SPATIAL INTERPOLATION AND MAPPING OF RAINFALL (SIMAR)

VOLUME 1. MAINTENANCE AND UPGRADING OF RADAR AND RAINGAUGE INFRASTRUCTURE

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by the

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Executive Summary

The programme ***Spatial Interpolation and Mapping of Rainfall (SIMAR)*** was a three-year initiative encompassing three component projects, viz:

- Maintenance and upgrading of radar and raingauge infrastructure
- Radar and satellite products
- Optimal integration of raingauge, radar and satellite derived data in the production of daily rainfall maps

The final report on this programme, which was undertaken by scientists, researchers and engineers of the METSYS group of the South African Weather Service (SAWS) and the School of Civil Engineering of the University of Natal, in collaboration with the Department of Water Affairs (DWAF) and ESKOM, is contained in three volumes. The volumes are:

VOLUME 1. ***Maintenance and Upgrading of Radar and Raingauge Infrastructure***

VOLUME 2. ***Radar and Satellite Products***

VOLUME 3. ***Data Merging for Rainfall Map Production***

Rationale for SIMAR

Water resources in South Africa are not well buffered against natural rainfall variability. Rainfall deficits and excesses readily translate to droughts and floods, respectively. Well-developed water resource infrastructure, which South Africa is fortunate to possess, has to be managed extremely skillfully to successfully balance water surpluses and deficits at an inter-catchment level, as well as to achieve best trade-offs between flood mitigation and storage maximisation at basin level.

The concept of water resource management is no longer restricted to regulating flows, storage and abstractions in and from rivers, dams and aquifers. Water resource management is increasingly becoming concerned with applying measures to ensure resource (ecosystem) sustainability and also with activities in the catchment which impact on both sustainability and availability of water for abstraction and use. A particular focus in the 1998 Water Act is on activities, termed streamflow reduction activities, the licensing and regulation of which are provided for in the Act. To do this objectively requires defendable information on water usage associated with entities such as forests, agricultural lands, natural veld, farm dams, soil conservation schemes, etc. Such water usage is tightly linked, through the catchment water balance, to catchment water availability and thus rainfall, a link which imposes an obligation on catchment management agencies to obtain detailed and accurate rainfall measurements.

Since natural disasters and fluctuations in agricultural production are also closely linked to rainfall, these sectors have a similar need for such detailed rainfall information.

Raingauges have traditionally provided the rainfall measurements required for water resource management purposes. Because the national raingauge network is rapidly becoming too sparse to meet existing and anticipated management requirements, a new rainfall monitoring/information system, incorporating the optimal use of remote sensing, has become necessary to satisfy the needs of South Africa.

This need was envisaged to be best satisfied through an umbrella research and development programme (SIMAR) having the ultimate goal of merging satellite/radar/gauge data to produce **one field** that is acceptable to the water-resources (and hence also agricultural and disaster-management) users.

The specific aim was to produce a daily rainfall map of 24 hour accumulated rainfall to a resolution of 2 km, over the whole subcontinent, accessible on the Internet. This has been accomplished. Furthermore, this primary product can and will be refined where needed to finer time scales over selected areas. This refinement will be of particular interest to the disaster-management users and those involved with the mapping of the tendency for, or forecasting of, flash floods. As improvements to the data streams and modelling techniques become available, they will be incorporated into the products emanating from the research. Follow-on research projects supported by the Water Research Commission are designed to bring about such improvements.

Results of SIMAR component projects

Details of the results deriving from the three component projects included under the SIMAR umbrella are contained in the three volumes which make up the SIMAR final report. Some background information pertaining to these results, and the results *per se*, are summarised below.

VOLUME 1. ***Maintenance and Upgrading of Radar and Raingauge Infrastructure***

Since conventional meteorological infrastructure is dwindling at an alarming rate in South Africa, it became necessary to investigate the complementary use of conventional and less conventional infrastructure in sourcing rainfall data. The complementary sources here considered are surface networks and remote sensing sources, namely radar and satellite. The focus has fallen on maintaining current systems as well as using new technologies and techniques to upgrade systems, where necessary, with a view to securing and sustaining a reliable data flow from the above-mentioned data sources. The specific objectives of this part of the programme were as follows:

- Maintain automated surface gauge networks (Durban and Liebenbergsvlei) as well as investigate the application of new technology to ensure real time availability of data.
- Maintain and upgrade the National Weather Radar Network (NWRN) by improving the monitoring capabilities at each radar system, investigating the possible expansion of the network coverage and pursuing an improved funding base for the radar network.

- Utilise the latest remote sensing technology in order to improve the quality of products to be generated.
- In cooperation with other stakeholders, assist in establishing a real time precipitation database for South /southern Africa.
- Actively seek and promote collaboration with stakeholders, institutions and organisations, on a formal and informal basis, to expand and enhance surface coverage of precipitation measurements.
- Equip and train individuals, especially those from previously disadvantaged communities, with a view to their acquisition of remote sensing and electronic maintenance skills.

The raingauges of the Liebenbergsvlei and Durban networks played a vital role in investigations regarding elimination of ground clutter and in validation of radar-estimated rainfall on the ground. An investigation into the feasibility of using cell phone communication technology and infrastructure resulted in such technology being implemented in the Liebenbergsvlei and Durban networks, and gave rise to the vision of also implementing the technology at all the SA Weather Service second order stations.

Improvements and upgrades were introduced at the majority of radar installations within the network, while also ensuring a reliable power supply to the systems. A remote control and monitoring system, whereby the functioning of individual radar systems can be monitored from a central point, was implemented. This new capability has, for the first time, allowed objective assessments of the reliability of individual radar systems within the NWRN to be made. During the course of this project, the SAWS drastically increased its funding for maintenance and upgrading of the NWRN.

Unfortunately, the Meteosat Second Generation (MSG) satellite did not become operational during the lifetime of the SIMAR project as anticipated, as the MSG programme suffered lengthy delays prior to, and further problems after, the launch of the satellite. Nevertheless, research into utilising Meteosat 7 to fulfill the SIMAR project's objectives, continued. New techniques were developed which will be applied to MSG when it eventually becomes operational.

Close cooperation with the SAWS database developers led to provision being made for the archiving of real-time data generated by the SIMAR programme. The development of the new database has proceeded through different phases and will continue to be developed to accommodate such data products for routine applications and research purposes.

This component project succeeded in promoting data sharing between institutions, albeit on a small scale, and initially limited to operational exchange of data through collaboration with DWAF and Suidwes Agriculture. The pursuit of this objective of institutional collaboration will not end with SIMAR but will be carried on and expanded.

The training of personnel in the maintenance and upgrading of observational systems received high priority in the SIMAR project. The training initiative was also expanded to the international arena with training on SIMAR related subjects presented to students from other African countries such as Botswana and Tanzania.

VOLUME 2. ***Radar and Satellite Products***

The focus of this component project was to provide the two remote sensing-based rainfall fields – the one derived from radar and the other from satellite – to be merged with yet another rainfall field, derived from daily reporting raingauges.

The specific objectives were as follows:

Radar products

- Provide a Meteorological Data Volume (MDV)-based, real-time, radar rainfall map of the radar covered area of South Africa
- Optimize merging in areas of radar overlap and utilize the reflectivity measurements in these areas for additional performance testing
- Improve radar-rainfall algorithms which address the outstanding issues of data quality and integrity (hail, bright band, ground clutter and coastal/orographic rain)
- Include additional radar information as it becomes available and identify the most serious gaps in South Africa's weather radar coverage.

Satellite products

- Investigate and develop suitable rainfall estimation algorithms from satellite data for South Africa, which also address known problems related to coastal/orographic rain
- Incorporate the latest satellite (Meteosat Second Generation, which should have become available during the project period) in order to address issues related to temporal resolution
- Provide an MDV-based, real-time, satellite rainfall map of South Africa
- Integrate raingauge, radar and satellite rain fields to provide the desired daily rainfall maps, making use of the modelling component (reported in *VOLUME 3* of the SIMAR final report).

Despite the fact that the MSG Satellite did not become operational during this project as originally anticipated, SIMAR accomplished major advances in the estimation of rainfall using remote sensing techniques and the integrated mapping of rainfall over South Africa.

Radar rainfall estimation

South Africa's NWRN represents a unique system based on a local solution to the complex problem of networking of several individual radars and merging of their individual data fields. This system, developed in-house, is a combination of South African innovation and shareware/freeware available from various sources in the world. Very few countries in the world operate successful weather radar networks and even fewer a network as elegant and modular as the one in South Africa. The report gives a summary of how this was achieved and highlights the data flow and product generation from the eleven radars within the network.

A major advance in radar rainfall estimation is the unique methodology that was developed to filter the negative impact of ground clutter. This technique, that uses the scan-to-scan coherence in the echo field to dynamically build up a slowly evolving clutter mask, has all but solved the problems of ground clutter contamination. This advance has had a positive impact on the resolution of the rain fields that are archived, displayed and used as input to create the integrated satellite-radar-raingauge rain fields.

The verification of radar performance, and independent procedures and tests to investigate the inter-calibration of network radars, have been fully documented. Of significance is the success with which the sun has been used as an independent calibration source.

Conversion of radar reflectivity into rain rate and the computation of rainfall depth accumulations have been refined considerably. Using the dense Liebenbergsvlei raingauge network as a basis for comparison, the mean reflectivity in the vertical column was found to be a more appropriate input to the Z-R relationship than the customarily-used maximum reflectivity in the vertical column. The mean reflectivity has a smoothing effect on the enhanced or erroneous reflectivity caused by the occurrence of hail, or by the so-called *Bright-Band* and *Anomalous Propagation* phenomena.

Furthermore, methods have also been developed to generate a merged rain field from rain fields generated at the individual radar sites instead of from a merged reflectivity field. This allows the use of different (and more appropriate) Z-R relationships for different regions and also allows use of data with the finest temporal resolution. Rainfall estimates over South Africa obtained in this way has been evaluated using rainfall data from 60 automatic weather stations across South Africa.

The above-mentioned studies and advances all provided a sound foundation for improvements already made to the NWRN rainfall estimation techniques, or for improvements due to be implemented in the near future.

Satellite rainfall estimation
Building on a review of literature on past South African and international experience, a technique (probably the most sophisticated satellite-rainfall estimation technique yet available for South Africa) that makes optimal use of all three channels (IR, Visible, Water Vapour) of the current Meteosat 7 satellite was developed and implemented operationally. Particular attention was also given to the characteristics of the MSG Satellite. Although it did not become operational during the project as originally anticipated, some of the first data examples from this satellite are shown.

The first stage in the evolutionary development of the MSRR (Multi-Spectral Rain Rate technique) was the ITR (Infra-red Power Law Rain Rate technique), which gave rise to the intermediate BSRR (Bi-Spectral Rain Rate technique). The use of all three channels leads to improved methods for filtering out non-precipitating clouds and enhances the estimation of rainfall from maritime clouds. Image processing techniques (including edge detection and speckle removal techniques) were also introduced to better identify rainy pixels from those that are cloudy but not rainy. Systems to reformat and communicate the satellite data in the same MDV format being used for radar data were developed. A novel development in the satellite rainfall estimation was the use of topographical slope to enhance estimated rainfall over mountainous regions. The advantages of using a Geographical Information System to display and process the data and products from the various sources was clearly demonstrated.

Methods to verify the satellite rainfall estimates in terms of their spatial extent and quantitative values through comparisons with radar and raingauge estimates were developed and applied. It became clear that the satellite rainfall estimation technique which was developed achieves the objective of providing useful, large-scale rainfall fields for the southern Africa region.

Rainfall data integration and product distribution
An analysis of the strengths and weaknesses of raingauge-, radar- and satellite-derived rainfall information provided the basis for additional measures to address the major weaknesses in each source. The accuracy (including human-introduced error factors) and coverage of daily raingauge data, in particular, has become a matter that needs to be addressed as a national priority.

The generation of the merged satellite-radar-raingauge field is a stepwise process, starting with the merging of the radar and raingauge fields. Thereafter the satellite and raingauge fields are merged before the two resultant fields are combined.

SIMAR has a dedicated section on the South African Weather Service (METSYS) web page (http://metsys.weathersa.co.za) which displays the various individual daily rainfall fields (radar, gauge and satellite) together with the integrated fields. Archived data relating to these fields are also presented.

VOLUME 3. ***Data Merging for Rainfall Map Production***

This component project was initiated against the background of the following premises and objectives:

- There existed a large collection of daily-read rainfall data in the country, which were (and still are) continuously being added to. The first aim of the research was to be able to interpolate optimal rainfields between raingauges at individual locations and also to suggest the best estimates of catchment (areal) totals of rainfall, both historically and currently.
- The accuracy of radar in pinpointing, in considerable detail, where rain falls was not in question, but some difficulties still existed in terms of estimating rain rates from radar data. The second aim was to combine raingauge and radar data into a meaningful composite to provide an optimal rainfield acceptable to users. However, radars did and continue to cover only part of the country. There are less densely-populated areas with sparse raingauge coverage and no radars, but where satellite surveillance information could be accessed. It was therefore considered important to link satellite, radar and gauge data together to obtain the best estimate of rainfall in these remote areas.
- The third and main aim of the research was to devise a product to enable the publication, on a daily basis, of the 24-hour rainfall over the country. The means of achieving this aim was seen to be optimal integration of gauge, radar and satellite estimated data, which would of necessity improve with

commissioning of more radars, upgrading of software and introduction of a new generation of satellites.

Theoretical development
Combining the precision of raingauge data with the coverage of satellite data and the detail of radar data was, in effect, an important objective of this research. The techniques initially envisaged as a means of achieving this were optimal spatial interpolation using a technique called Kriging and an associated one called co-Kriging.

It turned out that co-Kriging was not a good option because of the large computational load. This load comes from the fact that there are of the order of one million small areas (pixels) approximately 1.5 kilometers square (the typical spatial resolution of a weather radar) covering the subcontinent and the surrounding oceans. The challenge was to be able to map the country's rainfall routinely to that detail. Even the quadrupling of computer speed, between the year 2000 (when the project was proposed) and its end in 2003, did not diminish the need to find a better way to process data, which would be easy to automate. A method of Kriging, exploiting the efficiency of the Fast Fourier Transform, was consequently developed. The process of development necessitated having to deal with a highly technical subject, involving some difficult and advanced mathematical ideas and theory.

Outcome and Technology Transfer
The techniques developed for optimal integration (merging) of data fields and their implementation to date have been most fruitful. The daily rainfall maps on the SAWS:METSYS website bear testimony to this successful outcome.

The Fast Fourier Transform approach to Kriging provided the basis for the coding of an algorithm to accomplish the massive computing task efficiently and speedily. Speed is of the essence in the delivery of the daily rainfall maps in real time. Information on the accumulated rainfall for the 24 hours until 8:00 am SA time, derived from the recording raingauges around the country, arrives at METSYS (Bethlehem) by 9:00 am daily. By that time, the previous 24 hours' satellite and radar images will have been used to produce the best estimates, respectively, of the rainfall totals per pixel over the whole area. The merging of the three fields: gauge, radar and satellite is then done and the result posted on the METSYS web-site by 11:30 am. A thorough description of the practical implementation of this methodology is presented in the body of *VOLUME 2* of the SIMAR final report. Some examples of the website output are reproduced therein.

