Development of a Real-Time, Non-Conventional Rainfall Mapping System

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  Mr Leon Booyens
  Mr Eugene Poolman

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* Dr Allan Seed for his valuable contribution.

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Dr G C Green	Water Research Commission (Chairman)
Ms A M du Toit	Water Research Commission (Secretary)
Mr H Maaren	Water Research Commission
Prof W J R Alexander	University of Pretoria
Prof W J van Biljon	University of Pretoria
Mr K Monnik	ISCW, Agricultural Research Council
Mr E Poolman	South African Weather Bureau
Mr D Terblanche	South African Weather Bureau
Mr G C Schulze	South African Weather Bureau
Mr S van Biljon	Department of Water Affairs and Forestry
Mr U Lourens	University of the Orange Free State

Foreword

Personnel involved during the RASRAIN project and their duties can be summarized as follows:

NAME	AFFILIATION	ACTIVITY
Prof J van Heerden	UP	Project Leader, co-ordination, Satellite algorithm development.
M M Truter	UP	Radar/satellite algorithms
C J de W Rautenbach	UP	Satellite image processing
M Mittermaier	UP	Cloud classification
Dr A Seed	DWAF	Radar algorithms, data base, satellite/radar calibration. Left project team November 1993.
Mr G Booysen	DWAF	Joined the project team in 1994. System development, integration and statistical analysis of radar data and cloud depth.
Mr E Poolman	WB	Co-ordination of WB participation.
Mr P C L Steyn	WB	Cloud base algorithm and data.
Mr L Booyens	WB	Satellite data capturing.
Mr D Terblanche	WB	Radar data capture, local gauge network, CAPPI processing.

(Supported by NPRP staff)

During the first phase of the research satellite, radar and rainfall gauge data were collected and prepared for analysis. Rainfall and radar data were collected at Bethlehem while the South African Weather Bureau archived Meteosat image data. Some difficulties were initially experienced with the retrieval of satellite data. During the research mode, it was not always possible to capture radar and satellite data simultaneously. Serious problems started developing at the beginning of 1994 after the departure of Dr Seed. He was the expert on the University of McGill software, radar analysis, as well as some other aspects. The Department of Water Affairs and Forestry agreed to second Mr Gerhard Booysen, a Senior Hydrologist (DWAF) to UP for post-graduate studies in hydrology. An important aspect of Mr Booysen's research is directly related to the aims and depends on the success of this project.

Dr Seed's experience with the University of McGill radar software formed a vital component of this project. Although all this software was available to the project team, Dr Seed's knowledge of this system as well as the operating system of the VAX were sorely missed. Only someone having Dr Seed's experience could have prevented the delay experienced. It took several months for project staff to gain the experience we lost with his departure.

Mr G Booysen joined the project team early in 1994. Due to our inexperience with the VAX operating system as well as the McGill software, the team decided to do all the data analysis and system development on a 486 50 MHz PC. Dr Seed's database routines were used for data management, but all the other software developed and based on the McGill software during the first part of the project, had to be rewritten. The VAX is an expensive system to maintain and has lost much ground to today's off the shelf 80486 personal computers.

The following international and local conferences were attended during the RASRAIN project:

Second International Conference on Hydrology and Application of Weather Radar, September 1992, United States of America (A W Seed).

Precipitation Conference, September 1993, United Kingdom (A W Seed).

Tenth Annual Conference of SASAS, October 1993.

Paper: Rainfall maps generated by the RASRAIN project (D D G Brooks)

Eleventh Annual Conference of SASAS, October 1994.

Paper: Rainfall and surface wind fields over the Bethlehem area during the 1993/94 RASRAIN project (I B Kgakatsi).

Paper: Rainfall maps generated after a classification of precipitating systems from the RASRAIN project (M Mittermaier).

Third International Symposium on Hydrological Applications of Weather Radars, August 1995, Sao Paulo, Brazil.

Paper: Radar-Satellite Rainfall Algorithms Developed in South Africa (M M Truter and M P Mittermaier)

Paper: Operational Procedures in the Radar-Satellite Rainfall Mapping System in South Africa (R G Booysen and J van Heerden)

Twelfth Annual Conference of SASAS, October 1995.

Paper: Radar-Satellite Rainfall Algorithms Developed in South Africa (M M Truter and M P Mittermaier)

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1. Introduction

1.1 Justification

Rainfall amounts, distribution, variability, intensity and duration are of major importance to South Africa. Severe droughts (four during the last ten years) interrupted by large scale flood events (Natal, September 1987 and Orange Free State, February 1988) are features of the South African rainfall picture. W J R Alexander (personal communication, University of Pretoria, 1994), supported by other researchers predicts severe water shortages in South Africa by the year 2020. These facts, supported by the need to better manage water resources, make it imperative to obtain the best possible rainfall record over South Africa on a daily basis. The Weather Bureau supports a rainfall gauge network of some 2100 stations. These are supplemented by localized gauge networks operated by the Department of Water Affairs and Forestry as well as The Agricultural Research Council. Some automated recording stations that report rainfall are also available. In spite of this, the distribution of this network over the country is far too sparse for a reliable rainfall distribution map. The collection of all this gauge data in real time also poses serious problems.

Most of the rainfall stations report only on a monthly basis. During the last few years the Weather Bureau upgraded the daily reporting gauge network to some 500 stations. This is still inadequate for the kind of information required for water management, flood advisory services as well as short term agricultural and industrial planning.

