes Vivarais - 8th September 2002, 12:00-14:50 UTC - satellite input to the region covered by radar (radar rain rate ≥ 10mm/h)

<table>
<thead>
<tr>
<th>Method</th>
<th>Period 12:00-12:50 UTC</th>
<th></th>
<th>Period 13:00-13:50 UTC</th>
<th></th>
<th>Period 14:00-14:50 UTC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not corrected [%]</td>
<td>Corrected [%]</td>
<td>Not corrected [%]</td>
<td>Corrected [%]</td>
<td>Not corrected [%]</td>
<td>Corrected [%]</td>
</tr>
<tr>
<td>Auto-Estimator (simple)</td>
<td>15.16</td>
<td>15.19</td>
<td>54.17</td>
<td>54.97</td>
<td>73.49</td>
<td>73.66</td>
</tr>
<tr>
<td>ECST</td>
<td>22.95</td>
<td>23.0</td>
<td>66.63</td>
<td>67.08</td>
<td>78.55</td>
<td>78.67</td>
</tr>
<tr>
<td>Modified ECST</td>
<td>37.57</td>
<td>-</td>
<td>54.17</td>
<td>-</td>
<td>79.58</td>
<td>-</td>
</tr>
<tr>
<td>Combined Method</td>
<td>45.84</td>
<td>45.93</td>
<td>74.13</td>
<td>77.25</td>
<td>87.44</td>
<td>87.59</td>
</tr>
</tbody>
</table>

In addition to the influence of current atmospheric as well as weather conditions to the orographic correction of satellite data the static features of underlying topography is considered. Hence the slope of topography to describe the measurement of the steepness, incline or gradient of the area under investigation was defined (Figure 13). A higher slope value indicates a steeper incline, which implies less precipitation input followed for a flash flood prone region by shorter run off times.

As shown in Figure 2 and 13 the slope of the Cévennes-Vivarais region is dominated by the lower altitudes depending on the Rhône valley as well as on the classification of a medium-elevation mountainous area (DELRIEU, 2006). Thus the mean slope value of the region is about 0.04 and the relative frequency to lower slope classes is higher than to upper. Hence whether the investigation area is affected by higher precipitation input followed by longer runoff times it results an enhanced flash flood hazard (like the event of 8-9th September 2002 in the region of Cévennes-Vivarais). Concerning the tendency of satellite derived rain to underestimate radar measurements the influence of slope on satellite data and their effects regarding flash flood prone regions is not yet tested.
4.2 Trentino-Alto Adige (Val Pusteria), Italy, 18th July 2005

During the afternoon of 18th July the region of South Tyrol was affected by some heavy thunderstorms with a west to east moving direction. At night only very regional heavy storms occurred and produced high rain rates (MUNARI, 2005).

The event was analysed between the period 13:30UTC to 15:30UTC and for the time step of 14:30UTC concerning the quality and quantity of satellite derived rain rates comparing to radar measurements (q.v. case study 1). The radar data were provided by the Italian cooperation partner for the radar station Monte Macaion.

The tested satellite techniques are the AUTO-ESTIMATOR TECHNIQUE (VICENTE, 1998) as a simple way to derive rain from cloud top temperature, the ECST developed for Europe (REUDENBACH, 2003), the modified ECST-Version (BENDIX, 2001) as well as the new developed COMBINED METHOD.

Additional information concerning the atmospheric and wind conditions of the tested time step is given in Table 7. As described for case study 1 the number of 2-dimensional values given in Table 7 is defined by the number of CMW segments for the investigated area.

<table>
<thead>
<tr>
<th>Atmospheric data measured by radiosonde</th>
<th>2-dimensional information for investigated area from MPEF products</th>
<th>UTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>-----------------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>10.7</td>
<td>36.5</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.4</td>
</tr>
</tbody>
</table>

A first comparison between the radar measured rain and AUTO-ESTIMATOR, ECST and COMBINED METHOD derived rain rates (without any additional rainfall correction) is done exemplarily for the time step of 14:30 UTC (Figure 14). The radar data are given by the mean of two consecutive measurements (q.v. case study 1).
Figure 14: Comparison between rain rates derived by AUTO-ESTIMATOR, ECST and COMBINED METHOD (without additional rainfall correction) and measured by radar Monte Macaion

On consideration of the extension of rain areas and their rain rates large differences between radar and satellite data are shown in Figure 14. Particularly in the north-east part of investigated area the satellite data yield more precipitation. There the area of radar measured rain is limited by the range of radar station itself.

A further comparison of radar and satellite data shows a spatial offset. As explained in case study 1 the offset maybe caused by a relocation of rainfall derived via satellite at the cloud top and measured at surface.

Comparing the several satellite derived rain differences between the techniques become apparent. Concerning the marginal information used as input for AUTO-ESTIMATOR TECHNIQUE the rain rate is not as much as high as for the complex method ECST. The COMBINED METHOD combines the features of several techniques. Thus the method is able to derive higher rain values following an area of maximised extension.

The influence of topography on the derived rain is given by the following figures. Considering the effect of application of empirical rain functions knowing the windward or lee situation is given in Figure 15. Hence the MODIFIED ECST method is compared with the ORIGINAL ECST.

Figure 15: Comparing the effects of using empirical rain functions knowing the windward or lee situation - A comparison between the ORIGINAL and the MODIFIED ECST
The impact of topography as well as current wind situation of satellite derived rain rates using a rain multiplier (formula 3.8) is represented in Figure 16 and 17. It is done exemplary for the ECST and the COMBINED METHOD. The AUTO-ESTIMATOR is given in the Appendix.

![Figure 16: Effect of using a rain multiplier to improve the ECST derived rain rates- A comparison between rain rates uncorrected (16a) and corrected (16b) with regard to orrographic and current wind situation](image)

![Figure 17: Effect of using a rain multiplier to improve the COMBINED METHOD derived rain rates- A comparison between rain rates uncorrected (17a) and corrected (17b) with regard to orrographic and current wind situation](image)

Figures 16 b) and 17 b) show that the rain multiplier intensifies and reduces the satellite derived rain rates in regions of distinct topography. The intensification of rain rates using the multiplier is caused by the high wind speed of 10.1 to 11.0m/s (Table 7). The spatial outline of satellite derived rain depends on the small range of tested surrounding pixels (3x3 environment, Chapter 3.3) used for determination of the rain multiplier. Thus the orographic attributes are considered well and the areas of increased or reduced satellite rain are very local.

Comparable to case study 1 all into M6/RS-SAS integrated techniques are tested concerning their amount entry of satellite derived rain to the catchments basin of Italian pilot site. Therefore the threshold of 10mm/h (BAUMGARTNER & LIEBSCHER, 1996) to differentiate between flash flood relevant rain or not is applied to radar (q.v. case study 1). Exemplary for the integrated methods the AUTO-ESTIMATOR, ECST, MODIFIED ECST and the new developed COMBINED METHOD the mean differences between satellite and radar (>= 10mm/h) for the time step of 18th July 2005, 14:30 UTC are shown in Figure 18.
Figure 18: Relative mean differences between the AUTO-ESTIMATOR, ECST, MODIFIED ECST and COMBINED METHOD derived rain (with and without rain correction) and radar (Monte Macaion) measured rain - radar rain rate >=10mm/h

A comparison of in Figure 18 shown satellite techniques with and without rain correction in account with radar measured rain represents still an underestimation for SIMPLE AUTO-ESTIMATOR. In contrast the ECST, MODIFIED ECST as well as COMBINED METHOD (derived rain rates) overestimate the radar measurements.

To analyse the tendency of satellite data to underestimate as well as to overestimate radar rain rates, also in consideration of topography and current wind situation, is tested for the period of 13:30-15:30UTC (q.v. case study 1). Exemplary for the period 14:30-15:30 UTC the statistic, represented by the min value (Min), maximum value (Max), mean value (Mean), standard derivation (SD) and standard error (SE) of differences, is given in Table 8.

