OPTIMISING THE USE OF UPDATED AND ADDITIONAL PRODUCTS FROM THE NOWCASTING SATELLITE APPLICATION FACILITY

Report to the

Water Research Commission

by

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EXECUTIVE SUMMARY

Background

Nowcasting is the science of anticipating ordinary and severe weather events in the next few hours. Severe weather events can include heavy rainfall, strong wind, hail and/or tornadoes. Various sectors of society need to be able to prepare for these events when they occur. The issuing of weather-related warnings for such events in South Africa is the mandate of the South African Weather Service (SAWS).

In an ideal world, radar systems provide the most useful information about the intensity, movement and characteristics of severe weather events, but these data sources are expensive to obtain and require extensive maintenance. Even in South Africa, radar systems do not provide coverage of the entire country and this leaves gaps between radars. In other southern African countries, very few operational radar systems exist. Despite the shortcomings in data resources, all meteorological centres still have to warn the public of pending severe weather events. The geostationary Meteosat Second Generation (MSG) satellite provides data coverage over all African countries. The operational use of satellite data as a possible solution for nowcasting of severe weather events in data-sparse regions is increasingly being considered by satellite users.

In order to optimise the use of satellite data, different centres were established in the European region to develop derived products for different purposes, including nowcasting. The Nowcasting Satellite Application Facility (NWC SAF) developed various tools, which can be very useful for nowcasting severe weather events. One of the products, developed within the NWC SAF framework by Météo-France, is called the Rapidly Developing Thunderstorms (RDT) product; another product is the Convective Rainfall Rate (CRR). The aim of the RDT product is to use data from satellite and a numerical weather prediction model to identify and track the more intense parts of thunderstorms. The CRR product gives an estimation of convective rainfall rates. The software to generate this product can be downloaded from NWC SAF (http://www.nwcsaf.org/HD/MainNS.jsp) by any user.

The aims of this Water Research Commission (WRC) funded project was to:

- Test the 2012 version (v2012) of the software against the 2013 version (v2013).
- Test the effect of including lightning data into the RDT and CRR products.
- Verify this against observational data over South Africa.

Methodology

The NWC SAF software uses satellite data from the MSG satellite. European countries that use the RDT product mostly use data from the European Centre for Medium-range Weather Forecasts model as input to the product. In South Africa, the software had to be adjusted to use the local version of the United Kingdom Meteorological Office Unified Model (UM). This model is run once a day in South Africa, using a 12 km horizontal resolution and 38 vertical levels. The UM provides hourly output for up to 48 hours ahead. Satellite data from the MSG is readily available every 15 minutes.

Since 2014, v2013 of the NWC SAF software has been installed and operationally available on a server at SAWS. Several case studies were used to compare the quality of the RDT and CRR products in the older v2012 of the software to the newer v2013. The RDT was validated against the occurrence of lightning data from the South African Lightning Detection Network, and the CRR against daily rainfall totals from rain gauges over South Africa.

The effects of including lightning data as auxiliary data into the NWC SAF software was also tested. This was achieved by comparing the RDT with and without lightning data added to the software against radar data over South Africa. The inclusion of lightning data into the calculations of the CRR product was evaluated against daily rainfall totals from rain gauges over South Africa

Results

The results of 25 case studies over the South African domain were used to determine whether the v2012 of the RDT and CRR software could identify the more intense part of thunderstorms and give an accurate estimation of precipitation, respectively. The results indicated that the RDT product compared well with the lightning data and that the newer v2013 of the software performed similarly to the older v2012 of the software with indications of slight improvements in most cases. The results of the 20 cases over South Africa to validate the CRR product showed indications that the newer v2013 of the software improved the statistics slightly, but not significantly.

Including lightning data in the input data set for RDT and CRR showed indications from the case studies that this had a positive effect on the RDT product, but that the intensity of rainfall rates in the CRR was affected negatively. The RDT was validated against radar reflectivity data with a 35 dBZ threshold. The Heidke Skill Score showed that there was an improvement of about 5% in the performance of the RDT when lightning data was included in the input data set. Lightning as auxiliary data into the CRR product had very little effect on the performance of the product.