Conclusions and recommendations

SIMAR has successfully met its objectives and laid the foundation for a national (and potentially regional) rainfall observing system which promises to meet all reasonable requirements regarding spatial and temporal resolution and real-time availability of data.

There are several areas in which the current SIMAR system, with further attention to data availability, research and development, can be improved. These are:

- *Radar inter-calibration* – improved techniques to constantly monitor the complex radar calibrations within the NWRN.
- *Modern electronic techniques* – ongoing development and use of modern electronic technology to improve data collection, communication, processing and storage.
- *Radar and satellite product research* – ongoing research to improve the quality of remote sensed data and derived products.
- *Data exchange and availability* - It is evident that much more work is required on the issues related to institutional willingness to collaborate and share information. The process should occur at institutional level and be formalized through Memorandums of Understanding or other binding means. In addition government agencies should consider making remotely sensed data available free of charge and without any restriction or accessibility issues to researchers. This can only occur if government sponsors the necessary infrastructure to obtain remotely sensed data from an array of platforms to be utilised for research and training purposes.
- *Speeding up and refinement of merging algorithms* – the currently used method of combining gauge, radar and satellite measurements of rainfall can be refined using variants of Kriging which exploit the clustering of measured data and regions to be infilled.
- *Repair of weather radar images of rainfall* – ground clutter and anomalous propagation are nuisance contaminants of images of rainfall estimated by radar. These can be infilled with good estimates of rainfall if they have been identified correctly.
- *Accumulation of rainfall from radar and satellite images* – because the radar and satellite images are instantaneous snapshots of rainfields, the naïve superposition of the images gives a false accumulation field when total depths of rain are required. A method of morphing based on the calculated advection field will overcome this present deficiency.

The SIMAR system would also benefit from certain infrastructural improvements, the most crucial of these being:

- *Raingauge network* – incorporation of all qualifying raingauges in South Africa and the region, irrespective of institutional ownership. The modernization of the raingauge infrastructure through the use of modern electronics and communication systems to provide better temporal resolution on a real-time basis.
- *Radar network* – incorporation of all operational radars and standardisation of operations and data acquisition systems in the region. The expansion of the NWRN to fill areas not covered.
- *Satellite* – immediate exploitation of opportunities presented by the deployment of the MSG satellite.

The above envisaged improvements build on the existing platform of work developed under SIMAR and will make a considerably more acceptable product. Follow-on projects already under way are addressing these issues with energy.

Capacity development

The capacity developed at both technical and professional levels through SIMAR has provided a sound foundation upon which further capacity can be built.

The training of technical personnel in the maintenance and upgrading of observational systems received high priority in the SIMAR programme. Four individuals from the previously disadvantaged groups were trained in maintaining the electronic observational infrastructure thus ensuring the long-term sustainability of the observing systems. Training was conducted in-house, through courses as well as self-development. The training initiative was also expanded to the international arena with training on SIMAR related subjects presented to students from other African countries such as Botswana and Tanzania. As SIMAR products are used routinely by institutions, training will continue well beyond the lifetime of this project. It is especially training in the utilisation and interpretation of SIMAR products where a strong need exists. Users should also be trained and educated in the use of remotely sensed data, its advantages as well as its limitations.

There are two aspects to professional capacity building which were achieved here – indirect (people being exposed to the ideas and concepts but not working on the project) and direct (those people personally involved with aspects of the project). In addition, there was a strong component of Competency Development as a direct result of the project.

Indirect Capacity Development.
In the Hydrology Section of Umgeni Water, where one of the researchers (Scott Sinclair) worked in 2001 and 2002, two PDIs were kept abreast of the developments of the project in both informal and formal (reports, presentations) ways. The 2002 final year class of 28 Civil Engineering Students in Hydrology at the University of Natal, Durban, contained 16 PDIs (of whom 5 were women) and 2 white women. The project co-leader (Geoff Pegram) made frequent reference to the SIMAR in class and repeated the oral presentations given in this regard at the European Geophysical Society in Nice in April 2002. These presentations tempted two students from previously disadvantaged backgrounds to undertake dissertations under the project co-leader's supervision during the second semester of 2001

Direct Capacity Development.
In the second semester of 2001, a female final year student, Deanne Everitt, undertook a dissertation study under the supervision of the project leader entitled "Flood Impacts: Planning and Management". This was an overview study making use of the output from SIMAR, with special focus on the Umlazi catchment in Durban. A later addition to the team was Nokuphumula (Phums) Mkwananzi, a practising Engineer, who registered for an MScEng at Natal University under the supervision of the project co-leader in 2002, worked on the WRC project "Extension of Research on River Flow Nowcasting to include Levels of Inundation" which depended on SIMAR input of rainfields, and completed his Masters in September 2003.

Competency Development
Because of the nature of the Research, a number of people in Umgeni Water, Durban Metro/eThekwini Municipality, SAWS: METSYS and the University of Natal have

been exposed to new ideas and potentials for ameliorating flood damages using the ideas that are direct spinoffs from SIMAR; new technology has been developed and existing technology has been improved and refined. Every individual involved has grown in competence and benefited from the project; in the long run the wider community in the region will be beneficiaries.

Knowledge dissemination

Knowledge generated by SIMAR has been disseminated through peer-reviewed articles, conference presentations, workshops and during international visits. These include the annual South African Society for Atmospheric Sciences (SASAS) conferences. The SASAS conference that coincided with the World Summit on Sustainable Development (WSSD) in 2002 provided an international platform for three SIMAR presentations. Members of the SIMAR team also used opportunities during visits to Lesotho, Botswana, Mozambique, Burkina Faso and the Kenya Institute for Meteorological Training and Research as well as the Drought Monitoring Centre to present the progress within SIMAR. The potential agricultural applications of SIMAR products were presented by members of the research team at a workshop organised by an agricultural service provider.

An important means of relatively quick dissemination of the ideas that are the outcomes of research are via presentations at conferences and Symposia. Such presentations at National and International Fora include the following:

National:

1. Burger R.P., P.J.M. Visser, K.P.J. de Waal and D.E. Terblanche (2002). Convective Storm Climatology over the South African Interior. Annual Conference of the South African Society for Atmospheric Sciences. Pretoria, 2002.
2. Deyzel I.T.H. (2002). Application of Satellite Data in Estimating Surface Rainfall. Annual Conference of the South African Society for Atmospheric Sciences. Pretoria, 2002.
3. Kroese N.J., J.N.G. Swart and A.J. Lourens (2002). The Implementation of a real-time reporting raingauge network in South Africa. Annual Conference of the South African Society for Atmospheric Sciences. Pretoria, 2002.
4. Visser P.J.M, J.A. Blackie and S. Boersma (2002). Quality Control and Product Development for the National Weather Radar Network. Annual Conference of the South African Society for Atmospheric Sciences. Pretoria, 2002.
5. Fernandes L. and L. Dyson (2003) Comparison between SIMAR Rainfall and MM5 Rainfall Prognosis for the Rainfall of March 2003. Annual Conference of the South African Society for Atmospheric Sciences. Pretoria, 2003.
6. Kroese N.J. (2003). Meteosat Second Generation (MSG) and its application in South Africa. Annual Conference of the South African Society for Atmospheric Sciences. Pretoria, 2003.
7. Visser P.J.M. (2003). The Detection and Removal of Ground Clutter by Auto-Correlating Volume Scanned Radar Reflectivity Fields. Annual Conference of the South African Society for Atmospheric Sciences. Pretoria, 2003.

8. Nhlapo A.L. (2003). Weather Radar Reliability (*Poster presentation).* Annual Conference of the South African Society for Atmospheric Sciences. Pretoria, 2003.

International:

1. Seed A.W. and G.G.S. Pegram (2001). Using Kriging to Infill Gaps in Radar Data due to Ground Clutter in Real-Time. *Fifth International Symposium on Hydrologic Applications of Weather Radar - Radar Hydrology*, Kyoto, Japan, November.
2. Pegram, G.G.S.and Seed, A.W., (2002). 3-Dimensional Kriging using FFT to Infill Radar Data. Presentation at *27th EGS Assembly*, Nice, France. April.
3. Pegram, G.G.S., Seed, A.W. and Sinclair, D.S. (2002). Comparison of Methods of Short-Term Rainfield Nowcasting. Presentation at *27th EGS Assembly*, Nice, France. April.
4. Sinclair, D.S., Ehret, U., Bardossy, A and Pegram, G.G.S., (2003). Comparison of Conditional and Bayesian Methods of Merging Radar & Raingauge Estimates of Rainfields, Presentation at *EGS - AGU - EUG Joint Assembly*, Nice, France, April.

In yet other ways, SIMAR benefited substantially from international exchanges of knowledge. Initiatives to present data and results led to fruitful discussions and the pursuit of new ideas. In particular, Professor Geoff Pegram was active in fostering Australian and European links, as marked by the following personal invitations:

1999 - present : Invited to collaborate with the Australian Cooperative Research Centre for Catchment Hydrology

2001 - Mieyegunyah Distinguished Fellow Awardee, Melbourne University - Visiting Research Fellow (12 weeks)

2002, 2003 & 2004 - Visiting Research Fellow - Civil and Environmental Engineering Department - University of Melbourne - (8 weeks)

2002 - Keynote Speaker: 27th Hydrology and Water Resources Symposium, Melbourne, 20-23 May.

2003 - Invited to participate as rapporteur (and future full member of Steering committee) in European Union project: MUSIC / CARPE DIEM Joint Workshop with End Users, at Düsseldorf-Neuss, Germany, May 27 and 28, 2003: "Current Flood Forecasting Practices In Europe"

The knowledge gained by these interactions has benefited not only the participants in SIMAR but has already realized its potential to benefit the post-graduate students working on on-going projects which are out-growths of the Water Research Commission's investment in SIMAR.

ACKNOWLEDGEMENTS

The members of the Steering Committee for this project were:

Dr GC Green	:	Water Research Commission - Chairman
Dr DE Terblanche	:	SA Weather Services
Mr E Poolman	:	SA Weather Services
Mr K Estié	:	SA Weather Services
Mr S van Biljon	:	Department of Water Affairs and Forestry
Mr DB du Plessis	:	Department of Water Affairs and Forestry
Mr JC Perkins	:	Department of Water Affairs and Forestry
Prof GGS Pegram	:	University of Natal
Dr J C Smithers	:	University of Natal
Dr C Turner	:	Eskom
Prof S Walker	:	University of the Orange Free State
Dr D Sakulski	:	National Disaster Management Committee
Ms B van Wyk	:	Rand Water
Mr M Summerton	:	Umgeni Water

I am deeply indebted to the Steering Committee for funding and helping to make the SIMAR project so successful. The Water Research Commission's vision in appointing experts and interested parties to the steering committees, which guided, advised and monitored the researchers in their endeavours, has borne excellent fruit in this research. In particular, I want to single out the chairman, Dr George Green, for his contribution.

Appreciation is also extended to my colleagues at the METSYS division of the South African Weather Service for their encouragement and assistance during the project. I specially want to thank my colleagues from METSYS at Irene for their dedication and hard work in maintaining and upgrading the radar network.

Nico Kroese 3 December 2003

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GLOSSARY OF ACRONYMS

AMF	Auto Mains Failure
ARC	Agricultural Research Council
AVHRR	Advanced Very High Resolution Radiometer
AWS	Automatic Weather Station
DEAT	Department of Environmental Affairs and Tourism
DOS	Disk Operating System
DRAO	DelegatedRegionalAuthorizingOfficer
DWAF	Department of Water AffairsandForestry
EPS	EUMETSAT Polar Orbiting Satellite
ESD	Electronic Systems Development
FRN	Frame Relay Network
GTS	Global Telecommunication System
HRIT	High Rate of Information Transfer
IR	Infrared
ISCW	Institute for Soil Climate and Water
KMD	Kenyan Meteorological Department
LAN	Local Area Network
LRIT	Low Rate of Information Transfer
MDD	Meteorological Data Dissemination
MDV	Meteorological Data Volume data-format
METSYS	Meteorological Systems and Technology Division of SAWS
MPEF	Meteosat Product Extraction Facility
MOA	Memorandum of Agreement
MOP	Meteosat Operational Programme
MSG	Meteosat Second Generation
MTAP	Meteorological Transition in Africa Project
MTP	Meteosat Transition Programme
NAMPO	National Maize Producers Organization
NMS	National Meteorological Service
NOAA	National Oceanic and Atmospheric Administration
NPRP	National Precipitation Research Project
NWRN	National Weather Radar Network
PMU	Project Management Unit
PUMA	Programme for the Utilization of MSG in Africa
RDAS	Radar Data Acquisition System
RMRC	Radar Monitoring and Remote Control
SADC	Southern African Development Community
SAF	Satellite Application Facility
SAST	South African Standard Time
SAWS	South African Weather Service
SEVIRI	Spin Enhanced Visible and Infrared Imager
SIMAR	Spatial Interpolation and Mapping of Rainfall
SMS	Short Message Service
UPS	Uninterruptible Power Supply
UTC	Universal Time = Greenwich Mean Time (GMT)
VIPOS	Vaal Dam Integrated Precipitation Observing System
VIS	Visible
WAN	Wide Area Network

WMO	World Meteorological Organization
WRC	Water Research Commission
WV	Water Vapour

1.0 INTRODUCTION

Water is the single most important variable affecting life on the planet. Rainfall, the major source of water for human activities, is one of the least understood variables measured by weather services and other institutions. Our ability to measure rainfall accurately and adequately falls far short of the demands required by modern day technologies and lifestyles.

Against this background and the fact that conventional meteorological observing stations are dwindling at an alarming rate in South Africa, the SIMAR programme sought to develop a near real time, spatially high-resolution, rainfall measuring and mapping system for southern Africa based on both surface measurements and measurements using remote sensing techniques.

The aim of this project, a fundamental component of SIMAR, was to optimise the use of existing rainfall measurement infrastructure with a view to ensuring that objectives of SIMAR could be successfully met. To achieve this aim, latest technology was employed in establishing processes for maintaining, and upgrading existing infrastructure, as well as expanding networks to areas of limited coverage. The three main pillars (data sources), upon which the success of the rainfall monitoring and mapping system envisaged by SIMAR rests, are: a) Surface observations b) Radar rainfall estimations and c) Satellite rainfall estimations. This report deals mainly with the processes to secure and sustain a reliable data flow from the data sources mentioned above.

The specific objectives of this project were to:

- Maintain automated surface gauge networks (Durban and Liebenbergsvlei) as well as investigate the application of new technology to ensure real time availability of data.
- Maintain and upgrade the National Weather Radar Network by improving the monitoring capabilities at each radar system, investigating the possible expansion of the network coverage and pursuing an improved funding base for the radar network.
- Utilise the latest remote sensing technology in order to improve the quality of products to be generated.
- In cooperation with other stakeholders, assist in establishing a real time precipitation database for South / southern Africa.
- Actively seek and promote collaboration with stakeholders, institutions and organisations, on a formal and informal basis, to expand and enhance surface coverage of precipitation measurements.
- Equip and train individuals, especially those from the previously disadvantaged communities, with a view to their acquisition of remote sensing and electronic maintenance skills.