Table 8: Val Pusteria - Statistic of 18th July 2005, 14:30-15:30 UTC - satellite input to the region covered by radar (radar rain rate >=10mm/h)
Comparing the mean values (absolute, relative) for the time period 14:30-15:30 UTC assigned, except for MODIFIED ECST, an underestimation of derived rain to radar. This is caused by an occurrence of spatial offset between satellite and radar detected areas during the investigated period between 14:30 UTC and 15:30 UTC. The offset maybe caused by a relocation of satellite derived rainfall at the cloud top and ground measured rain. Hence it is possible that the satellite derived rain rates at the cloud top differ in spatial allocation between satellite and radar detected areas during the investigated period between 14:30 UTC and 15:30 UTC. The offset is maybe caused by a vertical movement of precipitation areas in the cloud. A further factor for spatial offset between satellite and radar rain is caused in the limitation of radar measurements depending on the range of radar station. Hence comparing to satellite the area of radar measured rain is limited. Thus a comparison between flash flood relevant radar rain rates up to 10mm/h with satellite data for a cell results an underestimation by satellite derived rain.

According to case study 1 the amount entry of satellite rain into the Italian pilot site for the period 13:30-15:30 UTC was analysed (Table 9). The analyses were done using the satellite derived rain rates as original and improved by the rain multiplier. The radar data from the Italian cooperation partner were used as reference, respectively as a precipitation input of 100%.

**Table 9: Val Pusteria - 18th July 2005, 13:30-15:30 UTC- satellite input to the region covered by radar (radar rain rate >=10mm/h)**

<table>
<thead>
<tr>
<th></th>
<th>13:30-14:20 UTC</th>
<th>14:30-15:30 UTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not corrected</td>
<td>Corrected</td>
</tr>
<tr>
<td>Auto-Estimator</td>
<td>55.44</td>
<td>60.9</td>
</tr>
<tr>
<td>(simple)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECST</td>
<td>92.87</td>
<td>104.19</td>
</tr>
<tr>
<td>Modified ECST</td>
<td>120.10</td>
<td>-</td>
</tr>
<tr>
<td>Combined Method</td>
<td>111.01</td>
<td>120.3</td>
</tr>
</tbody>
</table>

A comparison between the results within case study 1 accentuates the tendency of AUTO-ESTIMATOR to underestimate radar data more than the other satellite techniques. In contrast the ECST, COMBINED METHOD and MODIFIED ECST are capable of doing overestimate radar under specific topographic and wind conditions (e.g. for period 13:30-14:20 UTC). Hence the satellite data are able to supply additional rain of about 11.01-21.75% to the Italian investigation area covered by radar. That should be considered in runoff modelling.

Furthermore the influence of topography itself has to be considered. As described in case study 1 the slope represents the steepness or gradient of region. Figure 19 illustrates the distribution of slope values corresponding to their relative frequency.

**Figure 19: Val Pusteria - slope of investigation area**
The distribution of slope values is affected by the classification of region as an Alpine high-mountainous area (Delrieu, 2006). Thus the mean slope value of investigated Italian region averages 0.2. Comparing to case study 1 the investigated area is affected by one-fifth less precipitation input and one-fifth higher runoff times. The influence of slope for the Italian pilot site concerning the additional input of satellite derived rain is not yet tested.
5. Conclusions of the results for Meteosat-6 Rapid Scan

The aim of TU Dresden in Task 15 of FLOODsite project is to develop and test a satellite based Algorithm System (SAS). The developed system based on Meteosat-6 Rapid Scan data (M6/RS-SAS) integrates six different satellite rainfall estimation techniques. Analysing the reduction of spectral input information the satellite methods AUTO-ESTIMATOR (Vicente, 1998), GMSRA (BA & GRUBER, 2002) and the technique after GROSE (GROSE, 2001) are integrated as a simplified version by using only infrared (IR) channel information. To improve the results additional data like MPEF products and radiosonde data are implemented into M6/RS-SAS. Thus the current wind and the atmospheric condition can be considered.

Based on the integrated satellite methods AUTO-ESTIMATOR, GMSRA, GROSE and ECST a new method called COMBINED METHOD is developed using marginal spectral information based on IR input data. The different features of reference methods are unified in the new developed method.

To validate the derived rain rates as a result of M6/RS-SAS radar data from the FLOODsite co-operation partner are integrated, too. To compare the available data for one grid cell the radar are scaled to satellite resolution.

The M6/RS-SAS is tested for two case studies. The case studies are characterised by very local heavy rainfall in distinct topographic regions. Thus the several integrated satellite methods as well as the new developed method are tested to their ability to detect rainfall.

To define the influence of topographic and current wind situation the investigation area is tested concerning the windward and lee situation. By defining a rain multiplier the satellite derived rain can be intensified or reduced. For the ECST a modified version is implemented in the M6/RS-SAS knowing the orographic windward or lee situation and using empirical rain functions (BENDIX, 2001) instead of the derived rain multiplier.

The application of M6/RS-SAS to the Cévennes-Vivarais area in September 2002, pilot site of the French co-operation partner, shows large differences between the radar measured and the satellite derived rain rates. The difference between radar and satellite is caused by the different possibilities to observe a current rain event. The satellite uses only temperature values from the cloud top. The results of the tested event show, that the satellite data underestimate the measured radar data in regions were radar data are available. A comparison between the several satellite methods is done. In comparison to the methods using only IR input data the new developed method COMBINED METHOD results higher rain rates together with maximum dimension of the derived rain area. The integrated methods using more spectral input data like WV and VIS channels show more spatial limited areas. In case of ECST the areas are assigned with higher precipitation rates.

The influence of topography for MODIFIED ECST shows for the event 2002 that the applications of empirical windward or lee functions don’t have noticeable effects to the derived rain rates. Same results are shown by the use of a rain multiplier to the integrated satellite methods, except MODIFIED ECST. The marginal intensification or reduction of derived rain rates using the multiplier is caused by the weak wind speed provided by MPEF product CMW during investigation as well as a spatial offset between satellite and radar data.

To define the amount of entry of satellite derived rain to the French pilot site the data are compared with radar. Comparing satellite with radar data implies a discrimination of radar rain considering as heavy precipitation. Thus a threshold of about 10mm/h for defining radar rain as heavy rainfall (BAUMGARTNER & LIEBSCHER, 1996) was used to compare radar with satellite data. The analysis of differences results no additional precipitation input by satellite into the radar covered region.
The results for the second case study, the event of Val Pusteria in July 2005 in Italy show that the extension of radar measured rain areas, similar to French pilot side, is not as much as high as derived by satellite. During the event a spatial offset concerning satellite and radar detected rain areas occurs. As mentioned at French Case study the offset is given by the position of measured system and their abilities to get input information.

A comparison between the satellite techniques AUTO-ESTIMATOR, COMBINED METHOD and ECST shows that in case of Val Pusteria the AUTO-ESTIMATOR produces less rain than the other methods. The spatial extension of the COMBINED METHOD exceeds the other techniques.

As noticed at French pilot side the ECST derives more spatial limited rain areas associated with higher rain rates than COMBINED METHOD and AUTO-ESTIMATOR.

The influence of topography was tested for the MODIFIED ECST with special empirical rain functions and by using a rain multiplier for the satellite derived rain rates (except MODIFIED ECST). Both options offer good results in the improvement of satellite derived rain rates. For MODIFIED ECST the application of empirical windward and lee functions produces higher rain values than the ORIGINAL ECST. The application of the multiplier allows defining more exact areas of rainfall intensification or reduction. The investigation of event 2005 offers that the rain multiplier depends much on the current wind speed providing by CMW product.

A comparison of differences between satellite derived and radar measured rain concerning the amount of precipitation input to the radar covered region (as mentioned for case study 1) results for the Italian case study an additional precipitation input of about 11.01-21.75% using satellite data.

Investigations of the influence of topography slope are done for the two case studies (5.1 and 5.2) with showing potential differences in precipitation input and runoff time of one-fifth.
6. QPE with the Meteosat-8 based SAS (MSG-SAS)

Meteosat-8 is the first satellite of Meteosat Second Generation (MSG) and is therefore also called MSG-1. It was launched in 2002, has a nominal position at 0 degrees and is sending data operationally since January 2004. It carries the Spinning Enhanced Visible and Infrared Imager (SEVIRI) which observes the full disk of the earth with a repeat cycle of 15 minutes in 12 spectral channels (Table 10). The channels 1-11 have a spatial resolution of 3 x 3 km² at the Sub-Satellite Point (SSP) and channel 12 (High Resolution Visible, HRV) has a spatial resolution of 1 x 1 km² (SSP).