The current financial constraints imposed on the public sector also preclude the expansion of daily reporting networks. The only other viable solution for improving knowledge of the rainfall distribution and duration is the development of remote sensing techniques. Fortunately South Africa has adequate satellite data coverage. Thermal infrared (IR) images at the rate of 48 per day (half hourly intervals) and visible waveband images (VIS) at the rate of 24 per day are received in real time by the South African Weather Bureau from the European geostationary satellite METEOSAT.

Sandham (1993) provides a comprehensive summary of all the satellite/rainfall techniques researched since satellite data, especially geostationary, became freely available. His own work indicated that threshold techniques (cold cloud top temperatures), although lacking in sophistication may prove to be among the best techniques available. Sandham (1993) found that cloud top temperature colder than -30°C has a high probability of producing rainfall. The TAMSAT (Tropical Applications of Meteorology using Satellite Data) group at the University of Reading, UK, uses a cold cloud statistics technique. Satellite measured infra-red radiation from the earth, referred to as a pixel (5 x 5 km resolution) is converted to radiation temperature by means of calibration data supplied by the European Space Agency (ESA). Pixels below a given temperature threshold are identified on hourly or half-hourly imagery from METEOSAT. The number of pixels classified are accumulated over a period of ten days to provide a measure of the duration of active rain clouds over any pixel, which is then converted into a rainfall estimate using empirically determined regressions. This method is used operationally for drought monitoring and in hydrological research. (Milford and Dugdale, 1986).

The approach developed during the course of the RASRAIN project, although not completely new, contains elements which have not been used operationally elsewhere as far as could be determined.

1.2 Objectives

The objective of this research project was to develop, as a pilot study, a system for the real-time measurement of daily rainfall over the Wilge and upper Vaal River catchments. This system incorporates:

* Radar coverage from Bethlehem.
* Weather Bureau surface rain gauge network.
* Meteosat satellite image data and locally developed image to cloud algorithms.
* Integrated rainfall gauge, radar and satellite data.

1.3 Early investigations

When the project was initiated, the intention was to use software developed by McGill University in Montreal, Canada, as the basis for the development of the RASRAIN system. The then principal researcher, Dr Allan Seed, had had personal experience of the software and moreover, it seemed logical to avoid duplication of research and development effort to the greatest degree. The results achieved in the RASRAIN project up to the end of 1993 can be summarized as follows:

* A system was developed to incorporate some cloud dynamics/physics into the satellite-cloud algorithms. The first step in this procedure was to calculate the temperature difference between the cloud base and top of the cloud. Thereafter a 5 X 5 pixel window with the minimum cloud top temperature was identified. It was assumed that this area represents the active cloud updraught and (maximum) rain-producing area. The 3CTRT (Cold Core Cloud Top Relative Temperature) was then calculated as the difference between the mean cloud top temperature of the 5 x 5 window and a pixel in the cloud.

* The cloud base altitude (sloping beneath the anvil) was modelled as a hyperbolic function of distance away from the active updraught region. The effective thickness cloud pixel was calculated as the difference between the cloud top temperature and the modelled cloud base temperature.

* It was assumed that the raining pixel has a 3CTRT less than some threshold and also an effective thickness that exceeds some threshold. For the data selected (7 to 24 November 1992) the optimum threshold was found to be 10°K and the effective thickness threshold 17°K.

Figures 1(a) and 1(b) are 30-minute radar and satellite derived rainfall maps respectively for the 30 minute period starting at 1800 SAST on 14 November 1992. These figures illustrate the spatial mismatch between the two rainfields. This mismatch between the two images was thought to be due to poor satellite pixel earth location (navigation). The project team investigated this matter further during 1994.

When investigating the spatial mismatch between radar and satellite derived rainmaps, no proof could be found that this mismatch was due to navigational inaccuracies alone. This led to the further investigation of the procedure mentioned earlier, whereby a 5 x 5 pixel window was arbitrarily defined as the cloud base area. This area lies directly under the maximum updraught. Discussions with other researchers indicated that this approach as well as the hyperbolic cloudbase model could cause or contribute to the spatial mismatch between the satellite and radar rainfall images.

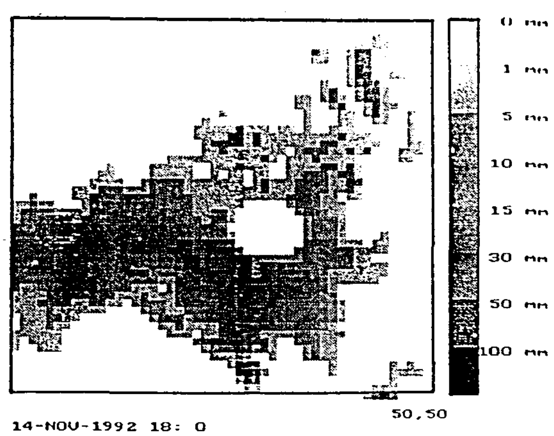

Figure 1(a). Radar derived 30-minute accumulated rain field for 14 November 1992, 18:00.

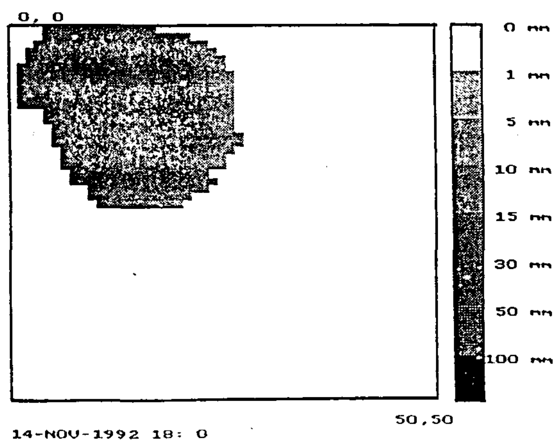

Figure 1(b). Satellite derived 30-minute accumulated ra field for 14 November 1992, 18:00.