This project took place within the context of dramatic transformations within the South African Weather Service. The most important of these was the transformation of the organisation from a public service body to a “Schedule 3A – National Public Entity” in terms of the signing of the South African Weather Service Act (Act No. 8 of 2001) on the 22nd of July 2001.

This report describes progress made in addressing the various objectives. In Section 2 attention will be given to the surface raingauge networks, which will be followed by a discussion on the National Weather Radar Network (NWRN) in Section 3 and the initiatives to secure this asset. Section 4 will highlight the progress made in utilizing meteorological satellites. This will be followed in Section 5 by a report on attempts to consolidate and establish a national database on real-time precipitation data. Section 6 will present overall conclusions and recommendations, and assess the contributions made by this project towards capacity building.

2.0 RAINGAUGE NETWORKS

2.1 Liebenbergsvlei Raingauge Network

This network was established towards the end of 1993 in order to serve the evaluation and verification component of the National Precipitation Research Programme (NPRP) that was conducted during the period 1990 to 1997. The comparison of radar-estimated rainfall with ground truth-values formed an important part of the evaluation process for the NPRP. Not only was the data from this network utilised during the rainfall enhancement project, but it was also used extensively in radar rainfall studies that were conducted in the NPRP and thereafter. In conjunction with the MRL5 radar situated near Bethlehem, this network also provided useful information to the Department of Water Affairs and Forestry during the 1996 floods over the Vaaldam catchment, and enabled satisfactory replies to numerous enquiries in connection with agricultural and climatological issues to be given.

The network consists of 45 tipping bucket type rainguages equipped with data loggers developed in house (Mather et al., 1997). With the continued utilisation of data from this network, the shortcomings and disadvantages of the methodology used in collecting the data became apparent. More than 5000 km were travelled and 200 man-hours spent annually in retrieving the data from the field. With the additional demands imposed by quality checks, archiving and dissemination, it became apparent that the methodology was in need of refinement. With regards to data quality, statistics indicated rapid degeneration and loss of data (Fig 1), attributable mainly to the ageing of equipment and the shortage of personnel needed to perform regular maintenance of instrumentation in the field.

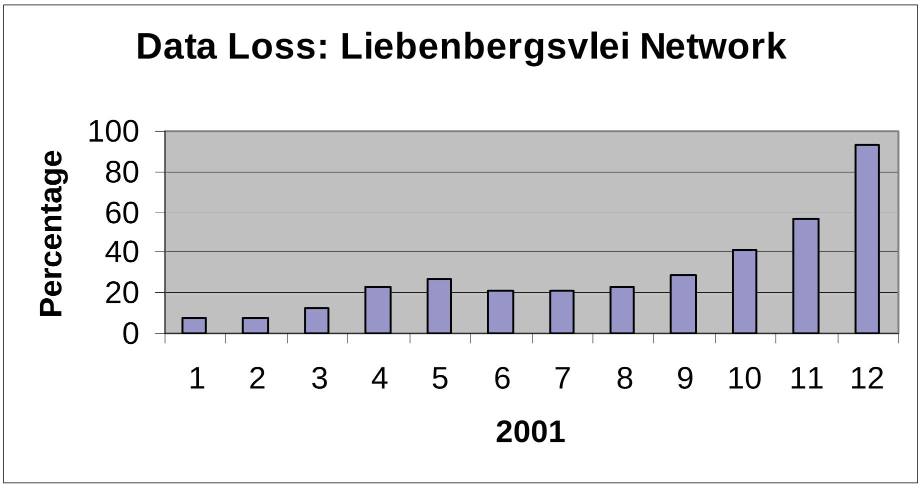


Figure 1 Percentage data loss for 2001 in the Liebenbergsvlei raingauge network.

From the METSYS (SAWS) perspective, the Liebenbergsvlei network served only a limited, albeit very important purpose, namely that of providing data for routine evaluation of radar-determined rainfall fields. In order to enhance the usefulness of the network within the context of SIMAR, rainfall data would need to provided in real-time.

With all the above taken into account, it became was apparent that the Liebenbergsvlei network was not functioning on a sustainable basis. Serious decisions needed to be made regarding the future of this network. The options available were:

1. To remove all instruments from the field and terminate operations completely.
2. To utilise appropriate technology to transform the network into a real-time reporting facility.

Option 1, though logistically attractive because availability of funding to maintain the network had become problematic within the SAWS, was nevertheless opposed to the organisation's desire to expand its surface observation network. With the Liebenbergsvlei network having provided high-resolution data, both spatially and temporally, since 1993, its closure would be a severe blow not only to the SAWS but, as also indicated by other users, to the country as a whole.

Option 2 offered the benefit, not only of extending the lifeline of the network, but also enhancing its usefulness. Use of cell phone communication technology would enable data to be made available in near real-time mode for ingestion by decision-making tools and processes. The drawback, however, was the expense, with initial costs determined to be about R 5 000 per raingauge.

After consultation within METSYS and the SAWS as well as with outside stakeholders, it was decided that a compromise between the options mentioned above presented the most viable solution to the problem of ensuring sustainability of the network, even beyond the lifetime of this project. Resulting from this decision, a considerably reduced rainfall network consisting of 20 stations equipped with real-time communication technology covering the whole Liebenbergsvlei River catchment was installed, after also taking into consideration the existing rainfall measurement infrastructure of the Department of Water Affairs and Forestry (DWAF). Table 1 gives a list of the new stations within the catchment area of the Liebenbergsvlei River deployed during January and February 2003. Refer also to **Appendix B** for a map indicating the location of the raingauges in the Liebenbergsvlei river catchment.

Table 1 List of the raingauges deployed in the Liebenbergsvlei River Catchment. These gauges are all equipment with the latest cell phone communication technology, ensuring real-time communication of rainfall data.

Station Name	**Id**	**Latitude (South)**	**Longitude (East)**
Highlands	L001	28˚23.39S	28˚15.24E
Aberfoyle	L002	28˚18.35S	28˚25.17E
Sweet Home	L003	28˚22.13S	28˚35.54E
BHM Weerkantoor	L004	28˚21.13S	28˚15.54E
Camori	L005	28˚13.50S	28˚27.40E
Groenkop	L006	28˚14.01S	28˚3918E
Maluti Vrugte Pakhuis	L007	28˚07.13S	28˚20.33E
Kransfontein			
Landgoed	L008	28˚07.50S	28˚33.33E
Brakpan	L009	28˚02.57S	28˚14.44E
Sophia	L010	28˚02.47S	28˚26.51E
Mosbank	L011	27˚57.26S	28˚16.10E
Strydfontein	L012	27˚57.68S	28˚27.50E
Grootgewaagd	L013	27˚52.08S	28˚12.29E
Tertuis	L014	27˚51.58S	28˚26.55E
Albrecht	L015	27˚46.34S	28˚08.37E
Torpedo	L016	27˚46.09S	28˚32.22E
Biesiesfontein	L017	27˚40.54S	28˚12.22E
Lorenco	L018	27˚42.52S	28˚25.25E
Kliprand	L019	27˚26.02S	28˚21.16E
Maanlaagte	L020	27˚35.02S	28˚35.01E

Considerations fundamental to the development of the new cell-phone technology are presented in Section 2.3.

2.2 Durban Raingauge Network

The raingauge network in Durban was newly established as part of this project and the SIMAR programme. This network consists of 16 raingauges and was established in 1999, becoming fully operational during December of that year. The need for this network stems from the fact that that the estimation of rainfall with radar in coastal areas has proven to be less accurate and to require separate calibration to maximise accuracy, compared to rainfall measurements over the interior, where convective storms are the dominant rainfall producing system. There are different rainfall mechanisms at work along the coast, where precipitating clouds of limited vertical extent are common. Other factors, such as topography, synoptic circulation (onshore or offshore flow) etc, also play a role.

Table 2 List of raingauges installed in the Durban Metropolitan area.

Station Name	**ID**	**Latitude (South)**	**Longitude (East)**
EWOS Site	D001	29^{0} 57' 00"	30^{0} 58' 00"
Clairewood Race Course	D002	29^{0} 54' 32"	30^{0} 58' 04"
Bluff Reservoir	D003	29^{0} 56' 01"	31^{0} 00' 21"
University of Natal	D004	29^{0} 52' 11"	30^{0} 54' 43"
Seafarers Club	D005	29^{0} 54' 11"	31^{0} 00' 37"
Point	D006		
Pinetown Swimming Pool	D007	29^{0} 48' 30"	30^{0} 51' 30"
Westville Prison	D008	29^{0} 51' 25"	30^{0} 54' 50"
Durban SPCA	D009	29^{0} 51' 32"	30^{0} 57' 51"
Greyville Race Course	D010	29^{0} 50' 31"	31^{0} 00' 41"
Chef Mushrooms	D011	29^{0} 47' 33"	30^{0} 44' 25"
Kloof Rainfall Station	D012	29^{0} 46' 28"	30^{0} 49' 38"
Wyebank Reservoir	D013	29^{0} 46' 51"	30^{0} 51' 53"
Durban Heights	D014	29^{0} 48' 01"	30^{0} 55' 45"
FOSA Hospital	D015	29^{0} 47' 07"	30^{0} 58' 05"
Durban North Reservoir	D016	29^{0} 46' 49"	31^{0} 04' 58"
Kwa Mashu Water Works	D017	29^{0} 43' 46"	31^{0} 00' 34"
AWS Virginia Airport	D018	29^{0} 46' 00"	31^{0} 03' 00"
AWS Mount Edgecombe	D019	29^{0} 42' 00"	31^{0} 03' 00"
Durban North Fire Station	D020	29^{0} 43' 33"	31^{0} 04' 11"
Umhlanga Water Works	D021	29^{0} 41' 48"	31^{0} 04' 52"
Phoenix Water Works	D022	29^{0} 40' 45"	31^{0} 02' 12"

The technology used in the Durban Raingauge Network was the same as that originally used in the Liebenbergsvlei, where systems developed in house were utilized to collect the data. Exactly the same problems were encountered in maintaining the network as with the Liebenbergsvlei network. An example of the loss of data from the Durban network is expressed in graphical format in Figure 2.

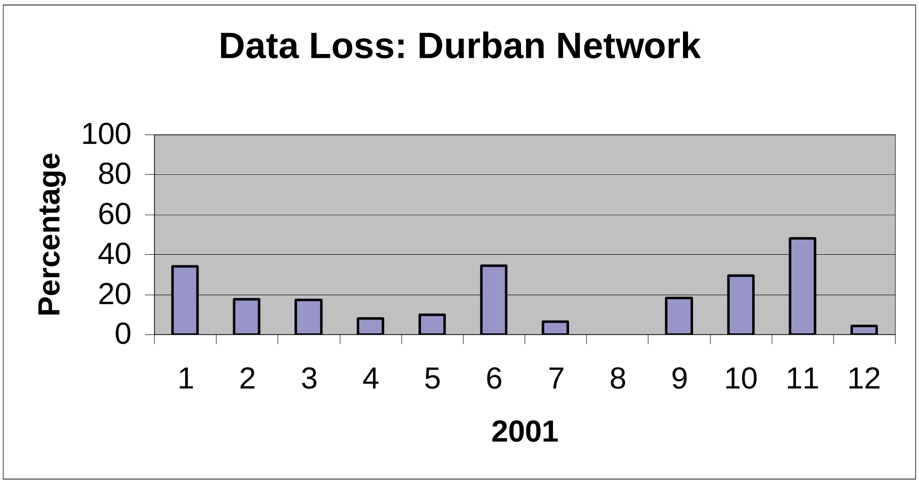


Figure 2 Percentage data loss for 2001 in the Durban Raingauge Network

Consideration has been given to continuation of the network after the project period has elapsed. The decision reached here is similar to that for the Liebenbergsvlei scenario, namely that rainfall infrastructure should be kept intact and where possible, be equipped with the new technology in order to enhance its future utilisation in real-time applications.

2.3 Upgrading of raingauges with real-time capabilities.

Soon after the implementation of the Liebenbergsvlei raingauge network in 1993 it was realised that rainfall data in real-time (or near real-time) hold far more promise and have infinitely more utilisation potential than historical data, which can only be used for "after the event case studies" and for responding to climatological enquiries. Even then, disaster management, precision farming and special event organisors could have benefited enormously from applications of real-time rainfall data. Unfortunately, no affordable technology for effective real-time communication was available at the time. With the introduction and advancement of cell-phone technology, that limitation has now been overcome.

Accordingly,the core of the new real-time raingauge system that has been developed is based on cell phone communication technology. The previous data logger developed in house was micro-controller–based, with a 64K non-volatile data and programme memory. The capacity of the logger memory was 2550 events, which is equivalent to 510 mm of rainfall using the 0.2 mm resolution of the Tipping Bucket Raingauge (TBR). Power consumption was 2 mA during the sleep mode and 5 mA during a tipping event. A sealed lead acid 6V battery was used as the power source and was housed within the enclosure of the TBR. Data retrieval was done using a laptop computer through a standard RS-232 connector, which was also utilized to reset the event logger for the next sampling interval

A later improvement on the previous system was the utilisation of solar power to recharge the batteries, extending not only their overall lifetime but also their time in operational use. Previously battery changes had to be done every 3 to 4 months contributing to the escalating costs of operating such a network.

The procedure whereby the new system operates is that once rainfall is detected, it will automatically send a message containing the rainfall information by SMS (Short Message Service) at 15-minute intervals to the data assimilation computer located at the regional weather office. It will do so for the duration of the rainfall event and thereafter go into sleep mode. At 08:00 SAST every day, a message providing the accumulated rainfall amount over the previous 24 hours is sent. If no rainfall has been detected during a 24 hour period, this is confirmed by a single daily SMS message transmitted only at 08:00 SAST. (See **Appendix A** for a more complete description of the system).

In future, the data collected at the different regional offices will be transferred via the SAWS Wide Area Network (WAN) to the central database in Pretoria from where interested parties such as METSYS will be able to download the data.

2.4 Cooperative Efforts

Apart from the real-time raingauge networks operated by METSYS in Bethlehem and Durban, data from the SAWS daily reporting network as well as the Automatic Weather Station network (AWS) are currently the only real-time raingauge data ingested in the process of producing daily rainfall maps for the country. This section describes the various initiatives that METSYS embarked upon in order to secure real-time precipitation data for utilisation in this project.

2.4.1 Department of Water Affairs and Forestry (DWAF)

An initiative to exchange mutually beneficial data between the SAWS and DWAF culminated in the establishment of a direct data link between the two organisations. Unfortunately, network security issues at DWAF prohibited the operation of the link between the two networks.

An alternative method currently being tested is the downloading of rainfall data from the DWAF website. This allows access to precipitation data collected at stream gauging points in the DWAF network

2.4.2 Agricultural Research Council (ARC)

The Agricultural Research Council, through the Institute for Soil Climate and Water (ISCW), maintains a precipitation database to which their own observation network as well as the SAWS observation and AWS networks contribute. The exchange and sharing of data between the SAWS and ARC has historically taken place on an unofficial basis. An official process, to be formalised in a Memorandum of Agreement (MOA) allowing for exchange of data between the two institutions is under negotiation. Unfortunately negotiations did not reach the stage which would have allowed precipitation data from this source to be incorporated into the envisaged SIMAR surface observation network.