<table>
<thead>
<tr>
<th>Channel</th>
<th>Spectral range</th>
<th>Measuring range in μm</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VIS</td>
<td>0.56 - 0.71</td>
<td>Reflected light in the VIS part of spectrum</td>
</tr>
<tr>
<td>2</td>
<td>VIS</td>
<td>0.74 - 0.88</td>
<td>Reflected light in the VIS part of spectrum</td>
</tr>
<tr>
<td>3</td>
<td>NIR</td>
<td>1.50 - 1.78</td>
<td>Both: reflected light in the VIS part and emitted radiation in the thermal part of spectrum</td>
</tr>
<tr>
<td>4</td>
<td>IR</td>
<td>3.48 - 4.36</td>
<td>Emitted radiation in the thermal part of spectrum</td>
</tr>
<tr>
<td>5</td>
<td>WV</td>
<td>5.35 - 7.15</td>
<td>Radiation of WV absorption bands of spectrum</td>
</tr>
<tr>
<td>6</td>
<td>WV</td>
<td>6.85 - 7.85</td>
<td>Radiation of WV absorption bands of spectrum</td>
</tr>
<tr>
<td>7</td>
<td>IR</td>
<td>8.30 - 9.10</td>
<td>Emitted radiation in the thermal part of spectrum</td>
</tr>
<tr>
<td>8</td>
<td>IR</td>
<td>9.38 - 9.94</td>
<td>Emitted radiation in the thermal part of spectrum</td>
</tr>
<tr>
<td>9</td>
<td>IR</td>
<td>9.80 - 11.8</td>
<td>Emitted radiation in the thermal part of spectrum</td>
</tr>
<tr>
<td>10</td>
<td>IR</td>
<td>11.0 - 13.0</td>
<td>Emitted radiation in the thermal part of spectrum</td>
</tr>
<tr>
<td>11</td>
<td>IR</td>
<td>12.4 - 14.4</td>
<td>Emitted radiation in the thermal part of spectrum</td>
</tr>
<tr>
<td>12</td>
<td>HRV</td>
<td>Broadband (about 0.4 - 1.1)</td>
<td>Reflected light in the VIS part of spectrum</td>
</tr>
</tbody>
</table>

6.1 Transformation from counts to brightness temperature and reflectance

The SEVIRI is equipped with an on-board calibration source to calibrate the IR channels. The calibration principle is based on the use of an on-board blackbody at a known temperature, of a known emissivity and on the observation of the deep space. This latter is done at every satellite revolution and allows to remove the actual offset (due to the instrument background) from the image line by line (EUMETSAT, 2006).

The SEVIRI design does not include a device to calibrate the solar channels on board. This imposes the use of vicarious methods. Vicarious calibration methods rely on an independent estimation of the radiance observed by SEVIRI. Three different techniques have been traded-off for the estimation of the radiance allowing the
calibration of the SEVIRI solar channels: satellite inter-comparison, calibration airborne campaign, and Radiative Transfer Modelling (RTM) computation (EUMETSAT, 2006).

The developed program for estimating precipitation with Meteosat-8 works with pgm-pictures which have to be created out of the raw files. This step has been done with David Taylor’s MSG Data Manager (David Taylor, 2007, [g]). The pgm-files consist of a header and the image data field (binary pixel). The relation between the binary pixel value (the pixel count) and the physical radiance units is fully defined for each spectral band by the relation:

\[
R = C_{\text{offset}} + \left( C_{\text{slope}} \cdot \text{Count} \right)
\]  

\[
R \quad \text{radiance (mW m}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-1})
\]

\[
C_{\text{offset}} / C_{\text{slope}} \quad \text{regression coefficients (mW m}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-1})
\]

\[
\text{Count} \quad \text{binary pixel value}
\]

The calibration offset and slope values are obtained from the repeat cycle prologue raw file disseminated for each image. They are also part of the header of each pgm-picture.

The conversion from radiance to temperature for the WV and IR channels is given by (EUMETSAT, 2004):

\[
T_B = \left[ C_2 \cdot v_c / \ln \left( \frac{C_1 \cdot v_c^3}{R} + 1 \right) - B \right] / A
\]  

\[
T_B \quad \text{brightness temperature (K)}
\]

\[
C_1 \quad 1.19104 \times 10^{-5} \text{ mW m}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-4}
\]

\[
C_2 \quad 1.43877 \text{ K}(\text{cm}^{-1})^{-1}
\]

\[
v_c \quad \text{central wavenumber of the channel (cm}^{-1})
\]

\[
A, B \quad \text{coefficients depending on the channel}
\]

The conversion from radiance to reflectance for the VIS channels is expressed as follows (EUMETSAT, 2004):

\[
r = \frac{100 \cdot R_i}{R_{TOA}, \cdot \cos \theta}
\]  

\[
r \quad \text{reflectance (\%)}
\]

\[
i \quad \text{ID of the channel... VIS0.6; VIS0.8; NIR1.6; HRV}
\]

\[
R \quad \text{radiance (mW m}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-1})
\]

\[
\theta \quad \text{sun zenith angle}
\]

\[
R_{TOA} \quad \text{Radiation at Top Of Atmosphere (mW m}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-1})
\]

One specific feature is given by channel 4 which receives energy from the emitted thermal radiation as well as from the reflected solar radiation during daytime. Therefore based on only one count both, brightness temperature and reflectance are calculable. Because of the complexity of calculation the process is not described more detailed in this document. All the formulas can be found in EUMETSAT (2004).
Furthermore, for each pixel of the selected area the geographic coordinates, the sun zenith angle and the satellite zenith angle are calculated using the equations given by EUMETSAT (1999) and LENOBLE, J. (1993).

### 6.2 Implemented algorithms for rainfall estimation

The following four algorithms for rainfall estimations are implemented in the MSG-SAS:

- **ENHANCED CONVECTIVE STRATIFORM TECHNIQUE** (ECST) after (REUDENBACH, 2003)
- **AUTO-ESTIMATOR** (AE) (VICENTE, 1998)
- **GOES MULTISPECTRAL RAINFALL ALGORITHM** (GMSRA) (BA & GRUBER, 2001)
- Method after KURINO (KURINO, 1997)

Table 11 shows some basic features of these four implemented algorithms.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Development satellite / area</th>
<th>Input</th>
<th>Threshold</th>
<th>Calibration</th>
<th>Stratiform / convective rain</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTO-ESTIMATOR</td>
<td>GOES, USA</td>
<td>$T_{IR}$</td>
<td>$190K \leq T_{IR} \leq 260K$</td>
<td>radar rain rates</td>
<td>Growth rate and moisture correction</td>
</tr>
<tr>
<td>ENHANCED CONVECTIVE STRATIFORM TECHNIQUE</td>
<td>Meteosat-6, Europe (mid-latitudes)</td>
<td>$T_{IR}$, $T_{WV}$</td>
<td>$T_{IR} &lt; 253K$, $T_{WV} - T_{IR} &gt; 0K$</td>
<td>radar rain rates</td>
<td>Discrimination of stratiform / convective rain, redux convection</td>
</tr>
<tr>
<td>GOES MULTISPECTRAL RAINFALL ALGORITHM</td>
<td>GOES, USA</td>
<td>$T_{IR}$, $T_{WV}$, $R_{VIS}$</td>
<td>$T_{IR} &lt; 250K$ (day), $R_{VIS} &gt; 40%$ (day), $T_{IR} &lt; 230K$ (night)</td>
<td>radar rain rates</td>
<td>Two parts: day, night; Includes reflectance (day), growth rate and moisture correction</td>
</tr>
<tr>
<td>Method after KURINO</td>
<td>GMS, Okinawa Islands, Japan</td>
<td>$T_{IR}$, $T_{WV}$</td>
<td>$T_{IR} &lt; 250K$</td>
<td>radar rain rates</td>
<td>Working with Look-Up Tables containing the probability of rain and the mean rain rate</td>
</tr>
</tbody>
</table>

With the AUTO-ESTIMATOR rain rates are calculated by using a regression function for all pixels with a brightness temperature of channel 9 between 190 K and 260 K. The results get corrected by a factor concerning the cloud life cycle and the atmospheric humidity between the surface and the 500 hPa level. The AUTO-ESTIMATOR generates two results, one without any correction (SIMPLE AE) and one including both correction factors (CORRECTED AE).