The fact that a uniform rainrate (5 mm per hour) was derived for the entire satellite rain map, was due to the fact that a rain rate of 2.5 mm per half hourly image was assigned to all the raining pixels in the image. This obviously inaccurate procedure was applied as a first approximation in an attempt to complete and test the system prior to Dr Seed's departure. In another experiment it was decided to model the cloudbase in the same manner (hyperbolic function), but to allow the rainrate of the pixels away from the maximum updraught area (along the modelled "anvil") to decrease hyperbolically. The results still proved to be unacceptable. The arbritarily chosen 5 x 5 pixel window cloud base proved to be a wrong approach. The project team eventually also discovered that the image mismatch was caused by incorrect modification of the image tracking software in the McGill software system. With the departure of Dr Seed the project team lacked the experience to correct this problem by further modification of the McGill software. This, together with a decision that the drastic modifications needed for the South African conditions would not be appropriate, led to the decision to use a new method.

2. Project domain

2.1 Geographical location of the research domain

The research was carried out over Bethlehem, situated in the North Eastern Free Sate. The 5 cm Enterprise radar, situated at the Weather Office covers an area of 200 x 200 km around Bethlehem and was used for calibration with surface rainfall data. A surface raingauge network that consisted of 16 tipping bucket raingauges was erected in the Kransfontein area during the course of the project. CAPPI data derived from the Bethlehem radar's volume scan data were used with rain gauge data to calibrate the Enterprise radar. The statistical relationships between radar derived rainfall and satellite image data that were used to produce daily rainfall maps over the entire country were determined using the Bethlehem calibration data alone.

2.2 General climate of the research domain

Bethlehem has a moderate climate with warm summers and fairly cold winters. The average maximum temperature for the summer (December, January and February) is 25°C and the mean minimum temperature is 12°C. During the winter months (June, July and August) the mean maximum temperature is 16°C while the mean minimum temperature is just below freezing (-0.9°C).

Mean surface pressure during summer is 832 mb and slightly higher during winter (836 mb). Bethlehem is situated in the summer rainfall region of South Africa and the mean rainfall for the summer months October to March is in the order of 530 mm. Mean relative humidity values are in the order of 65% for the summer months and 45% during the winter.

2.3 Equipment and instrumentation

Basic to the RASRAIN project is the 5 cm wavelength radar operated by the NPRP as well as image data from the geostationary satellite Meteosat. Satellite image data are all primary users data rectified to a standard image by EUMETSAT. Specifications of the Bethlehem Enterprise Radar can be summarized as follows (Steyn and Bruintjies, 1990):

*	Frequency:	5.635 GHz
*	Wavelength:	5.32 cm (C-band)
*	Peak power:	250 Kw
*	PRF:	250 s
*	Pulse duration:	1.95 μs
*	MDS:	-103 dBm
*	Beam width:	1 °
*	Antenna gain:	44.05 dB

The only other equipment is computers, large disk space, Exabyte tape devices, spares and other normal equipment required in a computer environment.

3. Algorithm and system development

3.1 Classification system

The project team is convinced that different cloud types and systems behave differently and may have different rain rates per class (system). This led to the development of a procedure whereby satellite images can be classified into four different cloud systems or rain types.

Table 1 summarizes the cloud (rain) image classification categories used in the identification process as well as the criteria used in isolating raining pixels. A threshold technique was used whereby all the satellite pixels (representing cloud top temperatures) with a value of less than 243 K (-30°C) were returned as probable raining pixels.

Table 1. Summary of the cloud classification categories used for the identification process.

GROUP	CLASSIFICATION CRITERIA
1. GENERAL RAIN	* more than 80 % of the pixels, that is 583 of the 729 pixels in a quadrant
2. COMPLEX CLUSTERS	* 30 - 80 % of the pixels, that is between 219 and 583 of the 729 pixels in the quadrant * diameter approximately 50 km * ratio of axes near unity
3. LINESTORMS	* 30 - 80 % of the pixels, that is between 219 and 583 of the 729 pixels in the quadrant * elongation greater than 50 km * ratio of axes deviates greatly from unity
4. ISOLATED CLUSTERS	* less than 30 % of the pixels, that is less than 219 of the 729 pixels per quadrant * does not satisfy the criteria for magnitude in 2.

3.2 RASRAIN system procedure

The following diagram illustrates the RASRAIN research procedure in general. The process starts with raw satellite and radar data originally from the Weather Bureau and the National Precipitation Research Project. The final product of the RASRAIN research project will be a satellite/radar calibrated daily rainfall map which is described in the RASRAIN operational procedure.

The RASRAIN research procedure

Procedure SAT 1
Raw satellite data (WB)

* Receive 2500 x 2500 pixel Meteosat image. (VIS + IR)
* Select 640 x 480 pixel window around South Africa. (VIS + IR)

Procedure RAD 1
Raw radar data (NPRP)

* Receive radar volume scan data (200 x 200 pixels) around Bethlehem.
* Generation of 4 minute interval CAPPI data on 2 km altitude.