2.4.3 Farmer Co-Ops and Agricultural Organizations

During the participation of METSYS at the 2001 annual NAMPO agricultural exhibition, contact was established with Suidwes Agriculture which manages 16 grain silos in the Bloemhof, Vryburg, Wolmaranstad area. The area served by Suidwes Agriculture is in excess of 13.5 million hectares, located mainly in the southwestern part of the North West Province (See **Appendix D** for a map of the area served by Suidwes Agriculture). The main crops being cultivated in the area are maize and ground nuts, the latter being particularly sensitive to rainfall, especially during the harvesting season when the nuts are left on the land to dry.

Each of the 16 silos is served by a network of 5 raingauges (80 in total) that report on a daily basis to the company’s headquarters located in Leeudoringstad. Daily reports from the raingauge network are compiled for the company’s own internal use and for planning purposes.

Suidwes Agriculture was approached with a view to obtaining the data and including it in the SIMAR surface network database. Data have been received from this institution since mid-2002. However, shortcomings in the data have prevented their use in this project. The gaps in reports corresponding to weekends and public holidays are just some of the problems that need to be addressed. A possible solution would be to deploy the new real-time raingauges also within this network. If successful, this initiative would provide the basis for further cooperation with other agricultural organisations and farmer co-operatives that collect precipitation data for their own purposes.

2.4.4 eThekwini Municipality (Durban Metro)

The City Engineers Department of the eThekwini Municipality (formerly known as the Durban Metropolitan Council) has since 1998 operated a raingauge network within the confines of the Durban metropolitan area. This network was put in operation mainly for the purpose of record keeping, planning (such as the outlay of new suburbs and industrial areas etc.), and the determination of design criteria for the construction of structures able to withstand prescribed rainfall intensities. Durban, like all the major cities in South Africa, has experienced an unprecedented influx of people due to industrialization and work opportunities. Accompanying the influx was the construction of the necessary infrastructure to provide housing for the people. In the late 1980's informal settlements began to appear and currently still present town planners and city engineers with major problems with regard to the provision of basic services such as water, sewage, road access, etc. The increase in areas that are built-up resulted in unexpected amounts of water inundating the city's storm water removal system, causing many instances of severe flooding. Further importance was now given to the rainfall measurement infrastructure, as it had to be used in the management of local flooding events after heavy rainfall episodes. With recognition of the limitations, of the available technology (similar to that initially used by the SAWS in the Liebenbergsvlei catchment), came the realisation that the proper management of flood situations needed infrastructure capable of providing real-time data.

eThekwini Municipality thus also embarked on a programme to enhance their network by upgrading their instruments so as to provide them with real-time capabilities. The route followed by them was to contract a third party to develop the cell phone-based communications technology. Five stations equipped with cell phone technology were deployed in October 2002. A further nine stations within their network will be equipped with the new technology during the course of 2003.

Since METSYS and eThekwini Municipality initiated the upgrading of their respective networks without being aware of the other's efforts, the two organisations have entered into a verbal agreement with each other, ensuring future cooperation. During discussions the following points were raised:

- Data from the networks operated by each organisation must be made accessible to both.
- There will be future collaboration on the expansion of the current network.
- Data formats will be standardised in order to simplify the data exchange.
- Institutions such as Umgeni Water and DWAF should be approached for collaboration on this initiative.

Appendix C gives a map of the eThekwini Municipal area and the location of the SAWS and eThekwini Municipality raingauge networks.

2.4.5 Eastern Cape – Expansion of the AWS Network

A proposal to expand the AWS network over the Eastern Cape has been submitted to the Poverty Relief Fund being managed by the Department of Environmental Affairs and Tourism (DEAT). METSYS proposes to develop a more affordable version of the current AWS, which is to be used in conjunction with a trained observer (a local person from the area) to provide an enhanced observation service to the SAWS. The observer will be trained according to SAWS observer standards and provide information on meteorological variables (cloud type, cloud height, visibility etc) not possible to measure with the instrument suite of the AWS. This initiative, in conjunction with the installation of a radar in Umtata, will receive priority within the SAWS. The initiative to expand the AWS network in the Eastern Cape also served as a trigger for the SAWS to embark on a strategy to replace all second and third order observation stations within the country with the downscaled version of the AWS currently under development in METSYS. As soon as the new AWS data become available, they will be incorporated in the real time rainfall database.

2.4.6 Southern African Development Community (SADC) Initiatives

Weather does not respect international boundaries, hence the imperative (also contained in Resolution 40 of the World Meteorological Organization (WMO)), that meteorological data be exchanged with our neighboring countries. The WMO has established a Global Telecommunications System (GTS) specifically for the exchange of meteorological data. The SAWS has been established as a regional hub for the collection and further dissemination of meteorological data from within the SADC region to the rest of the world via the GTS. Unfortunately, there are still barriers to full data exchange among the respective weather services, as can be seen in the following GTS status summary.

Country	**Status**	**Remarks**
Angola	Not Operational	Network was repaired with help from SAWS, but since December 2001 no data have been received.
Botswana	Operational	
Lesotho	Operational	
Mozambique	Operational	
Namibia	Not Operational	Experiencing hardware problems.
Swaziland	Operational	
Zambia	Not Operational	Have no funding to pay for network costs.
Zimbabwe	Not Operational	New network to be installed.

Even in countries where the GTS is operational, the amount of data received for real-time purposes are very limited, as the infrastructure is not geared for providing the data needed.

METSYS, as part of the SAWS, is involved in a programme to equip SADC countries with locally developed AWS systems. To date, two initiatives to supply Southern African countries with AWS instrumentation are underway. The first is in Tanzania, where 5 stations have been installed and the second in Namibia, to whom 10 AWS systems are to be supplied.

3.0 NATIONAL WEATHER RADAR NETWORK (NWRN)

Radar data form an integral part of the data stream needed to produce the SIMAR rainfall products. Radar probably represents the most important pillar upon which the whole SIMAR system rests. Precipitation data from the surface networks are used to standardise radar-determined rainfall, which in turn is utilised in the derivation and calibration of rainfall products from satellite data. Radar data are thus central to the evaluation, correlation and integration procedures that are performed to ensure the success of the whole rainfall monitoring and mapping system.

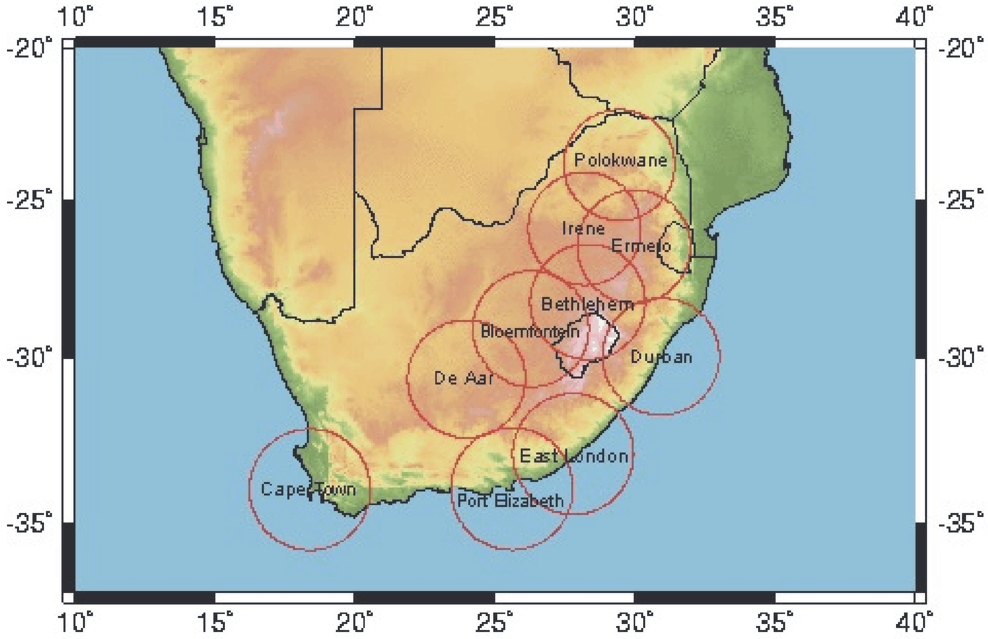


Figure 3 The National Weather Radar Network.

During the term of the SIMAR programme (January 2000 to March 2003) and this component project in particular, funding for maintenance and upgrading of the NWRN remained a factor which limited efforts to attain acceptable levels of reliability. As a result, the maintenance and reliability of the NWRN suffered considerably due to a shortage of spare parts, especially during the initial period of this project. However, due to an active process within the SAWS to promote the use of radar amongst the forecasting as well as disaster management fraternity, funding for the NWRN improved considerably towards the latter period of the project. Compared to the R 120 000 that was available to maintain the eleven radars in the network during the 2000/01 financial year, the R 1.2 and R 1.0 million for 2001/02 and 2002/03 financial years, respectively, represented a considerable improvement in the funds allocated to the radar network. Although still below the R 3.5 million estimated to properly maintain the network, the extra funds were put to good use in acquiring critical spare parts and systems for improving and maintaining the operational capabilities of the network.

3.1 Hardware Upgrades and Maintenance Procedures

Radar maintenance received priority attention during this project, with the objective not only to keep the radars operational in the short term through the acquisition of spare parts, but also to promote the long-term sustainability of the network.
One of the major problems that can affect radar's operation is an unreliable power supply. Not only will continuity of operation and the availability of data be affected, but an unreliable power supply can potentially damage the individual components of the system, such as the computers and the radar receiver unit, which are most vulnerable to power dips and surges. For this reason, during the course of this project, particular attention was paid to securing reliable power supplies to the radars within the NWRN. The following is a summary of the upgrades that have been performed since 2000:

3.1.1 Bethlehem Weather Office & MRL 5 Radar

The Bethlehem Weather Office can be regarded as the data nerve centre, where data from the 11 radars within the network are gathered and the rainfall products generated. From there the products are disseminated, utilising the SAWS Wide Area Network (WAN) and the Internet. Power failures in Bethlehem would have catastrophic effects on the radar network and the availability of products.

It was for this reason that a new 25kVA Uninterruptible Power Supply (UPS) was installed, with upgrades also being performed on the 50kVA diesel generator on the premises. With these precautionary measures in place everything possible had been done to ensure a reliable power supply. The Local Area Network (LAN) in Bethlehem, together with those of several other radar stations such as Irene, Bloemfontein and De Aar, also received major upgrades with the acquisition of LAN switches able to accommodate the amount of data on the network.

Upgrades to the MRL5 radar were also performed, with the installation of a new S-band magnetron towards the end of 2002. Whilst upgrades were performed on the MRL5, a previously installed Enterprise C-band radar was dismantled in expectation of its relocation to Umtata. A bearing upgrade was performed on this radar's antenna system to increase the load bearing capacity and reliability of the antenna drive system.

3.1.2 Irene Radar

The Irene radar was upgraded with the installation of a new 20 kVA UPS- system during November 2002, increasing the reliability of this system. The diesel generator was serviced and the radar room revamped to accommodate the UPS.

3.1.3 Polokwane Radar

The radar at Polokwane was commissioned in November 1999, in time for the onset of SIMAR. Subsequently, the radar power supply underwent a major overhaul, with maintenance and upgrades being performed on the UPS and diesel generator.

3.1.4 Durban Radar

At the Durban radar, a new 60 kVA diesel generator with an Auto Mains Failure (AMF) panel and a 800 litre diesel tank, was installed. This was complimented with the installation of a new 20kVA UPS that features network connectivity. Since the radar is located in a residential area, expenses were incurred in soundproofing the system. The three-phase distribution board was upgraded with lightning and surge charge protection devices. Renovations to the building also formed part of the upgrade.

3.1.5 Bloemfontein Radar

During the winter of 2002, the Bloemfontein radar, received a new UPS system with a by-pass unit. Power is supplied by the airport's diesel generator. A new distribution and sub-distribution board was installed and the network cabling within the building where the radar is housed, completely renovated.

3.1.6 Other Radars

The remaining radar systems will also be upgraded in due course, pending the availability of funds. At Ermelo, attention will be given to the radar's bearings, whilst an old UPS removed from Irene will be utilised at East London.

A maintenance schedule for the NWRN has been developed, whereby a preventative maintenance programme is followed during the winter months when most of the radars in the interior of the country are not in operation. In addition to the above, a system was implemented by which critical spare parts and parts having a high failure rate are kept on the radar premises to ensure that downtime is kept to a minimum during mechanical and electronic breakdowns.

3.2 Radar Monitoring & Remote Control (RMRC)

Each radar within the NWRN is maintained by METSYS technical personnel, some of whom are located at major outstations such as Cape Town, Durban and Port Elizabeth and East London. Nevertheless, the need to monitor the radars within the national network remotely, and where possible, also to control certain basic radar functions remotely, was recognised soon after the radars were networked. Networking the radars highlighted the fact that not all radars were comparable regarding certain important variables such as sensitivity, antenna alignment ,etc. Remote monitoring and conrol from a central location offered the means of addressing the problems of intercomparability.

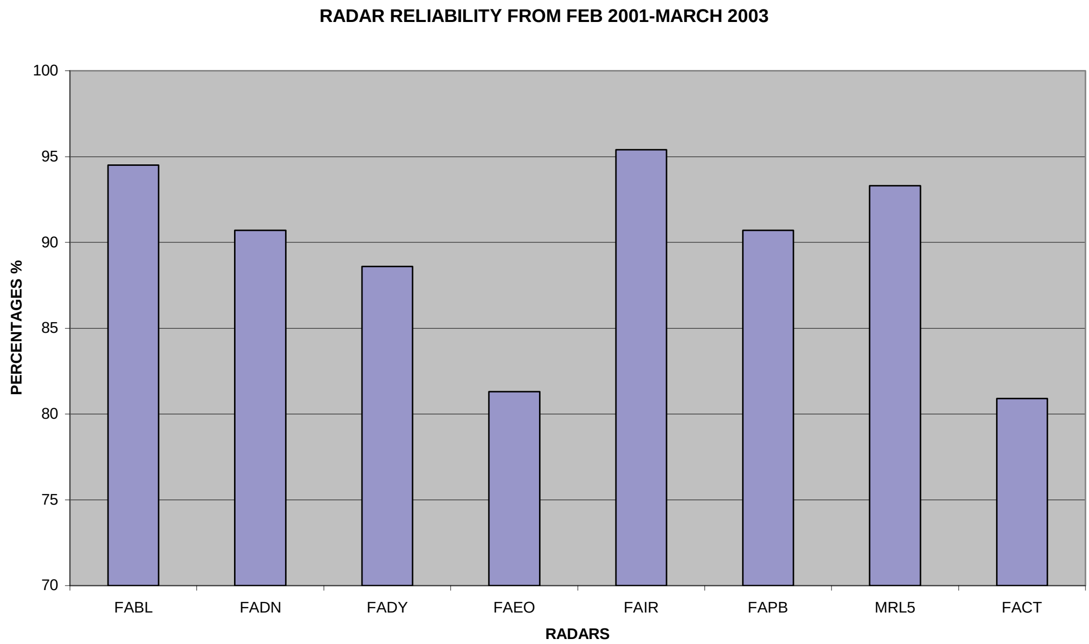
A prototype RMRC unit was developed and successfully tested. After considerable delays all the components necessary for the assembly of production units were acquired and subsequently all the radars in the network were fitted out with RMRC units.