The Enhanced Convective Stratiform Technique (ECST) uses the temperatures of a IR-channel (channel 10) and a WV-channel (channel 6). Only these pixels with $T_{IR}<253 K$ and $T_{WV} - T_{IR} > 0 K$ are considered to be possible raining pixels. The method includes the discrimination between convective and stratiform clouds. As a simplification the clustering of cloud pixels is omitted.

The implemented GOES Multispectral Rainfall Algorithm (GMSRA) is the most complex method which uses IR, WV and VIS input data. The algorithm allows differentiating between day and night. For daytime pixels with $T_{IR}$ between 250 K and 219 K in channel 9, a negative difference between channel 9 and 5, a reflectance >40 % in channel 1 and a reflectance <10 % in channel 4. For nighttime the pixels must have $T_{IR}$ between 230 K and 220 K in channel 9 and as well as a negative difference between channel 9 and 5. Finally, the results are corrected by a factor concerning the cloud
life cycle and the atmospheric humidity. The GMSRA is implemented in two forms, one without correction (SIMPLE GMSRA) and one with the two correction factors (CORRECTED GMSRA).

For the method after KURINO three parameters are derived for each pixel:
- the brightness temperature of channel 9
- the brightness temperature of channel 10
- the difference of the brightness temperatures of channel 9 and 5

These three parameters span two 3D Look-Up Tables (LUT) containing once the probability of rain (PoR) and once the mean rain rate (mRR). The product of PoR and mRR is used as the final rain rate (KURINO, 1997).

6.3 Correction of estimated rain rates

For the algorithms AUTO-ESTIMATOR and GMSRA a moisture and cloud growth rate correction have been applied.

6.3.1 Moisture correction factor

During dry conditions the rain is expected to evaporate completely or totally before reaching the surface. Further during wet conditions the rain is expected to get increased. That results in an overestimation of the rain rates in dry environments and an underestimation in wet environments. Therefore a moisture correction factor is used which is defined as the product of the precipitable water (PW) and the averaged relative humidity (RH) between the surface and the 500 hPa level (Equ. 7.4). The values for PW and RH are obtained from radiosonde data.

\[ PWRH = PW \cdot RH \] (7.4)

After VICENTE et al. (1998) the PWRH factor is empirically scaled from 0.0 to 2.0. If PWRH is less than 1.0 the environment is considered as dry. And if PWRH is greater than 1.0 it is considered to be very moist. So the moisture correction factor decreases or increases the estimated rain rates (VICENTE et al., 1998).

6.3.2 Cloud growth rate correction factor

It is a fact that the amount of the rainfall depends on the stage of life cycle of the raining cloud. For example, an active convective cell produces the highest rain rates when it is growing and getting colder. Otherwise, a decaying cell is getting warmer and the rainfall decreases or stops. Thus, it is necessary to examine the life cycle stage of the clouds in each satellite image. This is realised by investigating the changes in the brightness temperature of each pixel in two consecutive images whether they become colder, warmer or stay at the same temperature. For that the mean brightness temperatures is calculated in a window with the size of 3 x 3 pixels centered at the currently examined pixel for the current and previous image. Then the difference of these two mean temperatures is computed while no cloud drifting is assumed (BA & GRUBER, 2001). Three possibilities have to be differentiated:

- The difference is negative. That means the cloud is getting colder and precipitation is intensifying. So the pixels in the current image are associated with the heaviest rain rates and the estimated ones remain unchanged.
- The difference is positive. That means the cloud is getting warmer and precipitation is weakening. In this case the estimated rain rate is set to zero in the current image.
- There is no change in the temperature of the 3 x 3 window. As a result the searching window is expanded to 5 x 5 pixels. If there is still no change the estimated rain rate is not corrected (VICENTE et al., 1998).

Therefore, the growth rate factor is a binary number with a possible value of 0 or 1 and acts consequently as a mask (VICENTE et al., 1998).

6.3.3 The effects of the correction factors

The effects of the moisture and growth rate correction are presented exemplarily for the GMSRA for the heavy precipitation event of the 18th July 2005 in the Trentino-Alto Adige region in northern Italy.

Figure 1a-d shows the high influence of both correction factors, particularly of the cloud growth rate correction factor. The moisture factor decreases the estimated rain rates. Without the moisture correction the maximum rain rate is 33.4 mm/h and the mean rain rate is 7.4 mm/h. After correcting the rain rates using the moisture factor the maximum is 29.7 mm/h and the mean is 6.6 mm/h. The growth rate factor effects the rain field area which is much bigger without the growth correction. As a result the algorithm assumes that the raining clouds are decaying at this point of time.
6.3.4 MPEF and SAF products for Meteosat-8

From the image data of the satellites of Meteosat Second Generation various MPEF (Meteorological Product Extraction Facility) and SAF (Satellite Application Facility) products are generated which could be useful for the correction and validation of the estimated rain rates. The MPEF products (e.g. Atmospheric Motion Vectors, Tropospheric Humidity) are regularly produced, archived and distributed by EUMETSAT. They have a spatial resolution of 1° x 1° and different temporal resolutions (e.g. 15 min, 1 h, 3 h).

The SAF products (e.g. Precipitating Cloud, Convective Rainfall rate) are decentralised processed and generated in several member states. These products are mainly distributed to users on demand, either as finalised products or as product extraction algorithm software packages (EUMETSAT, 2002) for which a licence is needed. The SAFs have a spatial and temporal resolution equivalent to the MSG data resolution.

Both product types are encoded in the very complex and compressed BUFR (Binary Universal Form for the Representation of meteorological data) and GRIB II (GRIdded Binary II) data format. To work with them a special decoder is needed which is not working under Windows.

MPEF as well as SAF could not be included in the MSG-SAS within the FLOODsite project because of problems with the required licence and the data formats. For future works improving the satellite based rainfall estimation the inclusion of MPEF and SAF is advised and aimed.
7. Case studies for QPE with Meteosat-8

The MSG-SAS with the four implemented algorithms (Chapter 6.2) has been applied to heavy precipitation events in the pilot sites namely the Trentino-Alto Adige region in northern Italy (co-operation partner UniPad) and the Elbe river basin in Saxony (link to Task 21).

For both regions one event has been chosen to show the results concerning the estimated rain rates using Meteosat-8. The Italian event took place on the 18th July in 2005 in the afternoon and the event in Saxony was in the afternoon of the 16th June in 2006.

To analyse the results four different cases get examined for both events:

- spatial resolution 4 x 8 km² / 4 x 6 km²; one single time step
- spatial resolution 4 x 8 km² / 4 x 6 km²; one full hour
- spatial resolution 10 x 10 km²; one single time step
- spatial resolution 10 x 10 km²; one full hour

Thereby the 4x8 km² / 4x6 km² resolution were chosen because of the spatial resolution of Meteosat-8 for the Saxon / Italian region. And 10x10 km² is assumed to be the size of a typical medium catchment area. For the examination of flash floods the input in a whole catchment area is important. For statistical analysis the radar data >= 10 mm/h were selected. Then the differences of them and the corresponding satellite data were calculated. The threshold of 10 mm/h was defined because a rain rate with at least such intensity is said to be a heavy one (BAUMGARTNER & LIEBSCHER, 1996).

For the comparisons of the results this satellite scan was chosen who was temporal the closest to the radar time. In contrast to Meteosat-6 the time stamp of a Meteosat-8 picture denotes the start of the scan of this picture (EUMETSAT 2006a). The scan always starts in the south-east (South Pole) and took about 13 minutes till its end in the north-west (North Pole). So after about 9 and 10 minutes north Italy and Saxony are scanned.

The one hour value for Meteosat-8 rain rates is calculated by averaging the four values of this hour. Exemplarily only a part of the pictures and tables for the four cases are presented here. The others can be found in the appendix.

7.1 Trentino - Alto Adige (Val Pusteria), Italy, 18th July 2005

As a reference the rain rates derived by the radar station located at the Monte Macaion are shown in Figure 21. They have a spatial resolution of 1 x 1 km² and a temporal resolution of 5 min (q.v. Chapter 2.2) containing the rain intensity in mm/h. To get the value for one hour the twelve 5min-values of this hour were averaged. The figures 22a-f show the estimated rain rates for each implemented algorithm. From the radiosonde data of Udine at 12.00 UTC come the required additional data relative humidity and precipitable water for the PWRH correction of the AUTO-ESTIMATOR and the GMSRA. At that point of time the relative humidity between surface and the 500 hPa level was 61.85 %. The precipitable water for the entire sounding was 1.44 inch. That results in a PWRH factor of 0.89.