Discussion and conclusion

The v2012 and v2013 of the RDT and CRR products were compared to see if there were differences between the two products. The RDT was validated against lightning data while the CRR was evaluated against daily rainfall totals from rain gauges. In most cases, the RDT v2013 performed similarly to the RDT v2012. All 25 cases showed signs of slight improvements in the product. Small changes could be seen when images for individual times were compared (v2012 to v2013), but in general, the results showed a slight improvement due to the minor updates in the latest version of the software. For the CRR product, most cases showed that the v2013 was very similar or slightly better than the v2012. The CRR v2013 overestimated the intensity of rainfall, more so than v2012. Small changes could be seen when images for individual days were compared (v2012 to v2013), but in general the results were very similar.

Lightning data over South Africa was included into the RDT and CRR software. The RDT with and without lightning data included in the input data set over South Africa was evaluated against radar data. In most cases, the RDT with lightning data added showed signs of a slight improvement of about 5% in performance compared to the RDT when no lightning data was added. In many cases, the inclusion of lightning data in the input data set identified storms that were not at first identified when lightning was not added. The CRR product, with and without lightning data as input over South Africa, was compared using the daily rainfall totals from the rain gauges as ground truth. In most cases, the CRR with lightning data was very similar or slightly better than the CRR without lightning data, but overestimated the intensity of the rainfall, more so than when lightning data was not included.

Several occasions were used to demonstrate the RDT and CRR products to operational forecasters in South Africa as well as in the southern African region through workshops as well as the annual Severe Weather Forecasting Demonstration Project training events. Positive feedback has already been received about this new nowcasting tool. Other African countries have expressed the need to share in the output of the RDT product.

The 2013 version of the NWC software was made operational at the SAWS during the second half of 2014. The data is archived on a server at SAWS. The RDT images are available on a website to forecasters in South Africa, but also on the Regional Specialised Meteorological Centre website for forecasters from our neighbouring countries. Satellite-based nowcasting tools such as the RDT product can be very useful to identify and track the more intense parts of thunderstorms in data-sparse regions.

Recommendations

The results of the RDT and CRR case studies conducted are very encouraging. Several options exist for future work:

- Include the new high-resolution UM model in the NWC SAF software.
- Install the new 2016 version of the NWC SAF software that was released at the end of 2016 at SAWS.
- Use satellite and lightning data from the new Meteosat Third Generation (MTG) satellite with lightning imager, which will be launched in 2019/20, in the processing of NWC SAF software.
- Evaluate the RDT and CRR products over a longer period (preferably over all the seasons).
- Use some of the other NWC SAF products, such as satellite-based instability indices and wind fields.
- Create a new rainfall rate relationship to lightning occurrence for South Africa, which can improve the CRR rainfall rates.

This project highlights the importance of using satellite data (together with numerical weather prediction and lightning information where available) to provide forecasters and various industries with valuable information on intense and rapidly developing thunderstorms. This work is especially applicable to data-sparse regions where very little observational data, such as radar data, is available. The geostationary MSG satellite provides data coverage over all African countries. Products derived from satellite information, such as the RDT and CRR, could provide these data-sparse regions with an excellent second option for nowcasting purposes in order to save lives and prevent damage to property.

The project team is optimistic about all the new possibilities that exist to use, improve and validate the NWC SAF products. The new MTG geostationary satellite will be launched in 2019 or 2020. This satellite will offer additional channels as well as an improved temporal resolution (10 minutes). The satellite will also carry a lightning imager on board, which will provide very useful lightning observations over the entire African continent.