Procedure SAT 2
Satellite data classification (UP)

* Filter non-precipitating clouds.
* Select 53 x 53 pixel window around Bethlehem.
* Classify sat. image into 4 categories.
* Calculate cloud depth.
* Explode 53 x 53 pixel window to 200 x 200 pixel window.

Procedure RAD 2
CAPPI assimilation (UP)

* Transformation from UNIX to PC format.
* Conversion of CAPPI data to 30 min rain rates.
* Calculation of mean rain rates.

Procedure CAL
Calibration

* Rank SAT and RAD data
* Filtering of data
* Curve fitting

Procedure RAINMAP

SATELLITE RAINMAP FOR SOUTH AFRICA

The following diagrams describe each of the above procedures in considerable detail. The flow diagrams are not computer program flow diagrams. They are designed to describe the process. Computer program description and codes would occupy a great deal of space. It is impractical to provide these in a report. If this system is to be implemented operationally, it will need to be adapted to the operator's hardware systems. The only way to achieve this in an efficient manner is with the project's team participation.

RASRAIN research procedure

PROCEDURE SAT 1

The South African Weather Bureau receives 24 VIS and 48 IR Meteosat images daily. IR pixel resolution at sub-satellite point (0°S, 0°E) is 5 x 5 km.

↓

The 640 x 480 pixel window (2413 x 1810 km) around South Africa is extracted and stored on EXABYTE magnetic tape. Image pixels allocated to 4 x 4 km pixel by a sampling process.

PROCEDURE RAD 1

During the 1993/94 summer season, the 5 cm radar at Bethlehem was operated in 18 elevation steps, the lowest being 1.5° and the highest 45.6°. A blanketing zone extended to 14 km from the radar and the maximum range was 150 km.

↓

The volume scan reflectivity data are processed to generate CAPPI data at 2 km altitude. A relationship of $Z = 200R^{1.4}$ (Terblanche, 1993) is used to generate rain rate in mm per hour. The CAPPI data represent a horizontal area of 200 x 200 km.

Procedure SAT 2

The first step in this procedure is to filter out the high, non-precipitating clouds. This is achieved by selecting all the pixels in the IR and VIS images for which the following hold:

* IR pixels colder than 243°K (-30°C)
* VIS pixels with reflectivity value exceeding 170. Reflectivity values of 250 represents bright white cloud tops.

The numerical temperature value of the selected pixels is written to cloud identification file.

↓

The 53 X 53 pixel window around Bethlehem is extracted as:

27° 21°S, 27° 21°E
29° 07°S, 29° 07°E

↓

The 53 x 53 pixel window around Bethlehem containing pixel groups colder than -30°C is classified (using computer based procedures) as either:

(i)	General rain	(iii)	Line storms
(ii)	Complex systems	(iv)	Isolated systems

↓

A Laplace transformation process is used to remove irregularities from the cloud top temperature field (short wave filtering). Using the Laplace transformation process, pixels with low cloud top temperature are smoothed.

↓

The area covered by less than the threshold temperature level in the IR image determines the horizontal area of the precipitating cloud. Cloud base temperature is determined from screen (1.2 m) temperature and dew points. Figure 2 illustrates the procedure to calculate cloud depth per pixel. Due to the fact that some of these selected pixels may still represent high cirrus clouds, the unrealisticly high cloud depth values (> 120°K) are ignored for further calculations.

↓

The final step in this procedure is to expand the 53 x 53 (4 km square) pixel) to a 200 x 200 (1 km square pixels) pixel window, which corresponds with the CAPPI data. A sampling process is used. Prior smoothing removes irregularities.

PROCEDURE RAD 2

The first step in this procedure is to transform the CAPPI data generated by NPRP personnel from UNIX byte order to PC byte order.

↓

The four minute interval CAPPI data are accumulated to the corresponding satellite image time interval (30 minutes).

↓

Dividing the accumulated rainfall by the number of CAPPI files used for the specific accumulation, gives the average rainfall rate for the half hour period.

PROCEDURE CAL

In this procedure the satellite and radar data for corresponding time intervals are written in ASCII format. The two datastrings are then ranked after removing null values. Radar derived rainfall rates are ranked in steps of 0.1 mm to the highest radar rain rate in the string. Radar derived rainfall rates are expressed in mm per hour.

↓

The cloud depth string is ranked by value. Cloud depth is expressed in terms of temperature (°K). Each of these strings may contain up to 40 000 data points
(200 x 200 pixels, 1 pixel = 1 x 1 km).

The number of data points are reduced by grouping all the numerically identified rainfall rates (RR) and cloud depths (CD) in each string. A single pair (RR,CD) may now represent many independent values.

↓

The final step in the calibration procedure is to plot all the pairs. Satellite derived cloud depth (independent variable) is plotted against the radar derived rainfall rate. For each class of image a curve is fitted.

RASRAIN operational procedure

PROCEDURE RAINMAP
Each filtered satellite image (containing pixel groups colder than -30°C) is sectorised into 200 x 200 km windows. Each 200 x 200 km window is classified as either general rain, complex clusters, line storms or isolated clusters. For each window the cloud depth in terms of temperature is calculated. Cloud base temperature is determined for the selected cloud groups by using surface temperature and dewpoint data.

↓

The corresponding statistical relationship is applied to a specific classified window to determine rainfall rate. The calculated rainfall rates are written to an output file. This process is repeated for all half-hourly satellite images during the period 0630 to 0600 the next day. The accumulated rainfall rates for the specific 24 hour period is then plotted.