Figure 21: Radar data Monte Macaion, 18th July 2005, 14.30 UTC, 4 x 6 km²
It can be seen that there are big differences between the radar and satellite derived rain rates and also between the six satellite estimation techniques. These differences concern the range of the rain rates as well as the size and location of the rain field area. The rain field area derived by radar is only partly covered by the satellite derived rain rates but the satellite rain field is much bigger and relocated in the north-east of the researched area. However, the areas with the highest rain rates are situated near the highest radar rain rates. Thus a spatial offset is distinguishable. For the four algorithms the maximum rain rate varies from 7.6 mm/h (KURINO) to 32.3 mm/h (GMSRA) while the maximum of radar rain rates is 31.5 mm/h. There is a general tendency of the satellite estimation techniques to underestimate the radar rain rates of these grid cells having rates ≥ 10 mm/h. This results in negative values for the means (Table 12) of the differences between radar and satellite rain rate. Beside of the absolute and
relative mean, Table 12 contains the statistical parameters minimum (Min), maximum (Max), standard deviation (SD) and the standard error of the mean (SE) of these differences.

The tendency to underestimate is most distinct for the CORRECTED AUTO-ESTIMATOR and GMSRA what results from the PWRH correction (PWRH < 1.0). For the areas with little or no radar derived rain the satellite techniques tend to an overestimation, especially the SIMPLE GMSRA and the ECST. Both tendencies (over- and underestimation) are partly a consequence of the relocation of the satellite rain field. This relocation may results of the different angle of view of the two systems radar and satellite and the different points in time of scanning.

Table 12: Statistical parameter of the differences between radar and satellite rain rate for the 18th July 2005, 14.30 UTC, 4 x 6 km²

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>AUTO-ESTIMATOR</th>
<th>ECST</th>
<th>GMSRA</th>
<th>KURINO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>simple</td>
<td>corrected</td>
<td>simple</td>
<td>corrected</td>
</tr>
<tr>
<td>Min</td>
<td>mm/h</td>
<td>-21.80</td>
<td>-29.05</td>
<td>-25.44</td>
<td>-31.47</td>
</tr>
<tr>
<td>Max</td>
<td>mm/h</td>
<td>-0.98</td>
<td>-2.17</td>
<td>11.15</td>
<td>12.64</td>
</tr>
<tr>
<td>Mean</td>
<td>mm/h</td>
<td>-10.75</td>
<td>-13.80</td>
<td>-7.69</td>
<td>-2.75</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>-68.06</td>
<td>-87.32</td>
<td>-48.65</td>
<td>-17.38</td>
</tr>
<tr>
<td>SD</td>
<td>mm/h</td>
<td>5.49</td>
<td>6.42</td>
<td>9.92</td>
<td>11.44</td>
</tr>
<tr>
<td>SE</td>
<td>mm/h</td>
<td>1.17</td>
<td>1.37</td>
<td>2.11</td>
<td>2.44</td>
</tr>
</tbody>
</table>

7.2 Saxon part of the Elbe river basin, 16th June 2006

Saxony is a federal state in the South-East of Germany. It covers lowlands as well as medium-elevation mountains (Figure 23). The mountainous region is part of the ore mountains up to a height of around 1200 m. Saxony also covers the Mulde and a part of the Elbe river basin which are the topic of research within Task 21. Therefore one heavy rain fall event is selected for this region.

Figure 23 shows the slope of the Saxon region of the Elbe pilot site describing its steepness. The mean slope is 0.02 what is a relatively low value in comparison to the Italian pilot site which has a ten times higher mean slope of 0.2. In the figures 25 and 26 the histograms of the relative frequencies of the slope are shown for these both regions. It can be seen that the slope of the Italian region covers a wider range while the frequencies are much lower.
The slope of a region has two important effects on the development of flash floods:

- The higher the slope the shorter the runoff times
- The higher the slope the smaller the catchment area

That means for these two regions that the mean runoff time in Saxony is ten times lower than the runoff in the Italian pilot site. And the flash flood relevant catchment area is ten times bigger in the Saxon region than in the Italian region.

During the 16th June 2006 the Saxon region was influenced by a low-pressured system with an eastwards moving cold front who separated subtropical warm air over in the south and east of Germany from cold maritime air over the northwest. In Saxony the temperatures reached values around 30°C. In a consequence during the day a lot of thunderstorms occurred.

The radar data for Saxony region result from the work of the RIMAX project EXTRA (TU Dresden, 2007, [f]). They are measured by a DWD (Deutscher Wetterdienst) radar station located at Dresden. They have a spatial resolution of 1 x 1 km² and temporal resolution of 5 min containing the intensity in mm/5min. To get the intensity for one hour the 12 values of this hour have been summated.

The value for one hour of the satellite derived rain rates was again calculated by averaging the four values of this hour.

For the PWRH correction of the AUTO-ESTIMATOR and the GMSRA the relative humidity and the precipitable water are required. They are coming from the radiosonde data of Lindenberg at 12.00 UTC. At that point of time the relative humidity between the surface and the 500 hPa level was 61.08 % and the precipitable water for the entire sounding was 1.44 inch. The outcome of this is a PWRH correction factor of 0.70.

In this example the rain rates derived by the radar station located at Dresden are shown as a reference in Figure 27. Then the following six figures (Figure 28a-f) show again the rain rates estimated by the implemented algorithms.
Figure 27: Radar data Dresden, 16th June 2006, 13.00-14.00 UTC, 4 x 8 km²

Figure 28a: AUTO-ESTIMATOR; 16th June 2006, 13.00-14.00 UTC, 4 x 8 km²

Figure 28b: CORRECTED AUTO-ESTIMATOR; 16th June 2006, 13.00-14.00 UTC, 4 x 8 km²

Figure 28c: GMSRA; 16th June 2006, 13.00-14.00 UTC, 4 x 8 km²

Figure 28d: CORRECTED GMSRA; 16th June 2006, 13.00-14.00 UTC, 4 x 8 km²

Figure 28e: ECST; 16th June 2006, 13.00-14.00 UTC, 4 x 8 km²

Figure 28f: Method after KURINO; 16th June 2006, 13.00-14.00 UTC, 4 x 8 km²
Like in case study 1 also for this event there are big differences in range and area between the radar and satellite derived rain rates and between the six satellite estimation techniques, too. Again the rain field area derived by radar is only partly covered by the satellite one which is much bigger than the radar field. The structure of the left part of the satellite rain field partly resembles the radar one. Also for this event it can be seen that the areas with the highest rain rates are situated near the highest radar rain rates what suggests again a spatial offset for the satellite rain rates. For the four algorithms the maximum rain rate differs between 7.8 mm/h (Method after KURINO) and 31.9 mm/h (GMSRA) while the maximum of radar rain rates is 51.3 mm/h. There is again a general tendency of the satellite estimation techniques to underestimate the radar rain rates of these grid cells with rates $\geq 10$ mm/h what results in negative means (Table 13) of the differences between radar and satellite rain rate. Beside of the absolute and relative mean, Table 13 contains again the statistical parameters minimum (Min), maximum (Max), standard deviation (SD) and the standard error of the mean (SE) of these differences. The tendency of underestimation is most distinct for the CORRECTED AUTO-ESTIMATOR and GMSRA and the Method after KURINO. For these both corrected techniques the underestimation is increased by the PWRH correction factor which is again below 1.0. Overestimation by the satellite rain rates can also for this event be found for the areas with little or no radar derived rain rates. This is most distinct for the ECST and the SIMPLE GMSRA like in case study 1. Both tendencies (over- and underestimation) are again partly a consequence of the relocation of the satellite rain field. This relocation may results of the different angle of view of the two systems radar and satellite and the different points in time of scanning.