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ABBREVIATIONS

ARS	–	Automatic Rainfall Station
AvRDP	–	Aviation Research Demonstration Project
BUFR	–	Binary Universal Form for the Representation of Meteorological Data
CC	–	Cloud-to-cloud
CG	–	Cloud-to-ground
CRR	–	Convective Rainfall Rate
CSI	–	Critical Success Index
ETS	–	Equitable Threat Score
EUMETSAT	–	European Organization for the Exploitation of Meteorological Satellites
FARatio	–	False Alarm Ratio
FARate	–	False Alarm Rate
HKS	–	Hanssen–Kuipers Score
HSS	–	Heidke Skill Score
IC	–	Intra-cloud
IPWG	–	International Precipitation Working Group
IR	–	Infrared
KZN	–	KwaZulu-Natal
MAE	–	Mean Absolute Error
ME	–	Mean Error
MSG	–	Meteosat Second Generation
MTG	–	Meteosat Third Generation
NOAA	–	National Oceanic and Atmospheric Administration
NWC SAF	–	Nowcasting Satellite Application Facility
NWP	–	Numerical Weather Prediction
POD	–	Probability of Detection
RDT	–	Rapid Development Thunderstorms
RMSE	–	Root Mean Square Error
RR	–	Rainfall Rate
RSMC	–	Regional Specialised Meteorological Centre
SADC	–	Southern African Development Community
SAF	–	Satellite Application Facility
SALDN	–	South African Lightning Detection Network
SASAS	–	South African Society for Atmospheric Scientists
SAST	–	South African Standard Time
SAWS	–	South African Weather Service
SWFDP	–	Severe Weather Forecasting Demonstration Project
TS	–	Threat Score
UKMO	–	Unite Kingdom Meteorological Office
UM	–	Unified Model
UTC	–	Coordinated Universal Time
VIS	–	Visible
v2012	–	Version 2012
v2013	–	Version 2013
WMO	–	World Meteorological Organization
WRC	–	Water Research Commission
WV	–	Water Vapour

CHAPTER 1. BACKGROUND

1.1 Rationale of the Study

Nowcasting “comprises the detailed description of the current weather along with forecasts obtained by extrapolating for a period of 0–6 hours ahead” (WMO, n.d.). The latest radar, satellite and observational data are powerful tools when operational forecasters have to warn the public of hazardous, high-impact weather such as thunderstorms, tornadoes, lightning strikes and destructive winds. Effective and accurate nowcasting contributes to reducing fatalities, injuries and damage to property, as well as improving efficiency for various industries including transport and agriculture. Nowcasting also plays a key role in aviation weather forecasts – both at the terminal as well as in the *en route* environment.

Ideally, radar systems are the most important part of nowcasting; however, many developing countries and even more so, least developed countries do not have operational radar systems at all. Some countries, which are fortunate enough to have radar systems, are struggling to maintain these powerful data sources. Geostationary satellite data, from Meteosat Second Generation (MSG) in the case of African countries, provide real-time coverage of the entire African continent. It currently updates every 15 minutes and has a resolution of 3 km for most of the 12 channels. The use of MSG data in combination with input from local numerical weather prediction (NWP) models can be an excellent second option for nowcasting purposes in areas that are not covered by radar data or where no radar systems are available (De Coning, 2013a).

Satellite application facilities (SAFs) are dedicated centres for processing satellite data for different purposes by using specialist expertise from the European Union Member States. *The Agreement of Co-operation of a Satellite Application Facility on Support to Nowcasting and Very Short-Range Forecasting* was signed by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the Institute for National Meteorology in Spain in December 1996. The project aims to produce software to deal with nowcasting and very short-range forecasting using the characteristics of the MSG, the National Oceanic and Atmospheric Administration (NOAA) and other satellite data from polar-orbiting satellites (EUMETSAT, n.d.).

One of the SAFs developed is called the Nowcasting SAF (NWC SAF). The NWC SAF has developed various products for the purpose of nowcasting. Two of these products are the Rapidly Developing Thunderstorms (RDT) and the Convective Rainfall Rate (CRR) products. The RDT product provides information on significant and developing convective systems, which can be a useful tool for meteorological and aviation forecasters. The CRR product provides information on the location and intensity of convective and the associated stratiform rainfall. The software is continuously improved and updated and new versions with updated products are released regularly.