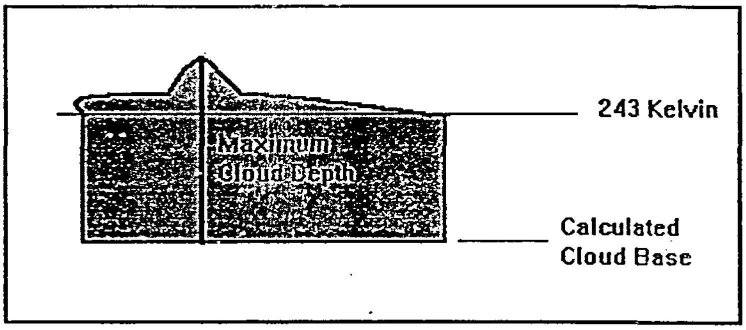

Figure 2. Model of the cloud depth scheme. The cloud depth is the difference between cloud base and cloud top temperatures for each pixel. Appicable only to those pixels with temperatures below 243°K.

4. Results and products

4.1 Relationship between cloud depths and radar rain rates

The post-1993 approach followed in this research project proved to produce more realistic results than the earlier approach. The new technique assumes small navigational mismatches between the radar and satellite image can exist and cannot be prevented. Considering the fact that the Meteosat satellite is situated some 35 000 kilometers from earth and the IR resolution (at sub-satellite point) is 5 kilometers squared, it is virtually impossible to expect an exact fit between the radar and satellite images. This led to the decision that the sought relationship can be obtained by comparing satellite cloud depth and radar rain rate by using a ranking system.

Considering the satellite cloud images themselves a system was adopted whereby the probable raining area is determined as being all pixels colder than the threshold temperature. For the procedures described here a threshold of -30 °C was considered acceptable. Further experimentation may result in threshold temperature change. Procedure SAT 2 describes this technique by means of a flow diagram. The horizontal extent of the "raining area" is modelled as the area below all the pixels passed by the threshold temperature. The vertical dimension is determined by the cloud depth (cloud top - cloud base temperature in °K).

4.1.1 General rain

General rain is usually associated with thick stratiform clouds, hence probably lower, warmer cloud tops with fairly uniform cloud top temperatures. However, for the interior of South Africa, research has shown that even general rain areas contain embedded and deep, cold mesoscale convective cores. These systems do produce heavy rain showers.

Figure 3(a) illustrates the relationship between cloud depth in degrees Kelvin and rain rate in 0,1 mm per hour for the general rain scenario. Rain rates of up to 6.8 mm per hour were determined from the CAPPI data. Cloud depths less than 40°K produce low rainfall, while cloud depths exceeding 60°K produce more precipitation. The fitted curve is accepted as a good approximation.

4.1.2 Complex clusters

Figure 3(b) illustrates a similar relationship to Figure 3(a) but in this case for complex systems. The maximum rain rates appear with cloud depths exceeding 45°K. No significant rain is produced in clouds thinner than 40°K. A rapid increase in estimated rain rate occurs when cloud depth increases from 45° to 50°K. A maximum rain rate of 2.25 mm per hour was associated with cloud depths of approximately 55°K. The fitted curve is considered to be a good approximation.

4.1.3 Line storms

Figure 3(c) illustrates the relationship between cloud depth and rain rate for line storms. Unfortunately, only six cases could be identified from the available satellite data. Cloud depths below 50°K produce insignificant rain rates. Maximum estimated rain rates of nearly 4 mm per hour are produced by cloud depths of 60°K.

4.1.4 Isolated clusters

Figure 3(d) illustrates the relationship between cloud depth and rain rates for isolated clusters. Twenty five 30 minute data sets were analyzed in this case. Significant radar rain rates appear from cloud depths exceeding 60°K. A cluster of datapoints is