The RMRC unit monitors the following parameters and processes:

- The presence of power from the radar’s main power supply.
- Output power from the mains as well as UPS.
- Status of the air conditioning unit (on/off).
- Several Radar functions, including transmitter power, servo power, “stand-by” indicator, etc.
- The currents of the two servo motors regulating the antenna’s azimuth and elevation positions.

By monitoring these parameters, the optimal functioning of the radars most critical processes can be traced and corrective action taken, when necessary. Remote communication and monitoring at each radar is made possible through the SAWS Frame Relay Network (FRN). A database is compiled on a monthly basis, summarising the performance of the radar as well as the availability of the data through the communications network. Since data from the RMRC-system has been available from February 2001, operational statistics of the NWRN can be constructed and graphically displayed. Figure 4 presents summarised information on the reliability of the radars in the NWRN during the period February 2001 to March 2003.

Missing from this summary report are the data for the Port Elizabeth (PE) and East London (EL) radars. Reliability statistics for different radars were compiled in Bethlehem of data received from each radar individually. Prior to being received at Bethlehem data from the EL radar were sent via the SAWS-LAN to PE where the data from the two stations were merged. The software used at Bethlehem was unable to compile reliability statistics from merged fields, explaining the lack of data from these radar sites. The problem has been addressed, resulting in the availability of reliability data for PE and EL from March 2003 onwards.



Legend : FAIR – Irene FAEO - Ermelo
FABL - Bloemfontein MRL5 - Bethlehem
FADY - De Aar FADN - Durban
FAPB - Polokwane FACT – Cape Town

Figure 4 The reliability of the National Weather Radar Network (NWRN) for the period February 2001 to March 2003, expressed in terms of the down-time percentage of individual radars in the network.

3.3 The development of RDAS under "LINUX"

The Radar Data Acquisition System (RDAS) currently functions under the DOS operating system, the reason being that DOS allows for high-speed, real-time data acquisition through interrupts as well as being the only platform available when RDAS was developed. With DOS no longer supported by the software industry, it became necessary to upgrade RDAS to another operating system such as Windows or LINUX.

The upgrading of the RDAS hard and software to function under LINUX, and the re-labelling thereof as RDAS 2000, was envisaged as part of this project. A private company Electronic Systems Development (ESD) was contracted to undertake the development of RDAS 2000. ESD in turn collaborated with an USA based company called RADTEC, with the latter providing expertise on the dopplerisation of radar systems.

The current status of RDAS 2000 is that the hardware development and a major part of the software development has been completed. Full completion is expected towards the end of 2003.

In anticipation of its impending availability, METSYS has developed a strategy for the deployment of RDAS 2000 on all the radars within the NWRN.

3.4 Cooperative Efforts

This section describes the various collaborative initiatives in which METSYS is involved in order to ensure necessary upgrading and sustainability of the NWRN and to promote links with neighbouring national networks to form a Southern African Radar Network .

3.4.1 Relocation of the Bethlehem C-band Radar to Umtata
The Eastern Cape is well known as an area frequently affected by severe weather events. These include thunderstorms that produce flash floods, hail, tornadoes and strong winds. Such events typically disrupt the lives of poor rural communities and subsistence farmers. Weather radar constitutes the best tool with which to observe these events at sufficiently high spatial and temporal resolution in order to support related disaster mitigation, water resource management and flood warning activities. In addition, it creates unique training and research opportunities in science and technology within the area served by the radar.

Of the 11 radars that constitute the NWRN in South Africa, two are located at Port Elizabeth and East London in the Eastern Cape. Although data from these systems are collected up to a 200 km range, vast areas of the Eastern Cape interior, where the majority of the storms occur, are either not under radar coverage or not covered sufficiently. The Figure below illustrates the current radar coverage and the area to be covered with the addition of a radar located at Umtata (centre circle).

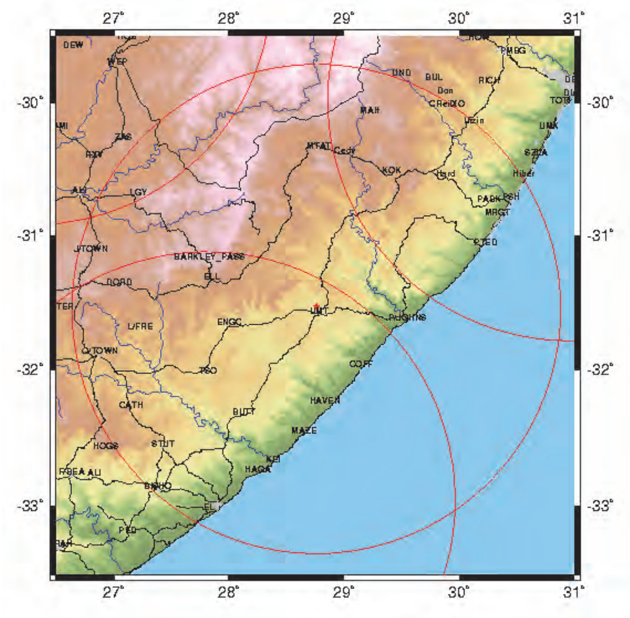


Figure 5 Envisaged radar coverage over the Eastern Cape.

The SAWS, in collaboration with Fort Hare University, jointly identified the need to improve radar coverage over the Eastern Cape and to use the technology as a vehicle to expand their partnership to include the people of the region. The perception that "advanced technology is only for the benefit of the privileged few" is in dire need of being disproved. This project offers a unique opportunity to:

- Enable, through appropriate training, a new generation of technical and scientific personnel, drawn from the previously disadvantaged communities, to acquire expertise in radar and remote sensing.
- Create awareness of the benefits of advanced technology to improve the everyday life of ordinary people.
- Address issues of communicating weather information to rural areas.
- Present the data and information generated through the radar installation in an understandable format so that it can be used by people in a way that affects their lives positively.

The radar to be relocated has been identified as a currently unused Enterprise WSR81 C-band radar at the Bethlehem weather office. With the close proximity of the MRL5 radar to Bethlehem this radar previously only served as a backup and was not used optimally. The decision to relocate the Bethlehem radar was already made during 2000, but the lack of funding and difficulty in obtaining permission to use a suitable site prevented the project from going ahead.

The designated radar site is on communal land within the borders of Umtata town (Lat: 31^0 32.045' S Lon: 28^0 45.694' E). The legal documents to transfer the property to the SAWS, were signed by the community leaders during a ceremony to commemorate World Meteorological Day on the 23rd of March 2002.

Figure 6 Image depicting the view from the selected radar site at Umtata.

Deployment of the radar has, however, been plagued by several difficulties. One of these is the funding issue. While some funds have been secured from the Eastern Cape

Provincial Government, a decision regarding an application for complementary funding to the Poverty Relief Fund of the Department of Environmental Affairs and Tourism is still being awaited. The current target date for the commissioning of the Umtata radar is the 23rd of March 2004.

3.4.2 Botswana radar

The Botswana Weather Service operated a radar system in the Gaborone area for a number of years. Owing to a lack of in-house technical expertise, however, this system was not in use for most of the period, despite the occasional assistance of SAWS technicians.

During 1998 the Botswana Meteorological Service decided to purchase a new Enterprise S-band Doppler radar, and used South African specialists from METSYS to oversee the radar acquisition process, from the initial planning phase through to final commissioning. This process was successfully completed towards the end of 2002, when the radar was commissioned. Requests by METSYS, through regional (SADC) and WMO structures for access to data from this radar have not been successful, but renewed efforts are underway to establish a mutually beneficial link with the Botswana Meteorological Service.

The Botswana radar would provide South Africa with radar coverage over a large part of the North West Province where currently no such coverage exists. Since the general movement of weather patterns over southern Africa is from west to east, the location of the radar is ideal for early severe-weather warning purposes. Botswana on the other hand, would gain considerably from a formal agreement in that their radar would become part of an extended NWRN, thus giving Botswana access to the South African systems, data and technical expertise. The area of overlap between the Gaborone and Irene radars would, for instance, be of great value for inter-calibration purposes (using methods described in Volume 2).

3.4.3 Other SADC Initiatives

Apart from the radar that was commissioned in Gaborone, Botswana, radars are also operated in Zimbabwe and plans are under way to install systems in Mozambique.

The Zimbabwean Meteorological Service possesses four meteorological radar systems of French origin, commissioned in the late 1990's. These are located at Harare, Bulawayo, Victoria Falls and Chiredzi (see **Appendix E** for a map indicating the location of radars in the Zimbabwean network). METSYS plans to explore the possibility of cooperating with the Zimbabwean Meteorological Service with a view to furthering the development of a regional network through the linking of national networks.

After being ravaged by tropical cyclone Eline towards the end of 2000, the plight of Mozambique received worldwide media attention, highlighting the fact that natural disasters affect the poor to a far greater extent than ever before imagined. The meteorological community has also recognised the inadequacy of the meteorological infrastructure in Mozambique to provide the means of effectively warning Mozambiquans of imminent weather hazards. The WMO is spearheading the upgrading of meteorological infrastructure in Mozambique. This would include the installation of at least one radar system, possibly in the Maputo area. The SAWS has already assisted Mozambique in upgrading its data communication link with Pretoria (GTS-System). Specialists from METSYS have also assisted Mozambique in assessing the placement of the proposed new radars at Beira and Xai-Xai. The Mozambique Meteorological Service has two C-band Gematronik radars on order as part of the WMO and European Union reconstruction programme in that country. They made provision for technologists from METSYS to undergo training on these systems together with its own personnel. These developments bode well for the future sharing of meteorological data, including radar data, which continues to be strongly promoted by members of the METSYS team along with the concept of including Mozambique's radars in a regional radar network (see **Appendix F** for a map indicating the radar coverage afforded by the Botswana and Mozambique radars and their respective position within an envisaged Southern African Radar Network).

While the focus is at present on Southern Africa, there is also a developing vision for Africa as a whole, illustrated by the fact that the WMO has approached the SAWS to undertake a review of all radar systems in Africa, and to make recommendations on the way forward.

4.0 SATELLITE REMOTE SENSING

Satellite remote sensing represents the third souce of data to be integrated with data from the other two sources (raingauges and radar) in creating SIMAR products. Satellite technology presents the opportunity to observe a large expanse of the earth's surface, a characteristic not offered by surface raingauge networks or even radar.

It was with great anticipation that METSYS together with the rest of the meteorological community awaited the launch of the revolutionary Meteosat Second Generation (MSG) satellite, which was originally scheduled for commissioning in the latter half of 2000. Due to delays in the development of the image-processing element, the launch had to be postponed to a later date. Upon resolving the first problem, a second problem, namely excessive shock levels created by the Ariane-5 launcher, was encountered. MSG was eventually launched on the 29th of August 2002 from Kourou in French Guyana and placed into geostationary orbit 36 000 km above the earth's surface. Since then, the satellite has been, and still is, undergoing a commissioning phase which includes several tests of the electronics, the communication systems, the radiometer and the ground station equipment. During this phase more problems, which included one of the broadcast channels becoming dysfunctional, were encountered. Procedures to rectify the problem caused further delays in the satellite implementation schedule. Although examples of MSG images are already available on the Internet, current indications are that MSG will only become operational during the first quarter of 2004.

Lengthy delays in the implementation of MSG adversely affected this project's aim to use the satellite's advanced capabilities to the advantage of SIMAR.. This meant that Meteosat 7 was the sole source of satellite data used to generate rainfall products. It is thus important that the characteristics of Meteosat 7 be discussed, analyzed and compared to those of MSG.

4.1 Meteosat Transition Programme (MTP=Meteosat 6&7)

The Meteosat Transition Programme (MTP) is the current programme responsible for the Meteosat system of geostationary meteorological satellites and consists of Meteosat 6 and 7. It was established to ensure the continuity of services between the end of the Meteosat Operational Programme (MOP) in 1995 and Meteosat Second Generation (MSG). MTP will in fact provide an overlap service with MSG by continuing with the current service until the end of 2005.

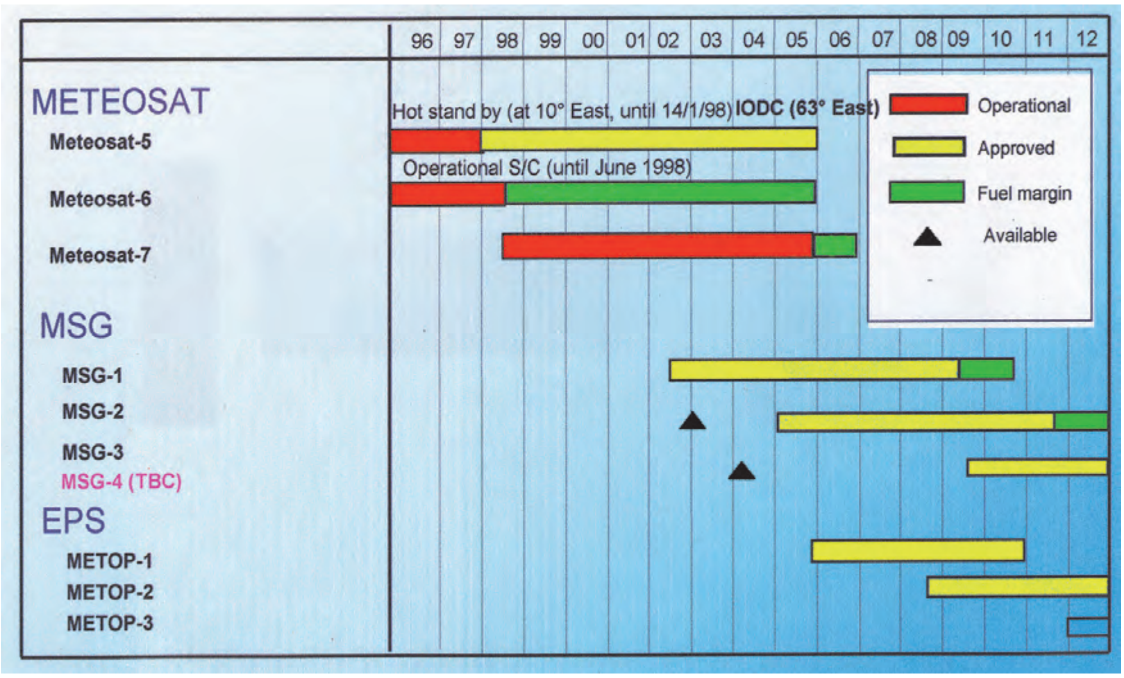


Figure 7 Schedule outlining the life expectancy of MTP satellites as well as the planned implementation of MSG and EUMETSAT's Polar Orbiting Programme.

The Meteosat system provides continuous and reliable meteorological observations from space to a large user community. Apart from images of the earth in three spectral channels (Visible, Infrared and Water Vapour) it also accommodates the transmission of processed meteorological products, data collected from data collection platforms and other meteorological information in graphical and text formats.