Table 13: Statistical parameters of the differences between radar and satellite rain rate for the 16th June 2006, 13.00-14.00 UTC, 4 x 8 km²

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>AUTO-ESTIMATOR</th>
<th>ECST</th>
<th>GMSRA</th>
<th>KURINO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>simple</td>
<td>corrected</td>
<td>simple</td>
<td>corrected</td>
</tr>
<tr>
<td>Min</td>
<td>mm/h</td>
<td>-36.94</td>
<td>-46.42</td>
<td>-35.28</td>
<td>-37.04</td>
</tr>
<tr>
<td>Max</td>
<td>mm/h</td>
<td>2.91</td>
<td>-1.84</td>
<td>13.09</td>
<td>12.07</td>
</tr>
<tr>
<td>Mean</td>
<td>mm/h</td>
<td>-11.78</td>
<td>-14.75</td>
<td>-8.98</td>
<td>-5.83</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>-64.77</td>
<td>-81.14</td>
<td>-49.35</td>
<td>-32.06</td>
</tr>
<tr>
<td>SD</td>
<td>mm/h</td>
<td>9.28</td>
<td>8.77</td>
<td>11.62</td>
<td>10.60</td>
</tr>
<tr>
<td>SE</td>
<td>mm/h</td>
<td>1.09</td>
<td>1.03</td>
<td>1.36</td>
<td>1.24</td>
</tr>
</tbody>
</table>
8. Conclusions of the results for Meteosat-8

For the QPE with Meteosat-8 four algorithms have been implemented in the MSG-SAS and tested for two heavy convective precipitation events. It could be seen that there are big differences between the rain rates derived by radar and satellite. These differences concern the size and location of the rain field area as well as the amount of the estimated rain rates. However, the structure of the radar rain field is partly distinguishable in the satellite estimated rain fields. This is the case for the simple and CORRECTED AUTO-ESTIMATOR and the CORRECTED GMSRA for the event of the 18th July 2005 in the Val Pusteria. For the Saxon event of the 16th June 2006 the structure is partly distinguishable in the rain fields derived by the SIMPLE AUTO-ESTIMATOR as well as by the SIMPLE and CORRECTED GMSRA.

All of the used algorithms show a tendency to underestimate the rain rates measured by radar for the grid cells having rain rates $\geq 10$ mm/h. This tendency is most distinct for the corrected methods of the AUTO-ESTIMATOR and GMSRA. This is the result of the moisture correction which decreased the estimated rain rates because of quite dry atmospheric conditions (PWRH < 1.0) during these two selected events. For the areas with less or no radar derived rain a tendency of overestimation is evident for all techniques especially for the ECST and the simple version of the GMSRA.

Both tendencies (over- and underestimation) are partly a consequence of the relocation of the satellite rain field. This relocation may results of the different angle of view of the two systems radar and satellite and the different points in time of scanning.

The Method after KURINO generates rain fields which are very equalised in their structures and values and it never overestimates the radar derived rain rates.

The results are better for the analysis of a longer time span like one hour (Saxon event) than for a single time step (Italian event). And an improvement is partly achieved by increasing the grid size from $4 \times 8$ km$^2$ / $4 \times 6$ km$^2$ to $10 \times 10$ km$^2$, e.g. for a research time of one hour in both case studies.

Every flash flood prone region is characterized by specific orographic conditions. They can be described with the slope. The slope of an area is important because it has a high influence on the runoff times and the size of the catchment areas. Here in these two case studies the mean slope for the Italian region is ten times higher than that of the Saxon region. This leads to ten times higher runoff times in the Italian region and ten times smaller catchment areas.

There are various problems and sources of error causing the discrepancies between the radar and satellite derived rain rates. First of all there is the basic problem that the satellite can only scan the top of clouds and it is unable to see which processes go on below a cloud. Therefore the rain rates have to be estimated from the temperature and reflectance of the cloud tops.

Another problem is that all of the implemented algorithms were developed for other satellites or regions. So they are not applicable to MSG without adjustments to its different spectral responses and spatial and temporal resolution.

Differences between the radar and satellite rain rates also result from the different spatial resolution of the radar data (1x1 km$^2$) and MSG (4x8 / 4x6 km$^2$) as well as from the different points in time of the measurement and scan.

It can be said that the satellite based estimation of rain rates already shows good approaches but for improving the accuracy in space and intensity it is necessary to adjust the algorithms to the used satellite and region. And there is a need of including additional data like orography, MPEF, SAF, wind data, atmospheric profiles, cloud life cycles and cloud models how it has already been partly done for the data of Meteosat-6 Rapid Scan.
9. Comparisons between Meteosat-6 and Meteosat-8

In the previous chapters several rainfall estimation techniques based on satellite input data from Meteosat-6 and Meteosat-8 were applied to three heavy precipitation events in different flash flood prone regions within distinct orography (France: Cévennes-Vivarais, Italy: Trentino-Alto Adige, Germany: Saxony- Ore Mountains). The satellite derived rain rates of each event were compared with radar measurements. The results of chapter 4 and 7 have shown great differences between satellite and radar measurements. This corresponds to the extension and the structure of the detected rain area as well as the values of the rain rates.

Further analyses are done comparing the satellite results with regard to the advantages using more spectral information provided by Meteosat-8 data (Figure 29). The comparison is done for the methods AUTO-ESTIMATOR and ECST for the 18th July 2005 for the period 14:30-15:30 UTC as well as for the time step 14:30 UTC.

![Figure 29: Comparison between rain rates derived by Rapid Scan and MSG data for the methods AUTO-ESTIMATOR and ECST](image)

A comparison of Meteosat-6 (disregarding the rain multiplier) and Meteosat-8 derived rain rates for the time step 14:30 UTC (Figure 31 and 32a) concerning to radar (Figure 30) demonstrates similar extensions in the detected rain area and differences in the quantity of rain rates. As discussed in Chapter 4 and 7 a spatial offset between the satellite derived rain rates (based on Meteosat-6 as well as Meteosat-8 data) and the radar measurements exist (Figure 30 vs. Figure 31, Figure 30 vs. Figure 32). The offset is not fully explainable and maybe caused by features of the measurement instruments itself.
Improving the Meteosat-6 rain rates using the multiplier as discussed in Chapter 3.3 enhanced the quantity of derived rain by Meteosat-6. Thus the amount of Meteosat-6 improved rain rates is approximated to Meteosat-8 data (Figure 31 and Figure 32b).

Figure 31 and Figure 32 represent an additional spatial offset between the two satellite data considering the assessment of rain. That maybe caused in the differences of sampling time, respectively the timestamp for Meteosat-6 and Meteosat-8. There the interpretation of time stamp for the both satellites differs. For Meteosat-6 the time stamp denotes the end of the repeating cycle, while for Meteosat-8 it denotes the start of the repeating cycle (EUMETSAT, 2006a). Accordingly for the 18th July 2005, 14:30 UTC the satellite data of 14:30 UTC (Meteosat-6) and 14:15 UTC (Meteosat-8) are compared. Concerning the different sampling times of 10 (MFG-6) to 15 minutes (MSG-1) that could take effect to the spatial assignment of rain.

The spatial and quantitative differences between Meteosat-6 (without and with considering rain multiplier) and Meteosat-8 (as reference) derived rain rates are given in Figure 33 and 34.
Similar to the AUTO-ESTIMATOR TECHNIQUE a further comparison between Meteosat-6 and Meteosat-8 derived rain rates is done for the ECST. The analysis of Figure 36 and 37a demonstrates fewer differences in the detected rain area but high differences in the quantity of rain rates. The Meteosat-8 data represents higher rain rates followed by increased extensions.
Using the rain multiplier for Metosat-6 data increased the quantity of derived rain rates (Figure 37b). A comparison between Figure 36 and Figure 37b clarifies higher rain values for the improved Meteosat-6 data as derived for Meteosat-8.

As mentioned for the AUTO-ESTIMATOR the differences between Meteosat-6 derived rain (without and with improvement by a multiplier) and Meteosat-8 rain rates are generated (Figure 38 and 39).

![Figure 38: Trentino-Alto Adige/ Val Pusteria: Difference between ECST derived rain rates based on Meteosat-8 (without any correction, and Meteosat-6 (without rain correction) for the 18th July 2005, 14:30 UTC, 5km x 8km](image1)

![Figure 39: Trentino-Alto Adige/ Val Pusteria: Difference between ECST derived rain rates based on Meteosat-8 (without any correction) and Meteosat-6 (with rain correction) for the 18th July 2005, 14:30 UTC, 5km x 8km](image2)

As well as for the AUTO-ESTIMATOR the results of both satellite data for ECST differ in spatial and quantitative assignment. Using the rain multiplier effects higher rain values for Meteosat-6 data in comparison to Meteosat-8 (Figure 39).