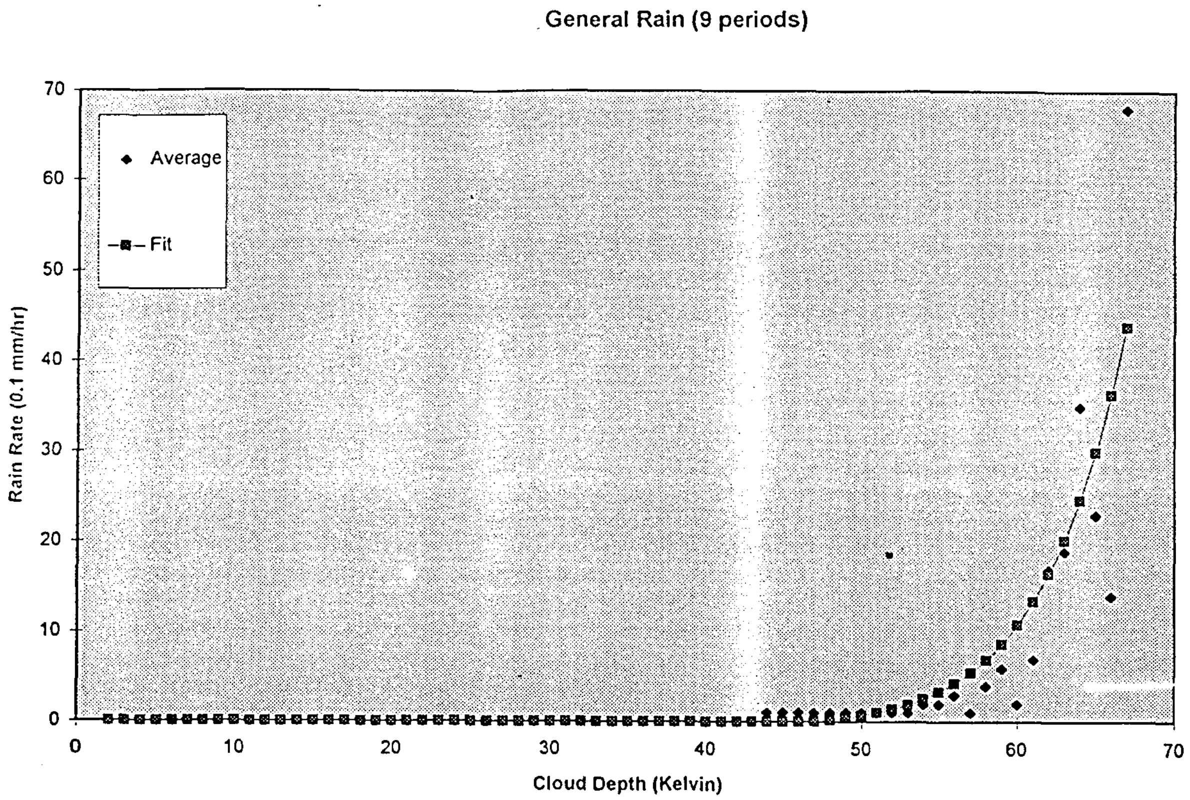

Figure 3(a). Relationship between cloud depth and rain rate for general rain.

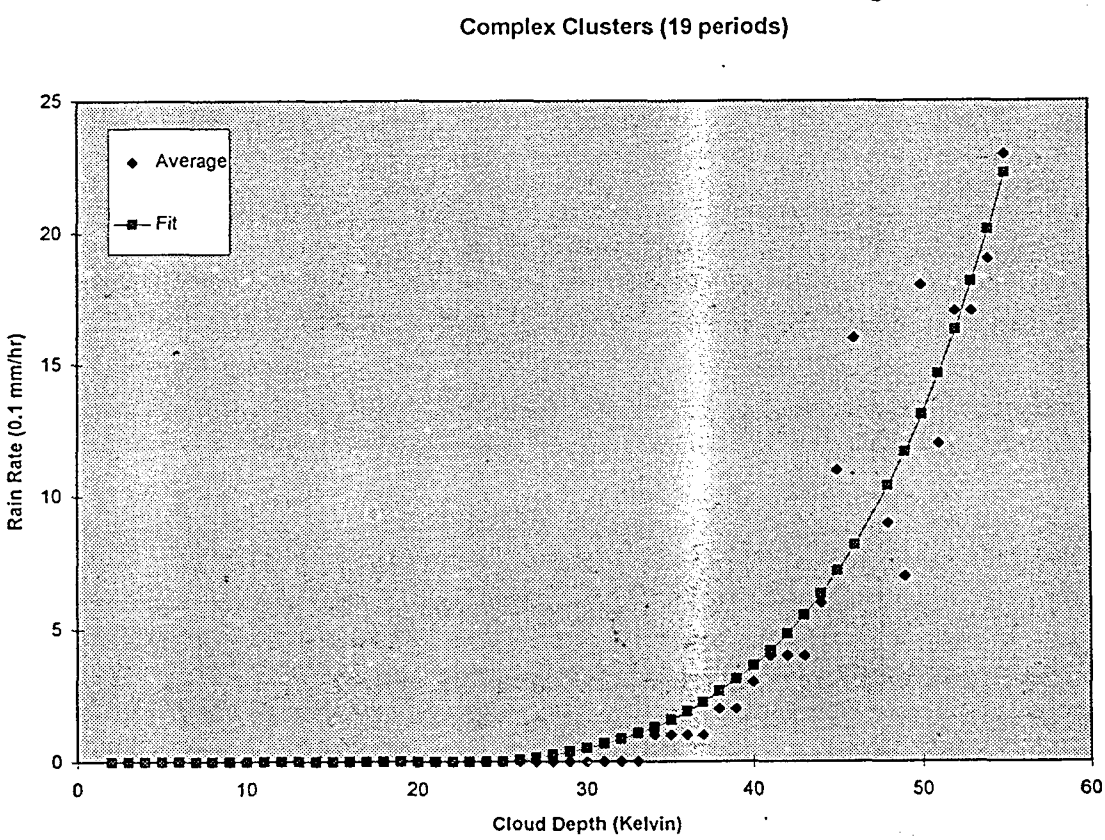

Figure 3(b). Relationship between cloud depth and rain rate for complex systems.

Line Storms (5 periods)