Meteosat 7 is the operational satellite located in geostationary orbit at 0^0 Latitude and 0^0 Longitude whilst Meteosat 6 acts as the hot standby system and is located at 0^0 Latitude and Longitude10^0 E. The Meteosat spin scan radiometer observes the earth in three spectral bands namely:

- Visible band (VIS)(0.5 – 0.9 µm): The visible image is composed of a 5000 x 5000 matrix of pixels relating to a spatial resolution of 2.5 x 2.5 km at the sub satellite point and is produced by radiation in the visible part of the electromagnetic spectrum being reflected from the earth to the sensitive radiometer on board the satellite. This band is used for scene analysis and has the disadvantage of only being useful during the daylight hours.
- Water Vapour band (WV)(5.7 – 7.1 µm): This spectral band is used to detect atmospheric water vapour content in the mid-tropospheric levels. The images are composed of a matrix of 2500 x 2500 pixels relating to a spatial resolution of 5 x 5 km at the sub-satellite point. Due to the increased need by users for VIS and IR images during the day time hours (06:00 – 18:00 UTC) placing an increased load on the data flow from the satellite, WV images are only available at 3-hourlyintervals. It is only during the off-peak times (18:30 to 05:30 UTC) that WV data are available at the same temporal frequency as IR data, namely every 30 minutes.
- Infrared band (IR)(10.5 – 12.5 µm): As with the WV images, images from the IR spectral band are also composed of a matrix of 2500 x 2500 pixels. The IR-band directly measures the intensity of radiation being emitted from the earth's surface and the clouds present in the troposphere. Since a high correlation exist between the radiant energy and the temperature of the object emitting the radiation, certain characteristics can be inferred from IR images. One such characteristic is the relationship between cloud top temperature and rainfall, which is being used in SIMAR and more elaborately described in Volume 2. IR images are available at a temporal frequency of 30 minutes and are unaffected by day or nighttime conditions.

Figure 8 shows a comparison between the MTP-range of satellites and MSG.

Meteosat Second Generation (MSG) **Meteosat First Generation (MTP)**

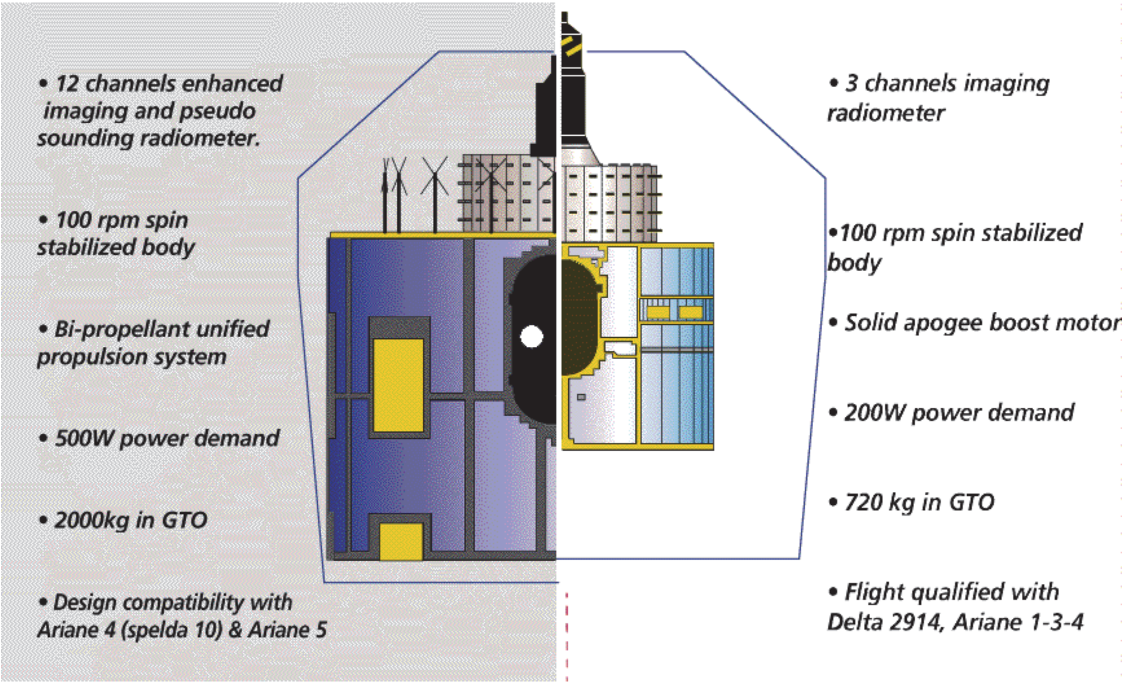


Figure 8 A comparison between the MTP-range of satellites and MSG, indicating the relative size difference as well as other characteristics.

4.2 Meteosat Second Generation Satellite (MSG)

The MSG satellite represents a significant leap in technology compared to its MTP predecessors (Meteosat 6 & 7). It will also be a geostationary satellite that, after its commissioning, will be centered on 0^0 Latitude and 0^0 Longitude. During the pre-commissioning phase, however, the satellite will be situated at 0^0 Latitude and Longitude 10^0 E. MSG will generate multi-spectral imagery of the earth's surface the cloud systems at double the current rate (every 15 minutes instead of 30 minutes) and for a much larger number of spectral channels (twelve compared to three for the current Meteosat). The geometrical resolution will also be improved to 1 km instead of the current 2.5 km on the Visible(VIS) channels and from 5 km to 3 km on the Infra Red (IR) channels. All the improvements will allow meteorologists to distinguish far better between the characteristics of different air masses and will result in improved imagery for utilisation in meteorology and various other applications that include hydrology, agriculture, environmental studies and disaster management. The main payload of the MSG satellite is the new improved radiometer called "The Spin Enhanced Visible and Infrared Imager" (SEVIRI) that has 12 spectral channels (Table 3).

Table 3 Overview of the 12 channels of the SEVIRI instrument located on MSG as well as their applications. It is worth noting that quite a number of these channels (wavelengths) correspond to those of the polar orbiting NOAA AVHRR instrument.

Channel No.	Channel Characteristics	Remarks / Applications
1	0.5 – 0.9 µm = HRV 0.7	High Resolution Visible channel (1km – resolution).
2	0.56 – 0.71 µm = VIS 0.6	VIS Window Channel used for Cloud detection, cloud tracking, aerosol, scene identification and land surface and vegetation monitoring. This channel corresponds to an AVHRR channel
3	0.74 – 0.88 µm = VIS 0.8	Same as above
4	1.50 – 1.78 µm = NIR 1.6	Near infra-red Window channel. Discriminates between snow and cloud, ice and water clouds and provides aerosol information
5	3.48 – 4.36 µm = IR 3.9	A Window channel able to discriminate sub-pixel effects such as fires and cirrus clouds. Applications include : Low cloud and Fog detection Heat island & fire detection Detection of thin cirrus over lower cloud layers Supports temperature measurements of land and sea surfaces at night and gives low level winds by low level cloud tracking. Also an AVHRR channel
6	5.35 – 7.15 µm = WV 6.2	A Water Vapour (WV) Absorption Channel mainly between the 300 – 600 HPa-level (Lower for dry atmospheric conditions). No depiction of characteristics in lower atmosphere or near ground. Detects High cloud such as Cb-Anvils and gives a clue to rain. Helps in the height allocation of semi-transparent clouds
7	6.85 – 7.85 µm = WV 7.3	Same as above but absorption by WV mainly between the 400 – 700 HPa levels (lower in dry atmosphere)
8	8.30 – 9.10 µm = IR 8.7	Window channel providing information on thin Cirrus clouds. Discriminates between ice & water-clouds
9	9.38 – 9.94 µm = IR 9.7	Ozone Detection – Tracks ozone patterns in lower stratosphere and can be utilized for wind detection at that levels. Absorption channel
10	9.8 – 11.8 µm = IR 10.8	Split window channel to measure ocean, land and cloud-top temperatures. Can also be used to detect

		cirrus and volcanic ash clouds. An AVHRR channel
11	11.0 – 13.0 µm = IR 12.0	Same as above
12	12.4 – 14.4 µm = IR 13.4	CO_2 – Absorption channel – provides height allocation of cirrus clouds and temperature information from the lower troposphere

Apart from the high spatial and temporal resolution images that will be broadcast via the High Rate Information Transfer (HRIT) system, other baseline products are also generated. These will be broadcast mainly via the Low Rate Information Transfer (LRIT) system,This facility is called the Meteorological Product Extraction Facility (MPEF). The products provided by the MPEF are listed in Table 4.

Table 4 List of products generated on a routine basis by the Meteosat Product Extraction Facility (MPEF)

Product	**Dissemination Frequency**	**Mode of Delivery**
Atmospheric Motion Vectors (AMV)	Hourly	GTS & LRIT
Cloud Analysis (CLA)	3-Hourly	GTS & LRIT
Cloud Analysis Image (CLAI)	3-Hourly	LRIT
Cloud Mask (CLM)	Hourly	LRIT
Clear Sky Radiance (CSR)	3-Hourly	GTS
Cloud Top Height (CTH)	3-Hourly	LRIT
Global Instability Index (GII)	As needed	LRIT
Tropospheric Humidity (TH)	Hourly	GTS
Calibration Monitoring (CAL)		LRIT
Climate Data Set (CDS)	Hourly	On demand
High Res Precip Index (HPI)	Daily	GPCP users only
ISCCP Data set (IDS)	5 per month	Only to ISCCP users
Total Ozone (TOZ)	3-Hourly	GTS
Foreign Satellite Data	3-Hourly	LRIT

Another service provided by EUMETSAT to Meteorological Services on the African continent, is the distribution of meteorological products via the Global Telecommunication System (GTS) and LRIT system, called the Meteorological Data

Dissemination Service (MDD). This service consists mainly of numerical products in the form of meteorological charts, especially adapted to the African continent.

Yet another specialised service provided by EUMETSAT to the different European member countries is the development of so called Satellite Application Facilities (SAFs). A SAF, in essence, is a centre of expertise consisting of institutions, usually European Meteorological Services, which collaborate with one another to develop higher level products and services and manage further research and development. Usually one institution plays the leading role in a particular SAF and acts as the focal point for the development of products and services. Data from MSG and the EUMETSAT Polar Satellite (EPS) are to be used in the development of higher level products.

Currently seven SAFs are under development, each covering a “theme” that addresses meteorology and other related sciences. The following table (Table 5) summarizes the different SAFs and the products that are under development. More information on the different SAFs and associated products are available on the EUMETSAT web-page as well as the individual SAF web-pages.

Table 5 Summary of the various Satellite Application Facilities (SAFs) and the products they will be generating. The lead institution is indicated in bold print. Note also that many of the products and software generated by the SAFs are only applicable to the European continent and adjacent regions. The first priority for Southern African institutions collaborating with established SAFs will be to make these products compatible for African and in particular Southern African conditions.

Name of SAF	**Participating Institutions**	**Products under Development**	**Remarks**
Now casting and Short Range Weather Forecasting (NWC-SAF)	**Spanish Met. Institute** Meteo-France Swedish Met Institute Austrian Met Institute	1. Cloud mask & cloud amount. 2.Cloud type 3.Precipitating clouds 4.Convective rainfall rate 5. Total precipitable water 6. Layer precipitable water. 7. Stability Analysis 8. High resolution wind vectors. 9. Automatic Sat Image interpretation. 10. Rapidly developing Thunder storms 11. Air mass Analysis	The NWC-SAF web-pages are located at : http://www.inm.es/wwg
Ocean & Sea Ice OSI-SAF	Met Services of :	1. Near surface wind vectors.	http://www.meteorologie.eu.org/safo

	France Norway Denmark Sweden Netherlands French Inst for Oceanography	2. Atlantic low and high latitude surface radiative fluxes. 3. Atlantic low and mid-latitude SST. 4. Merged Atlantic SST 5. Merged Atlantic surface radiative fluxes. 6.Regional SST 7. Atlantic sea ice edge 8. Atlantic sea ice cover 9. Atlantic sea ice type	Not all the products listed in the previous column are available for the southern and mid-Atlantic ocean such as 1, 6, 7, 8 and 9.
Ozone Monitoring SAF (Started in Oct 1997)	Met Services of : **Finland** Greece Germany Netherlands Denmark France Belgium	1.GOME-2 total ozone. 2. GOME-2 ozone profiles. 3. Aerosols. 4. HIRS total ozone. 5. Clear sky UV-fields	http://ozone.fmi.fi/o3group/o3saf.html
Climate Monitoring SAF (Started Dec 1998)	**German Met. Institute** Belgium Met Institute Finland Met Institute Netherlands Met Service Swedish Met Service	1. Cloud parameters. 2. Components of the surface radiation budget (SRB). 3. Components of the radiation budget at the top of the atmosphere. (TOA) 4. Ocean state parameters 5. Humidity composite product	http://dwd.de/research/saf
Numerical Weather Prediction (NWP-SAF)	**UK Met Office** Meteo-France Netherlands Met Service. ECMWF		The NWP-SAF differs from some of the other SAF's in that their work will be a programme of continuous software development with periodic releases of deliverables. http://www.met-office.gov.uk/sec5/NWP/NWPSAF

Land Surface Analysis SAF Started Sept 1999	**Portuguese Met. Institute.** Belgium Met. Service Meteo-France Greece Met Service German Met. Service Italian Met Service Spanish Met. Institute Swedish Met Institute	1.Surface albedo 2.Downward surface short-wave fluxes. 3. Land surface temp. 4. Downward surface long wave fluxes. 5. Snow cover 6. Evapo-transpiration. 7. Vegetation Index.	http://meteo.pt/landsaf
GRAS Meteorology SAF (Only for use with the EUMETSAT polar orbiting satellites)	**Danish Met. Institute** Spanish Met. Institute UK Met. Office	1.Refractivity profile. 2. Observation characteristics. 3. Temp profile. 4. Humidity profile. 5. Pressure profile.	Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS) This system utilizes the array of GPS satellites to determine variables listed in the previous column. I also give global coverage of these variables.

4.3 The PUMA Initiative and the role of the South African Weather Service

In order to assist 53 African countries to participate and share in the advantages promised by MSG, the European Commission has made available 11 Million Euro to supply ground receiver equipment, training and application support for using the data for a multitude of purposes. This initiative is called the Planned Utilization of MSG in Africa Project (PUMA). A Trust Fund set up under the auspices of the World Meteorological Organization (WMO) will enable countries like South Africa and North African countries (Algeria, Egypt, Libya, Morocco and Tunisia) which are not signatories of the Lomé Convention and were therefore not part of the original PUMA initiative, to also participate in PUMA, thus giving it a continental dimension.

The PUMA project is managed by a Delegated Regional Authorising Officer (DRAO), currently the Director of the Kenyan Meteorological Department (KMD). He is assisted by the Project Management Unit (PMU) that runs the day-to-day activities of the project.