To define the differences in the statistic values of the derived rain rates concerning the radar rain rates >=10mm/h the results of AUTO-ESTIMATOR and ECST (based on Meteosat-6 Rapid Scan and Meteosat-8 data) for the time step 14:30UTC are tested. The results of the minimum value (Min), maximum value (Max), mean value (Mean), standard derivation (SD) and standard error of mean (SE) are given in Table 14.

<table>
<thead>
<tr>
<th>AE (simple) 14:30UTC</th>
<th>ECST 14:30UTC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Satellite (Meteosat-6, Meteosat-8)</strong></td>
<td><strong>Satellite (Meteosat-6, Meteosat-8)</strong></td>
</tr>
<tr>
<td>No rainfall correction</td>
<td>Rainfall correction</td>
</tr>
<tr>
<td><strong>Min [mm/h]</strong></td>
<td>-17.28</td>
</tr>
<tr>
<td><strong>Max [mm/h]</strong></td>
<td>-0.8</td>
</tr>
<tr>
<td><strong>Mean (abs) [mm/h]</strong></td>
<td>-6.55</td>
</tr>
<tr>
<td><strong>Mean (rel) [%]</strong></td>
<td>-44.2</td>
</tr>
<tr>
<td><strong>SD [mm/h]</strong></td>
<td>4.88</td>
</tr>
<tr>
<td><strong>SE [mm/h]</strong></td>
<td>1.12</td>
</tr>
</tbody>
</table>
As shown in Table 14 the results for the AUTO-ESTIMATOR and the ECST for both satellites differ. The AUTO-ESTIMATOR derived rain rates underestimate the radar measurements (>= 10mm). Comparing the results of both satellites, Meteosat-8 tends to underestimate radar more than Meteosat-6 (about 24%). This is maybe caused by the differences in the scanning time and the filter functions of the input channels.

For the ECST it can be seen that the Meteosat-6 tends to overestimate radar and Meteosat-8 tends to underestimate again. Possible reasons are the differences in scanning time, detected areas with high rain rates as well as the spatial offset between radar and satellite.

To analyse the tendency of the rain multiplier offering higher rain rates as derived for Meteosat-8 data the period 14:30-15:30 UTC for the 18th July 2005 is tested exemplarily for the AUTO-ESTIMATOR and ECST. The analyses are done using the differences between satellite and radar measurements (q.v. Chapter 4.2, Chapter 7.1) and evaluating statistically. The results of the minimum value (Min), maximum value (Max), mean value (Mean), standard derivation (SD) and standard error of mean (SE) are given in Table 15.

Table 15: Difference between satellite (Meteosat-6, Meteosat-8) and radar - Comparison of statistical parameters for AUTO-ESTIMATOR and ECST with and without rainfall correction by a multiplier for the 18th July 2005, 14:30-15:30 UTC

<table>
<thead>
<tr>
<th></th>
<th>AE (simple) 14:30-15:30UTC</th>
<th>ECST 14:30-15:30UTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meteosat-6</td>
<td>Rainfall correction</td>
</tr>
<tr>
<td>Min [mm/h]</td>
<td>-17.84</td>
<td>-17.84</td>
</tr>
<tr>
<td>Max [mm/h]</td>
<td>-1.74</td>
<td>-1.13</td>
</tr>
<tr>
<td>Mean (abs) [mm/h]</td>
<td>-7.78</td>
<td>-7.72</td>
</tr>
<tr>
<td>Mean (rel) [%]</td>
<td>-55.25</td>
<td>-54.86</td>
</tr>
<tr>
<td>SD [mm/h]</td>
<td>3.88</td>
<td>4.01</td>
</tr>
<tr>
<td>SE [mm/h]</td>
<td>0.75</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Considering the Mean values (absolute, relative) in Table 15 the application of the rain multiplier effects less improvement to derived Meteosat-6 rain rates. This is shown for the AUTO-ESTIMATOR as well as for the ECST. By contrast the rain multiplier is not able to reach the Mean values of Meteosat-8 derived rain rates. This may be due to the feature of Meteosat-6 Rapid Scan data to underestimate the derived rain rates in comparison to Meteosat-8 based on the marginal spectral information of Meteosat-6 used as input for the satellite estimation methods.

A comparison of Mean values (absolute, relative) for Meteosat-6 and Meteosat-8 represents an underestimation for the AUTO-ESTIMATOR TECHNIQUE which is more distinct for Meteosat-6 (about 15%).

The results of the ECST show a tendency of underestimation for Meteosat-6 and overestimation for Meteosat-8. This overestimation is explainable with the higher extension of the detected heavy rainfall area. Thereby the results should be less influenced by the already discussed offsets (spatial and temporal) due to the smoothing effect over the time span. Furthermore the application of the ECST to the Meteosat-8 data is not completely clarified until now (REUDENBACH, 2005). And the effect of this is difficult to discuss.

Following NEGRI & ADLER (1993), SCOFIELD & KULIGOWSKI (2003) as well as the results of the satellite team of TU Dresden it can not explicitly be said whether satellite estimation techniques
under- or overestimate radar measurements. It depends on various conditions (atmospheric conditions, orography, technical features of the instrument, estimation method,…).

As a conclusion it can be noted that the results depend on the applied satellite based estimation technique as well as on the used satellite input data (Meteosat-6, Meteosat-8). At least Meteosat-8 offers improved rainfall estimations because of its better spatial resolution and the increased spectral information (12 channels) but the estimation techniques have to be adapted to that.

The project work of TU Dresden pointed out that the satellite based rainfall estimation still includes several uncertainties and require reference data (ground measurements). Nevertheless the satellite derived rain rates provide helpful additional information of researched rainfall areas, particularly in regions low or not covered by ground measurements.

The current use of satellite data as an input to flash flood prone regions should be considered by a weighting to ground measurements. This is done exemplarily within the RIMAX project EXTRA (TU Dresden, 2007, [f]).
Appendix
Figure A1: Cévennes-Vivarais: Effect of using a rain multiplier to improve the ECST derived rain rates- A comparison between rain rates uncorrected (A1a) and corrected (A1b) with regard to orographic and current wind situation.

Figure A2: Cévennes-Vivarais: Effect of using a rain multiplier to improve the GMSRA derived rain rates- A comparison between rain rates uncorrected (A2a) and corrected (A2b) with regard to orographic and current wind situation.

Figure A3: Trentino-Alto Adige/ Val Pusteria: Effect of using a rain multiplier to improve the AUTO-ESTIMATOR derived rain rates- A comparison between rain rates uncorrected (A3a) and corrected (A3b) with regard to orographic and current wind situation.
Figure A4: Trentino-Alto Adige/ Val Pusteria: Effect of using a rain multiplier to improve the GMSRA derived rain rates - A comparison between rain rates uncorrected (A4a) and corrected (A4b) with regard to orographic and current wind situation

Table A3: Statistical parameters of the differences between radar and satellite rain rate for the 18th July 2005, 14.30-15.30 UTC, 4 x 6 km²

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>AUTO-ESTIMATOR</th>
<th>ECST</th>
<th>GMSRA</th>
<th>KURINO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>simple</td>
<td>corrected</td>
<td>simple</td>
<td>corrected</td>
</tr>
<tr>
<td>Min</td>
<td>mm/h</td>
<td>-14.03</td>
<td>-15.41</td>
<td>-12.34</td>
<td>-8.57</td>
</tr>
<tr>
<td>Max</td>
<td>mm/h</td>
<td>30.00</td>
<td>-2.55</td>
<td>13.10</td>
<td>14.25</td>
</tr>
<tr>
<td>Mean</td>
<td>mm/h</td>
<td>-4.96</td>
<td>-8.99</td>
<td>3.20</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>-39.59</td>
<td>-65.91</td>
<td>23.44</td>
<td>2.55</td>
</tr>
<tr>
<td>SD</td>
<td>mm/h</td>
<td>7.50</td>
<td>3.25</td>
<td>6.10</td>
<td>5.14</td>
</tr>
<tr>
<td>SE</td>
<td>mm/h</td>
<td>1.35</td>
<td>0.59</td>
<td>1.11</td>
<td>0.94</td>
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</tbody>
</table>