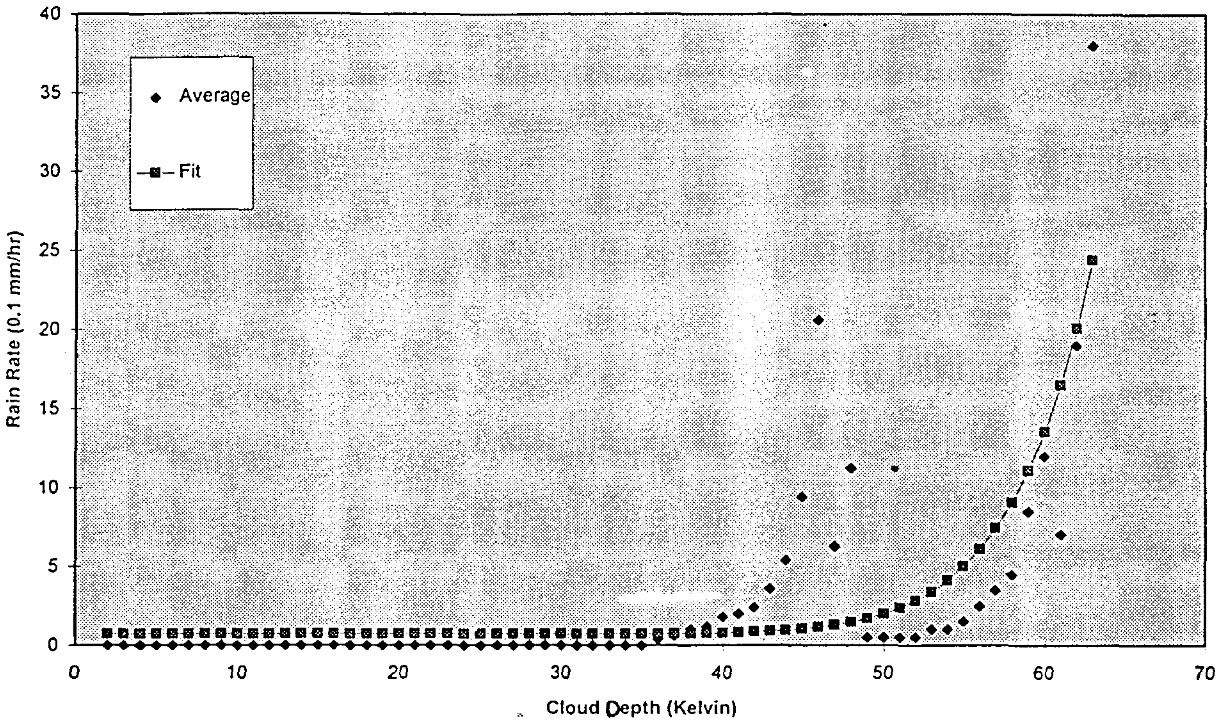

Figure 3(c). Relationship between cloud depth and rain rate for line storms.

Isolated Clusters (25 periods)

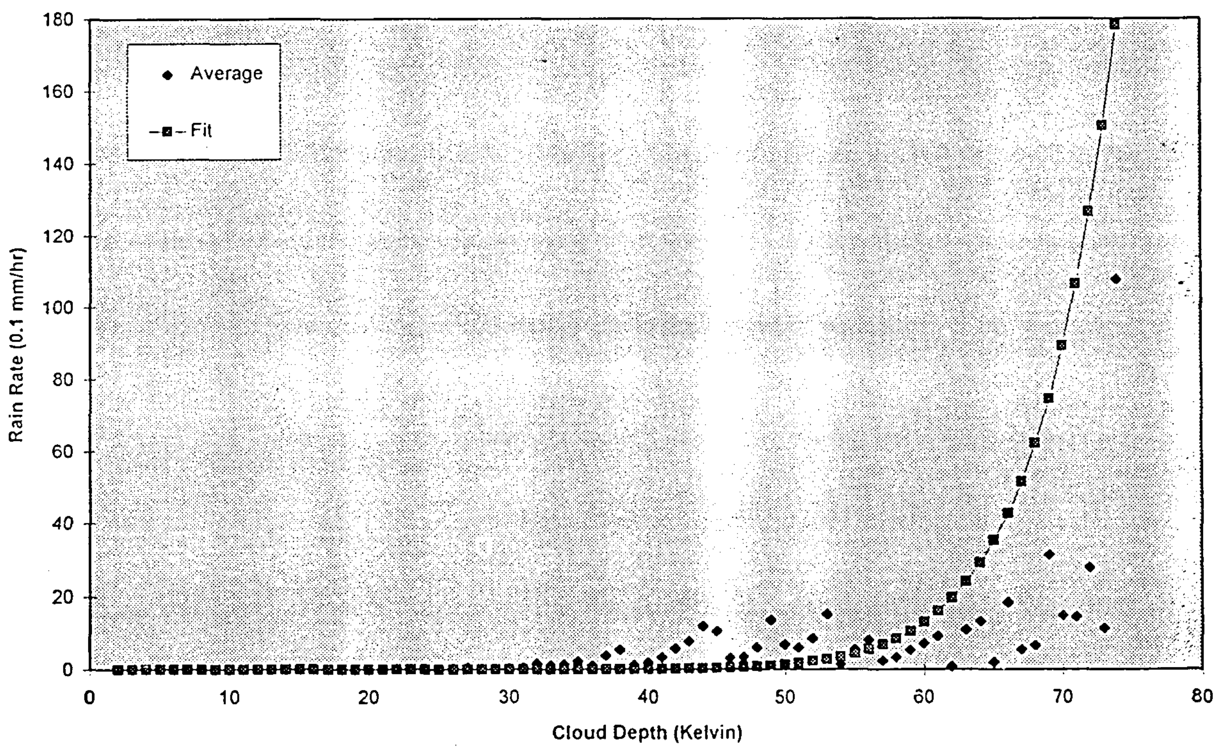

Figure 3(d). Relationship between cloud depth and rain rate for isolated systems.

evident between cloud depths of 60° and 70°K. Rain rates of 18 mm per hour occurred with a cloud depth as deep as 75°K. The analysis indicates that isolated systems produce low rainfall except where isolated systems have extensive vertical extent.

4.1.5 General remarks

Generally cloud depth less than 40°K produce very low rain rates. Conventional meteorological observations determined that maritime clouds produce precipitation with cloud depths well below 3 km (20°K). The technique used will have to be adapted for maritime clouds. Table 2 describes the statistical relationship between cloud depth and radar rainfall rate.