The PUMA project, also called the Meteorological Transition in Africa Project (MTAP) is based on three pillars:

- The replacement of old Meteosat 6&7 receiver equipment with new MSG ground equipment in every African country.
- The training of both technical and scientific staff at all the National Meteorological Services (NMS) on the African continent
- The dissemination of MSG data to more users outside the sphere of meteorology (Outlook Activities).

4.3.1 Supply of Ground Receiver Equipment

Ground receiver equipment to assure the continuous direct reception of MSG data from the satellite at all the African NMSs. This exercise is by far the most daunting and costliest part of the MTAP initiative. In order to ensure standardization of equipment, only one supplier of ground receiver equipment was chosen, namely Alcatel of France.

The ground station rollout plan envisaged the establishment of 6 test centres where ground equipment will be installed for testing during the commissioning phase of the satellite. South Africa has been added to the list as a seventh test centre for MSG ground equipment evaluation.

4.3.2 The Training Activities

In order to train individuals of all the African NMSs, an elaborate training programme is envisaged as part of the MTAP initiative. Scientific as well as technical training is needed to help NMSs to interpret and effectively utilise the improved capabilities of MSG as well as be able to perform maintenance on the receiver equipment. Currently only two training centres, Nairobi-Kenya and Niamey-Niger, exist, where Anglo-phone and Franco-phone teaching, respectively, are accommodated.. It is evident that in order for MTAP training to be successful, more training centres need to be established.

The SA Weather Service was identified as such an additional training facility and negotiations are under way to formalise the establishment thereof with the signing of a Memorandum of Agreement (MOA). The advantage for South Africa will be that individuals from the SAWS will receive in-depth training on the scientific as well as technical aspects of MSG and the ground equipment, to enable them to train personnel from other SADC NMSs.

4.3.3 The Outlook Activities

The Outlook Activity initiative was designed to ensure that the transition from MTP to MSG occurs without the interruption of services to the African NMSs and to ensure and develop a wider community of meteorological satellite data users to more effectively utilise the improved capabilities of MSG.

The process followed to achieve the above objectives, was to invite African countries to submit pilot project proposals that are in accordance with strict guidelines laid down by the PMU. On behalf of South Africa, the SAWS (as lead agency), in collaboration with various other institutions, submitted such a proposal and currently still awaits the outcome.

It is clear that South Africa, and specifically the SA Weather Service, has an important role to fulfill in matters related to MSG, not only from a national perspective, but also for the benefit of the region as a whole.

5.0 NATIONAL PRECIPITATION DATABASE

5.1 The Weather Service's Climate Data Base

As custodian of the country's climate data, the SAWS has a very important role to fulfill in providing clients with accurate and reliable meteorological data. Coinciding with the SIMAR programme, the development of a Climate Database was one of the major projects to be undertaken at the SAWS since 2000. With the aid of Norwegian donor funding, the project was initiated with the purchase of the necessary hard and software and has progressed through different phases of implementation.

The development is currently still in progress, but already superior data retrieval procedures are in place. This is of huge benefit to SIMAR, which requires precipitation data on a real-time (24-hourly) basis. The following table (Table 6) gives a brief overview of the implementation schedule and current status of the new database.

Table 6 Schedule for SAWS Climate Data Base development

DESCRIPTION	STATUS
PHASE I:	
Database Design Phase	Completed May 2001
Purchase of H/W & S/W	Completed July 2001
Training Phase	Completed December 2001
Development Phase	Completed December 2001
Quality Control and data extraction procedure development	Ongoing
Implementation & Commissioning	Completed March 2002
PHASE II:	
1-Incorporation of Upper Air Data 2-Transfer of historical data to new database. 3-Installation of Quality Check routines for AWS data. 4- Extraction applications – Improve	Completed December 2002 Completed Completed Ongoing

current applications and develop new ones. 5- Training of staff	 Ongoing
PHASE III:	
1- Adapt database to contain specialized meteorological data: GAW-data Radar & Satellite data Model data GTS-data	No Progress
PHASE IV:	
1- Data capturing and quality control at Regional Offices. 2- Investigation of data from non-SAWS data sources: CCWR National Disaster Management Centre SA Data Centre for Oceanography Agricultural Research Council	Ongoing No Progress

The SAWS database serves as the main source of surface-based precipitation data for the needs of the SIMAR programme. Until the completion of Phases III & IV, the unconventional data sources, e.g. 24 hourly rainfall data from non-SAWS sources, will be sourced on an ad hoc basis by METSYS for application in the context of procedures and algorithms used to create the SIMAR products.

5.2 The Real-Time Precipitation Database

For the purpose of creating SIMAR products, METSYS extracts the real-time precipitation data (24 hourly raingauge data) from the main database and transforms it into MDV-format to be compatible with the remotely sensed data (radar and satellite). METSYS also maintains the radar and satellite rainfall data base. These are all archived in MDV-format. A description of MDV-format data is given in Volume 2.

Merging of the data to create the SIMAR products (Volume 2) is then performed using techniques, the development of which are reported on in Volume 3. The result is a specialised database containing real-time data which meet the objectives of SIMAR and can be used to generate SIMAR products on a 24-hour temporal resolution. This represents a huge step forward for flood warning and disaster mitigation purposes.

The database containing the three data sources became operational in August 2002 and is still in its infancy with regard its utilisation by users outside of SIMAR. There is expected to be a close and beneficial interconnection between the quantity and quality of data in the database, the use of the data and feedback received from users .

6.0 CAPACITY BUILDING

The capacity building programme related to this project came in full swing during 2001. Six data technologists, of whom four are from the previously disadvantaged group, were appointed at METSYS towards the end of 2000 and started their training with an extensive in-house programme focused on the maintenance of radars. A procedure was put in place whereby a trainee would be accompanied by an experienced technologist when attending to a malfunctioning radar, thereby enabling him to gain hands-on experience while being mentored by his senior. This procedure allowed for effective training and information exchange coupled with solving of problems encountered in real-life situations. Radar training manuals were also compiled and arrangements made for technologists to undergo refresher training courses on radar systems. In addition to the in-house training programme, the technologists have also been subjected to specialised factory training conducted by the manufacturers of the radar test and calibration equipment.

The same procedure as above has been followed with regards to the AWS network of the SAWS, which is currently the prime source of surface based real-time data. Supplying SADC countries with AWS instruments will also include a comprehensive training component. Apart from the training individuals receive on maintaining the instruments, they are also exposed to the design and assembly of the system from scratch through to the installation in the field. This in-depth exposure is regarded as essential, especially to enable personnel from neighboring countries to effectively manage their own network and ensure data quality and continuity. With the envisaged expansion of the AWS network in the Eastern Cape, which will include training of individuals as volunteer observers, some members of the community will also be assured of a basic income for the services they render to the SAWS. This programme will not be limited only to the Eastern Cape, since a strategy has been adopted within the SAWS to expand this initiative emanating from SIMAR to all SAWS second and third order observation stations throughout South Africa in the next 3 years.

METSYS, within its scientific ranks, has made provision for the appointment of four candidates, two of whom have already been appointed, to undergo training in the combined field of remote sensing technology (radar and satellite) and Geographical Information Systems (GIS). Numerous students at tertiary institutions have been exposed to remote-sensing training lectures presented by members of METSYS. The student complement included individuals from Tanzania and Botswana, giving an international character to the training provided. Meteorology students from Pretoria University have regularly visited METSYS for vacation work and been exposed to radar and satellite remote sensing with the intention to stimulate some to pursue a career in this direction

With the deployment of a weather radar in Umtata, a whole range of opportunities to expose local school learners to the latest technologies will arise. The availability of radar data will also present uniqe opportunities for research and training at the University of Fort Hare, which supports a strong GIS department. It is planned to cement this cooperation with Fort Hare by creating a direct link between the radar and the University, enabling the institution to obtain real-time data for training and research purposes

7.0 SUMMARY OF ACHIEVEMENTS AND CONCLUSIONS.

The infrastructure upgrading and maintenance component of the SIMAR project provided the scientists and engineers of the METSYS group of the South African Weather Service with a major challenge. Consideration of the original aims of this component against the milestones achieved, brings the following to light:

Aim1: *Maintain automated surface gauge networks (Durban and Liebenbergsvlei) as well as investigate the application of new technology to ensure real time availability of data.*

The raingauges of the Liebenbergsvlei and Durban networks played a vital role in the investigations of eliminating ground clutter and other radar phenomena as reported in Volume 2. The investigation into the feasibility of using cell phone communication infrastructure resulted in the technology being implemented in the Liebenbergsvlei and Durban networks with a vision to also implement the technology at all the SA Weather Service second order stations.

Aim2: *Maintain and upgrade the National Weather Radar Network by improving the monitoring capabilities at each radar system, investigating the possible expansion of the network coverage and pursuing an improved funding base for the radar network.*

The National Weather Radar Network(NWRN) remained the cornerstone of development and upgrading during the course of this project. Vast improvements and upgrades were implemented at the majority of radars within the network in ensuring a reliable power supply to the systems. A remote control and monitoring system whereby the functioning of individual radar systems could be monitored from a central point has been implemented. This kind of information was available for the first time allowing objective evaluation the reliability of individual radar systems within the NWRN. The SAWS during the course of this project drastically increased its funding for maintenance and upgrading purposes on the NWRN.

Aim 3: *Utilise the latest remote sensing technology in order to improve the quality of products to be generated.*

The promise of Meteosat Second Generation becoming operational during the SIMAR project's lifetime, led to numerous disappointments as the MSG programme suffered lengthy delays and problems after its launch. This resulted in the satellite only now becoming operational in 2004. In spite of the disappointments research continued in utilizing Meteosat 7 to fulfill the SIMAR project's objectives. New techniques were developed which can be applied to MSG when it eventually becomes operational. This aspect of the SIMAR project was not in the project teams sphere of influence

Aim 4: *In cooperation with other stakeholders, assist in establishing a real time precipitation database for South / southern Africa.*

Close cooperation with the South African Weather Service database developers led to the inclusion of real-time data, such as generated by the SIMAR project to be considered for archiving purposes. The new database has developed through different phases and will continue to develop to include SIMAR data for routine and research purposes.

Aim 6: *Actively seek and promote collaboration with stakeholders, institutions and organisations, on a formal and informal basis, to expand and enhance surface coverage of precipitation measurements.*

The SIMAR project did manage to promote cooperation between institutions albeit on a very small scale and limited to operational exchange of data e.g. the collaboration with DWAF and Suidwes Agriculture. It is however the cooperation between other large institutions such as the ARC that were seeked but the project failed to achieve. This objective of institutional collaboration will not end with SIMAR but will be carried on and expanded.

Aim 7: *Equip and train individuals, especially those from the previously disadvantaged communities, with a view to their acquisition of remote sensing and electronic maintenance skills.*

The training of personnel in the maintenance and upgrading of observational systems received high priority in the SIMAR project. Four individuals from the previously disadvantaged groups were trained in maintaining the electronic observational infrastructure thus ensuring the long term sustainability of the observing systems. Training was conducted in-house, through courses as well as self development. The training initiative was also expanded to the international arena with training on SIMAR related subjects presented to students from other African countries such as Botswana and Tanzania. As SIMAR products are used routinely by institutions, training will continue well beyond the lifetime of this project. It is especially training in the utilization and interpretation of SIMAR products where a strong need exists. Users should also be trained and educated in the use of remotely sensed data, its advantages as well as its limitations.

From the above it is clear that the majority of the objectives were achieved, some to a lesser extent than others. It is evident that much more work is required on the issues related to aim 6 as it deals with institutional willingness to collaborate and share information. It will need the involvement of all parties and stakeholders to agree on a strategy on the sharing of meteorological data. The process should occur at institutional level and be formalized through Memorandums Of Understanding or other binding means.

Aim 3 related to the improved prospects of an operational MSG satellite will still be explored beyond the SIMAR project making it possible for users of SIMAR products to reap the benefits albeit at a later stage. It should however be feasible for any institution utilizing remotely sensed data to obtain it free of charge without any restriction or accessibility issues. This can only occur if government sponsors the necessary infrastructure to obtain remotely sensed data from an array of platforms to be utilized for research and training purposes. A concerted effort by satellite remote sensing users, organised in a united front is suggested to enter into negotiations with government in the provision of the basic infrastructure.

8.0 REFERENCES.

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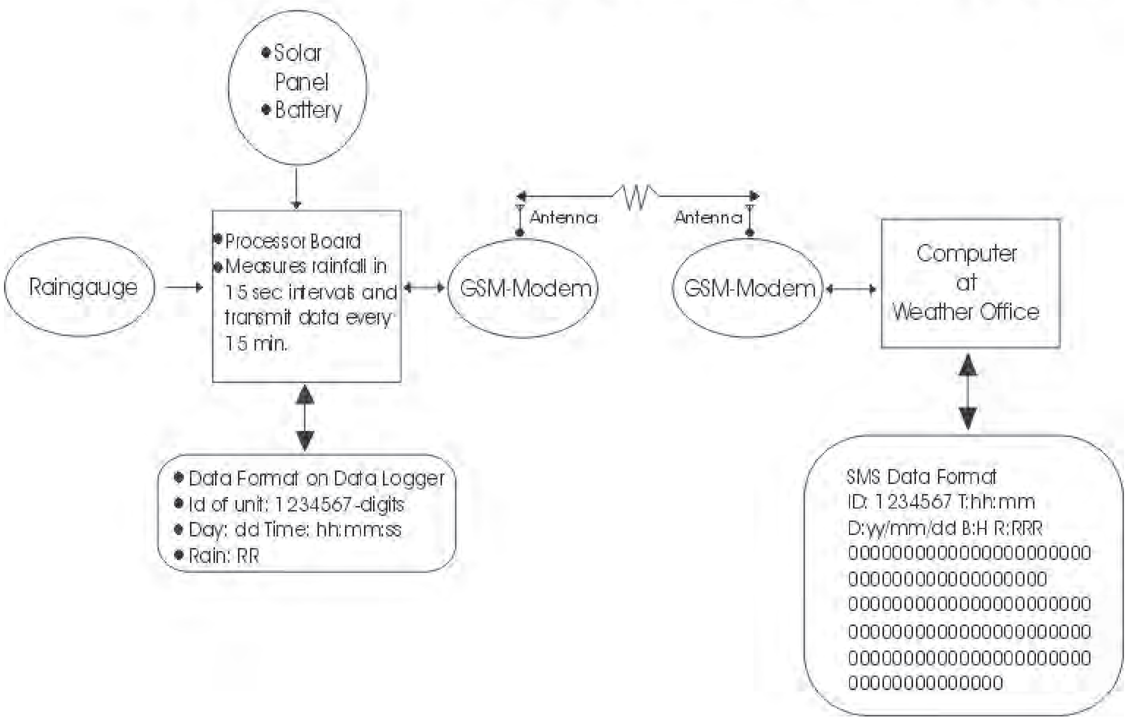
Mather G.K., Terblanche D.E., Steffens F.E., 1997: National Precipitation Research Programme: Final Report for the period 1993-1996, 147 pp, WRC Report No. 726/1/97, Pretoria, South Africa.

Terblanche D.E., Visser P.J.M., Mittermaier M.P., Kroese N.J., 2001: VIPOS: Vaal Dam Integrated Precipitation Observing System, 91 pp, WRC Report No. 954/1/01, Pretoria, South Africa.