Table A1: Statistical parameters of the differences between radar and satellite rain rate for the 18th July 2005, 14.30 UTC, 10 x 10 km²

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>AUTO-ESTIMATOR</th>
<th>ECST</th>
<th>GMSRA</th>
<th>KURINO</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>simple</td>
<td>corrected</td>
<td>simple</td>
<td>corrected</td>
</tr>
<tr>
<td>Min</td>
<td>mm/h</td>
<td>-19.87</td>
<td>-20.91</td>
<td>-14.75</td>
<td>-29.27</td>
</tr>
<tr>
<td>Max</td>
<td>mm/h</td>
<td>-1.16</td>
<td>-11.50</td>
<td>9.70</td>
<td>6.81</td>
</tr>
<tr>
<td>Mean</td>
<td>mm/h</td>
<td>-11.03</td>
<td>-14.45</td>
<td>-7.28</td>
<td>-6.88</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>-71.15</td>
<td>-93.23</td>
<td>-46.95</td>
<td>-44.40</td>
</tr>
<tr>
<td>SD</td>
<td>mm/h</td>
<td>5.74</td>
<td>3.33</td>
<td>9.55</td>
<td>11.95</td>
</tr>
<tr>
<td>SE</td>
<td>mm/h</td>
<td>2.03</td>
<td>1.18</td>
<td>3.38</td>
<td>4.22</td>
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</table>
### Table A2: Statistical parameters of the differences between radar and satellite rain rate for the 18th July 2005, 14.30-15.30 UTC, 10 x 10 km²

<table>
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<tr>
<th>Parameter</th>
<th>Unit</th>
<th>AUTO-ESTIMATOR</th>
<th>ECST</th>
<th>GMSRA</th>
<th>KURINO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>simple</td>
<td>corrected</td>
<td></td>
<td>simple</td>
</tr>
<tr>
<td>Min</td>
<td>mm/h</td>
<td>-14.92</td>
<td>-17.91</td>
<td>-10.12</td>
<td>-8.90</td>
</tr>
<tr>
<td>Max</td>
<td>mm/h</td>
<td>0.60</td>
<td>-3.08</td>
<td>12.49</td>
<td>14.34</td>
</tr>
<tr>
<td>Mean</td>
<td>mm/h</td>
<td>-5.51</td>
<td>-8.71</td>
<td>1.52</td>
<td>1.62</td>
</tr>
<tr>
<td>%</td>
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<td>-42.49</td>
<td>-67.12</td>
<td>11.73</td>
<td>12.46</td>
</tr>
<tr>
<td>SD</td>
<td>mm/h</td>
<td>4.29</td>
<td>4.05</td>
<td>7.25</td>
<td>6.78</td>
</tr>
<tr>
<td>SE</td>
<td>mm/h</td>
<td>1.36</td>
<td>1.28</td>
<td>2.29</td>
<td>2.14</td>
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</tbody>
</table>

### Table A4: Statistical parameters of the differences between radar and satellite rain rate for the 16th June 2006, 13.40 UTC, 4 x 8 km²

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>AUTO-ESTIMATOR</th>
<th>ECST</th>
<th>GMSRA</th>
<th>KURINO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>simple</td>
<td>corrected</td>
<td></td>
<td>simple</td>
</tr>
<tr>
<td>Min</td>
<td>mm/h</td>
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<td>-102.20</td>
<td>-93.01</td>
<td>-85.20</td>
</tr>
<tr>
<td>Max</td>
<td>mm/h</td>
<td>13.45</td>
<td>5.72</td>
<td>19.25</td>
<td>22.87</td>
</tr>
<tr>
<td>Mean</td>
<td>mm/h</td>
<td>-31.57</td>
<td>-35.32</td>
<td>-28.51</td>
<td>-24.63</td>
</tr>
<tr>
<td>%</td>
<td></td>
<td>-80.55</td>
<td>-90.12</td>
<td>-72.74</td>
<td>-62.82</td>
</tr>
<tr>
<td>SD</td>
<td>mm/h</td>
<td>28.84</td>
<td>28.30</td>
<td>30.19</td>
<td>30.62</td>
</tr>
<tr>
<td>SE</td>
<td>mm/h</td>
<td>4.08</td>
<td>4.00</td>
<td>4.27</td>
<td>4.33</td>
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</table>

### Table A5: Statistical parameters of the differences between radar and satellite rain rate for the 16th June 2006, 13.40 UTC, 10 x 10 km²

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>AUTO-ESTIMATOR</th>
<th>ECST</th>
<th>GMSRA</th>
<th>KURINO</th>
</tr>
</thead>
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<td></td>
<td>simple</td>
<td>corrected</td>
<td></td>
<td>simple</td>
</tr>
<tr>
<td>Min</td>
<td>mm/h</td>
<td>-92.49</td>
<td>-97.73</td>
<td>-85.12</td>
<td>-86.35</td>
</tr>
<tr>
<td>Max</td>
<td>mm/h</td>
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<td>15.24</td>
<td>17.58</td>
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<tr>
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<td>mm/h</td>
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<td>-25.91</td>
<td>-16.49</td>
<td>-16.97</td>
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<tr>
<td>%</td>
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<td>-83.10</td>
<td>-52.90</td>
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</tr>
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<td>SD</td>
<td>mm/h</td>
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<tr>
<td>SE</td>
<td>mm/h</td>
<td>7.54</td>
<td>7.21</td>
<td>7.81</td>
<td>7.92</td>
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</table>

### Table A6: Statistical parameters of the differences between radar and satellite rain rate for the 16th June 2006, 13.00-14.00 UTC, 10 x 10 km²

<table>
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<tr>
<th>Parameter</th>
<th>Unit</th>
<th>AUTO-ESTIMATOR</th>
<th>ECST</th>
<th>GMSRA</th>
<th>KURINO</th>
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</thead>
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<td></td>
<td></td>
<td>simple</td>
<td>corrected</td>
<td></td>
<td>simple</td>
</tr>
<tr>
<td>Min</td>
<td>mm/h</td>
<td>-51.97</td>
<td>-57.46</td>
<td>-50.24</td>
<td>-48.40</td>
</tr>
<tr>
<td>Max</td>
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<td>-1.50</td>
<td>15.03</td>
<td>11.14</td>
</tr>
<tr>
<td>Mean</td>
<td>mm/h</td>
<td>-9.49</td>
<td>-13.78</td>
<td>-7.67</td>
<td>-5.81</td>
</tr>
<tr>
<td>%</td>
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<td>-78.51</td>
<td>-43.64</td>
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<tr>
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<td>11.13</td>
<td>14.27</td>
<td>12.69</td>
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<tr>
<td>SE</td>
<td>mm/h</td>
<td>2.55</td>
<td>2.14</td>
<td>2.75</td>
<td>2.44</td>
</tr>
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</table>
10. References


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from World Wide Web:

[a] Content: Beaufort scale. DWD 1996-2007
Source: http://www.dwd.de/de/wir/Geschaeftsfelder/KlimaUmwelt/Leistungen/Schadensfall/Beaufortskala.htm
Date: 3rd June 2007, 11:36UTC

[b] Content: Vicarious calibration. EUMETSAT 2007
Source: http://www.eumetsat.int/Home/Main/Access_to_Data/Meteosat_Meteorological_Products/Calibration/SP_1119512203627?l=en
Date: 3rd June 2007, 12:11UTC

[c] Content: Meteosat VIS Channel Calibration. EUMETSAT 2007
Source: http://www.eumetsat.int/Home/Main/Access_to_Data/Meteosat_Meteorological_Products/Calibration/SP_1119512203627?l=en
Date: 3rd June 2007, 12:17UTC

Source: http://www.lthe.hmg.inpg.fr/OHM-CV/P234_cv.php
Date: 3rd June 2007, 16:25 UTC

[e] Content: BMBF-Förderaktivität "Risikomanagement extremer Hochwasserereignisse" (RIMAX). RIMAX 2007
Source: www.rimax-hochwasser.de
Date: 10th July 2007, 13:06 UTC

Source: http://tu-dresden.de/EXTRA
Date: 10th July 2007, 13:15 UTC

Source: www.satsignal.net
Date: 10th July 2007, 13:53 UTC