General Rain	Complex Clusters
$P = 0{,}855 \times 10^{-20} (D-2)^{11{,}9778}$	$P = 0{,}17960 \times 10^{-7} (D-2)^{5{,}2767}$
Line Storms	**Isolated Clusters**
$P = 0457 \times 10^{-20} (D-2)^{12{,}1628}$	$P = 0{,}1005 \times 10^{-20} (D)^{12{,}4377}$

* P = Precipitation rate (0,1 mm/h)
* D = Cloud Depth

Table 2. Statistical relationships between cloud depth and rain rate.

4.2 Products

The software developed in the RASRAIN procedure can be summarized as follows:

Program RAINMAP2.F (Fortran 77):

Read the 640 x 480 pixel satellite image data and filter out the cold, thin non-precipitating clouds. Select the 53 x 53 pixel window around Bethlehem.

Program ID2.F (Fortran 77):

Classify the satellite image into 4 raining categories.

Program COLDCORE.EXE (Borland C++):

Determines all the possible pixels colder than 243°K and writes the values to a data base.

Program CCMOD.EXE (Borland C++):

Calculates the cloud base temperature and cloud depth in terms of temperature.

Program EXPLODE.EXE (Borland C++):

Explodes the 53 x 53 pixel image to a 200 x 200 pixel image.

Program UXTOPC.EXE (Borland C++):

Converts the radar CAPPI data from UNIX byte order to PC byte order.

Program CAPACC.EXE (Borland C++):

Convert the 4 minute CAPPI data to 30 min average rain rates.

RADSTAT.EXE & SATSTAT.EXE (Borland C++):

Converts the binary files to ASCII files.

RASSTAT.EXE (Borland C++):

Combines the radar rain rates and satellite cloud depth ASCII files.

FILTER.EXE (Borland C++):

Filter the zero values and values that repeat itself.

4.3 Comparison between satellite computed and observed rainfall data

Rainfall maps for three days during the 1993/94 rainfall season were developed with the RASRAIN system. Figures 4(a), 4(c) and 4(e) illustrate the observed rainfall for 10 November 1993, 22 November 1993 and 3 December 1993 respectively in 10 mm intervals. Figures 4(b), 4(d) and 4(f) illustrate the satellite-derived rainfall map for the same period. Over most of the country the two maps compare well with each other, except over the coastal regions where the satellite-derived rainfall underestimate the observed rainfall.

This is especially evident in the maps for 3 December 1993 along the coastal areas of the Eastern Cape where satellite maps indicate up to 20 mm while amounts of approximately 70 mm were measured. On 22 November 1993 the satellite fared better along the Kwazulu-Natal coast. In this case the weather system was a synoptic scale trough system with clod tops moving across the coastal areas. Similar comments are valid for 10 November 1993 and the Eastern Cape area, while the satellite map underestimated rainfall over the southern coastal areas of the Western Cape.

Over the continental areas of South Africa the satellite map over-estimates rainfall. It is expected that further research and analysis will improve this. The map however gives a very good distribution of rainfall and provides detail never before achieved. It is also difficult to summarily dismiss the rainfall amounts in the satellite maps. The rain gauge distribution is inadequate for this. Generally it seems that the satellite maps may over-estimate by some 50% over areas of intense and widespread convection.

5. Conclusions

The RASRAIN project was by far the most exciting and significant project ever attempted by the project team. The scale and complexity of the process far exceeded our expectations. Experience gained during the RASRAIN project, together with other relevant facts showed that:

* It is very difficult to archive satellite data half-hourly on a 24 hour basis.
* Processing the 48 VIS and 24 IR images require large disk space, fast main storage devices and fast data transmission.
* It is not advisable to run the radar on a 24 hour basis. Continuous operation is only required when rain may be expected.

6. Recommendations

6.1 Further research

The following is recommended for future research:

* The cloud depth to CAPPI rainfall intercomparrison scheme (procedure CAL) must be removed from the main stream of the procedure. The calibration can be run daily on selected images and the algorithms updated monthly.
* Processing of more images may result in regrouping of the rain classes (classification process).
* The operational system may differ substantially from this experimentally developed process. Better statistical relationships may be available and each image can be treated separately. The entire process must operate in real time.
* In areas with available radar data, the radar data alone should be used. The final operational satellite rainmap should have windows where radar data alone apply, with the satellite derived rainfall filling the gaps.
* The RASRAIN process has wide potential for the entire subcontinent of Southern Africa. Drought and flood monitoring can benefit from this research, especially in countries where real time rainfall data is difficult to obtain. It is strongly recommended that the Water Research Commission support the development of a system for sub-tropical regions.

* Other research products that may evolve from this research are:

  Satellite-cloud climatology for South Africa should be developed using techniques developed in RASRAIN.

  Further research may link cloud climatology data with ENSO related teleconnections over Southern Africa.

  Evaluation of short term rainfall predictions.

6.2 Implementation of the RASRAIN procedure

It is strongly recommended that the procedures developed during this research be implemented operationally during 1995. Potential users of the rainfall data produced by this system are the Weather Bureau, Water Research Commission, Department of Water Affairs and Forestry, Department of Agriculture, Agricultural Research Council, Private Consulting Engineering Firms, ESKOM and other research institutions and universities.

The RASRAIN procedure can contribute significantly to international research projects such as the TRMM (Tropical Rainfall Measuring Mission) project, initiated by NASA in New York, USA. The potential for measuring rainfall over the rest of Southern Africa must also not be excluded.

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