9.0 APPENDICES

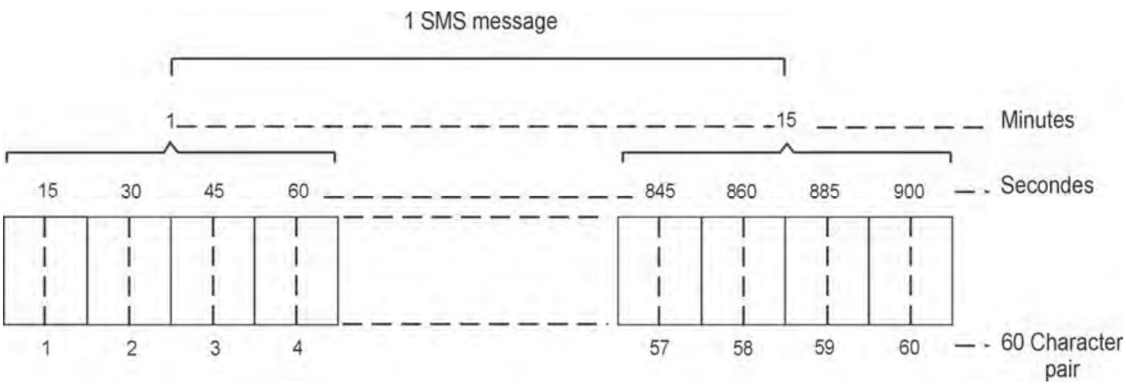
Appendix A: Schematic diagram of real-time raingauges



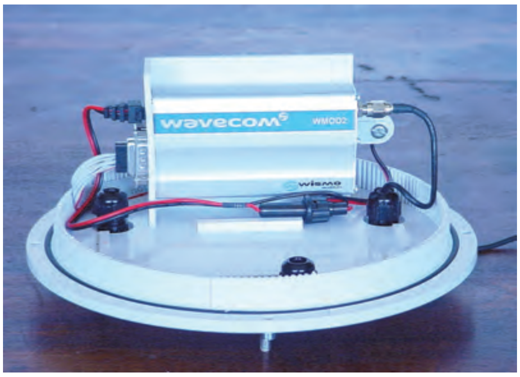
The schematic diagram above depicts the real-time reporting rainfall network system of operation. Real-time data is to be communicated using the SMS-facility (Short Message Service) on cell phones to a computer linked GSM-Modem located typically at Bethlehem or Durban Weather Offices from where it will be forwarded to the central database in Pretoria. The SMS data format allows only 160 characters per message, limiting the data capturing resolution to 15 seconds. Once rainfall is detected data capturing will commence in 15 second intervals and a SMS-message will be transmitted every 15 minutes during the rainfall event.

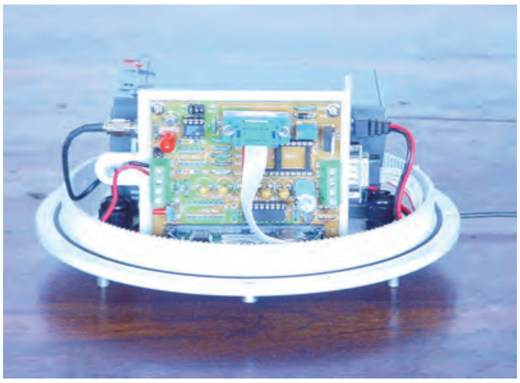
The SMS data format depicted in the schematic diagram is utilized as follows:

Character Amount	**REMARKS**
40 Characters – Used for Header	ID = 11 Characters Time = 7 Characters Date = 10 Characters Battery Status = 3 Characters Rainfall Total = 5 Characters Spacing = 4 Characters
120 Characters – Used for Rainfall Reporting	Rainfall reporting utilizes the remaining 120 characters depicted as 60 pairs of zero's. Depending on the 15 second interval that rainfall was detected, one can determine the exact time within the 15 minute reporting interval that rainfall was measured.
Total = 160 Characters	



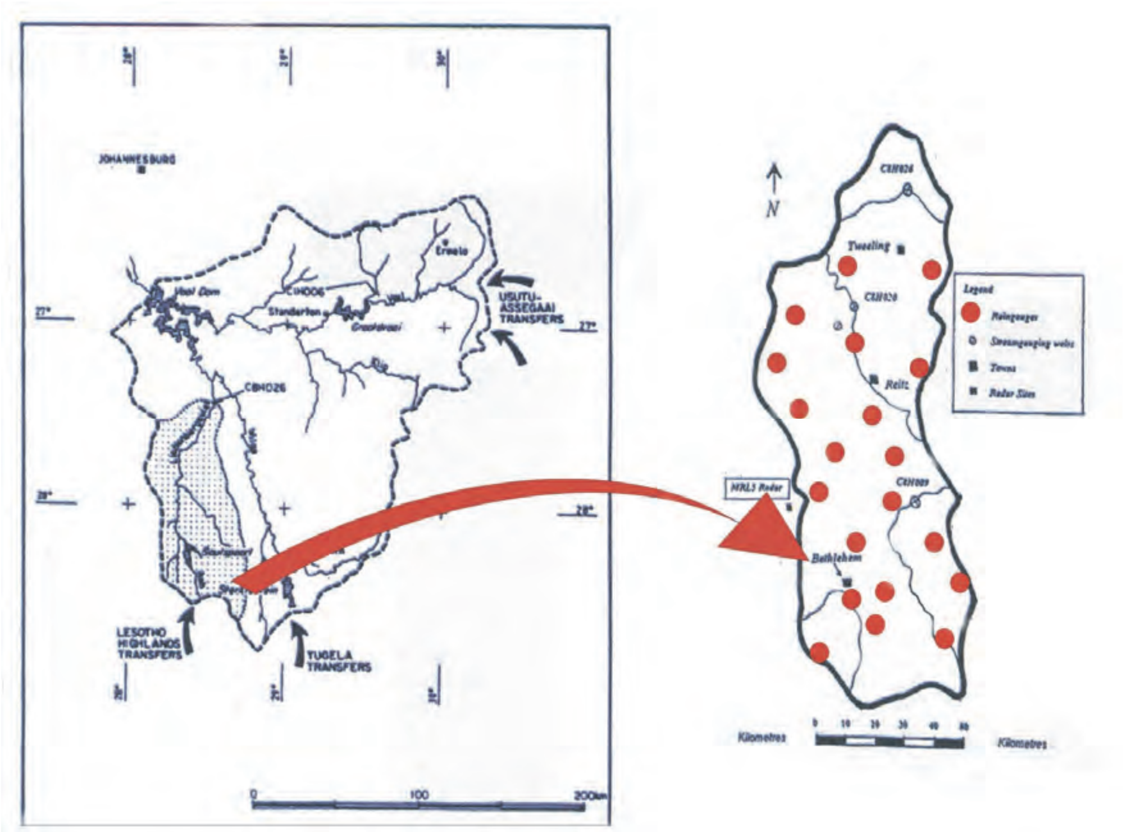
A SMS message is constructed of the header (40 characters) that contains data on the station Id, date, time etc. whilst the rainfall data is contained in the next 120 characters (60 character pairs). Depending on the location within the 60 character pairs, one is able to determine the time, to the nearest 15 seconds, when rainfall occurred within a 15 minute interval. The SMS message is constructed and transmitted every 15 minutes to the weather office where the data is archived on the database.





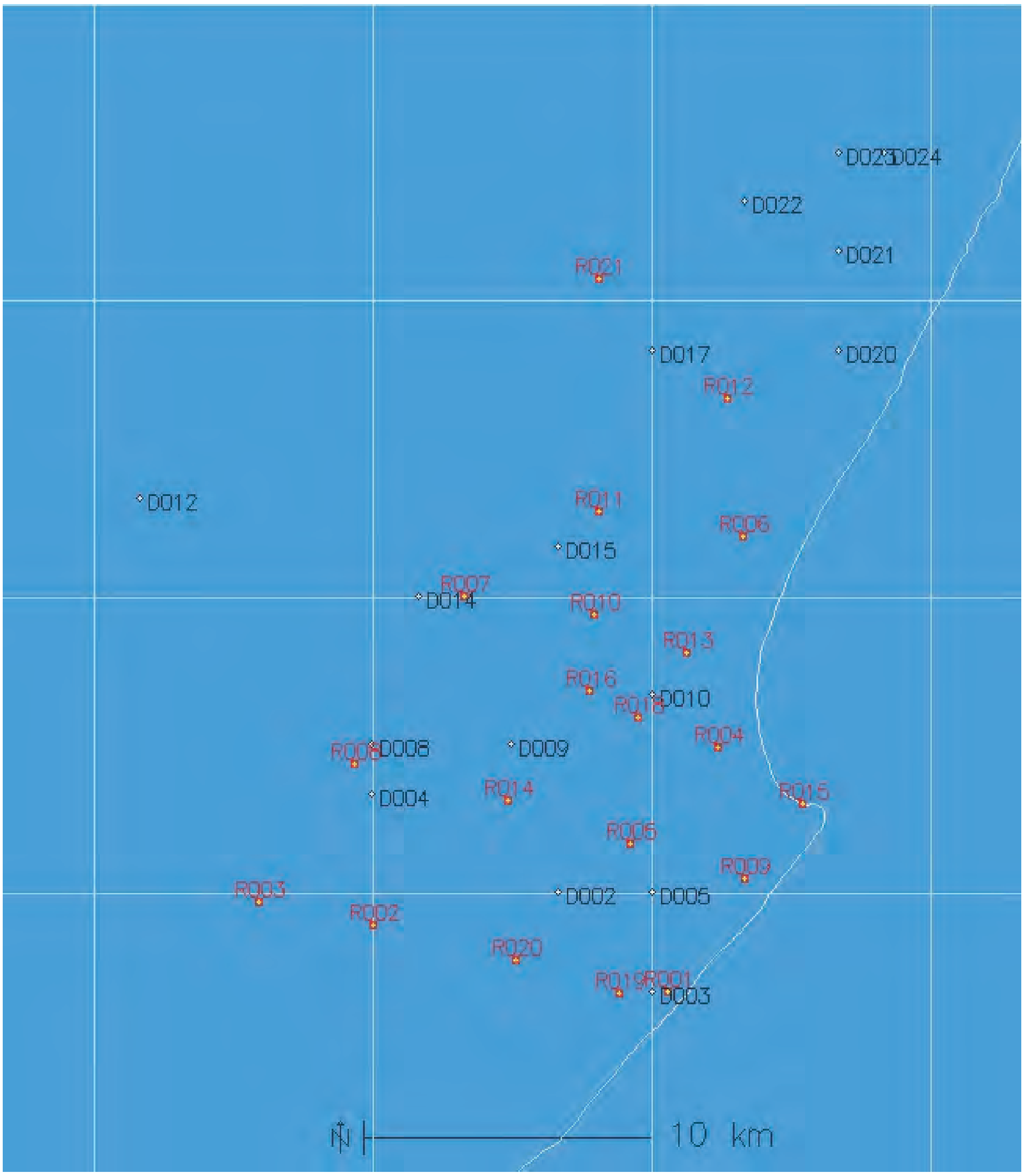
Images of the cell phone modem, electronic component board and the complete raingauge installation respectively.

APPENDIX B: Map of the Liebenbergsvlei River Raingauge Network



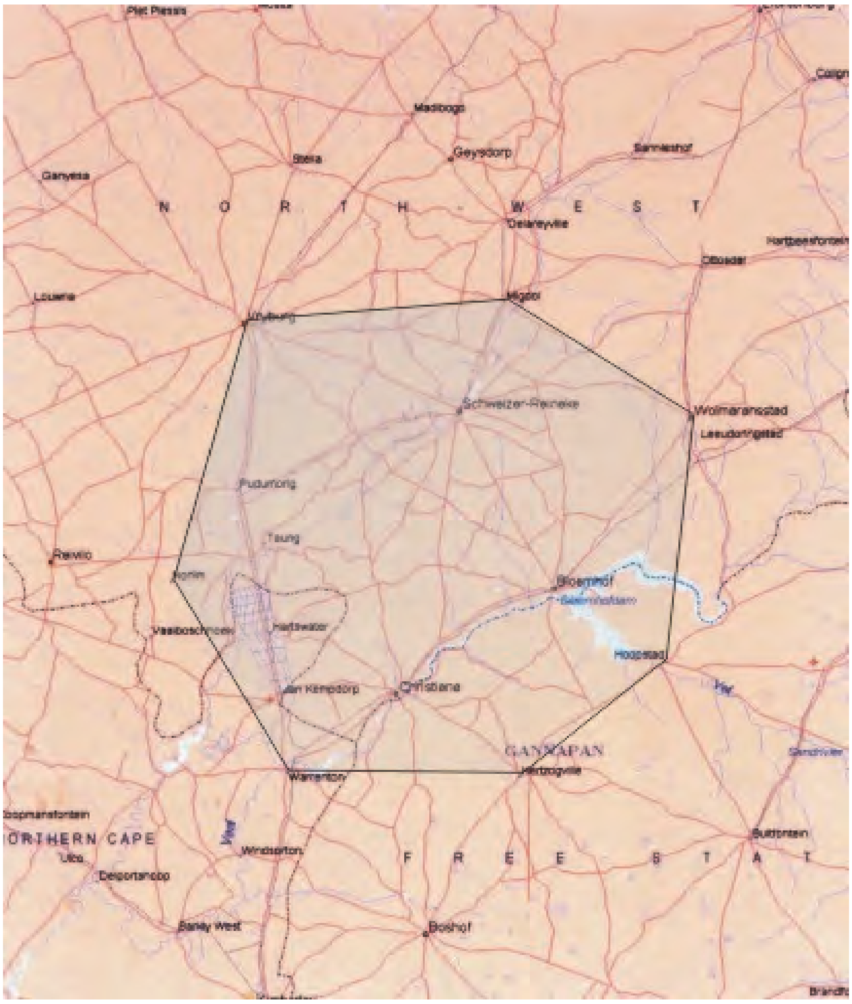
Map of the Vaal Dam catchment indicating the relative location of the Liebenbergsvlei River sub-catchment. Also indicated are individual raingauges in the network that are equipped with cell phone technology to facilitate real-time communication of data.

APPENDIX C:



This figure depicts a map of the Durban Metropolitan area with only the raingauge networks of the SAWS (black) and Durban Metro (red) indicated on it. Cooperation between these institutions in future to plan possible expansion of these networks will benefit both.

APPENDIX D:



This map depicts the area serviced by Suidwes Agriculture with 80 raingauges within the area reporting rainfall on a daily basis. No radar coverage currently exists over this area elevating the importance of this data for SIMAR product generation purposes.

APPENDIX E:

Map of Zimbabwe indicating the location of the four French meteorological radars located at Harare, Victoria Falls, Bulawayo and Chiredzi respectively.

APPENDIX F: **MAP OF RADAR COVERAGE PROVIDED BY THE ENVISAGED SOUTHERN AFRICAN RADAR NETWORK.**

Map indicating the radar network envisaged for Southern Africa. Also shown is an indication of the radar coverage from the Gaborone radar in Botswana as well as the two radars in Mozambique (Xai-Xai and Beira).