This research project aims to:

- Evaluate the newer version of the NWC SAF software (v2013) against the older version (v2012) for the RDT (which was used and tested in K5/2235, 2015) and CRR products.
- Add lightning data into the system for the calculation of both RDT and CRR products.

1.2 Definition of the RDT Product

One of the products developed by the NWC SAF is the so-called RDT product. It mainly uses geostationary MSG satellite data and provides information on clouds related to significant convective systems, from mesoscale down to smaller scales (< 1 km) (NWC SAF Documentation, 2013b).

The objectives of RDT are to:

- Identify, monitor and track intense convective system clouds.
- Detect rapidly developing convective cells.

RDT is one of the various satellite- and NWP-based applications that can be extremely useful in data-sparse countries. An objective validation of the RDT (using the 2011 version of the software) was conducted over Europe from April 2008 to October 2009 (northern hemisphere summer). Lightning activity over the European region was used as ground truth. The overall probability of detection (POD) was found to be 74%, the probability of false detection 2%, the false alarm ratio (FARatio) 22% and the threat score (TS) 61%. The conclusion of the validation report states: "RDT provides an accurate depiction of convective phenomena, from triggering phase to mature stage. The RDT object allows pointing out some areas of interest of a satellite image. It provides relevant information on triggering and development clouds and on mature systems. Even if the precocity on the first lightning occurrence remains to be improved, the subjective evaluation confirmed the precocity usefulness on moderate lightning activity" (NWC SAF Documentation, 2013f).

1.3 Definition of the CRR Product

Another product of the NWC SAF is the so-called CRR product (NWC SAF Documentation, 2013a). The CRR product is a nowcasting tool that provides information on convective and stratiform (which is associated to convection) instantaneous rainfall rates (RRs). This product uses infrared (IR), water vapour (WV) and visible (VIS) MSG channels and calibration functions generated from both satellite and radar. In the calibration process, radar data is compared pixel by pixel with geographically matched MSG data with the same resolution. The RR is obtained as a function of two or three variables (IR brightness temperature, IR-WV brightness temperature differences, and normalised VIS reflectance):

- RR = f (IR, IR-WV, VIS-N), for three channels.
- RR = f (IR, IR-WV), for two channels.

The basic mm/h RR value for each pixel is obtained from the calibration functions. During daytime hours (as determined by the sun zenith angle), the CRR is obtained using three MSG channels:

- IR from the 10.8 channel (IR108).
- WV from the 6.2 channel (WV062).
- VIS imagery from the 0.6 channel (VIS06).

During night-time, the solar channel cannot be used and thus the RR values are obtained from two channels only, namely, IR108 and WV062 imagery. To take the influence of environmental and orographic effects on the precipitation distribution into account, some corrections can be applied using NWP fields, if available. Such corrections to the basic CRR value include the moisture correction, the cloud top growth/decaying rates or evolution correction, the cloud top temperature gradient correction and the orographic correction. If lightning data is available, lightning activity can provide valuable information about convection. A lightning algorithm can be applied to derive a precipitation pattern that will be combined with the CRR computed in the previous step in order to complement it.

Validation studies done in Europe showed that the three-channel calibration analytical function gave better results than the two-channel function. This function is, however, only available during daytime (NWC SAF Documentation, 2013e).

1.4 The Aims of the Study

The aims of this research project were:

- To use and test the latest version of the NWC SAF software (v2013) against the previous version (v2012) for the RDT and CRR products on a dedicated server at the South African Weather Service (SAWS) using information from the MSG satellite and model input from the local version of the United Kingdom Meteorological Office (UKMO) Unified Model (UM).
- To include lightning data from the South African Lightning Detection Network (SALDN) as auxiliary data to further enhance the accuracy of the products.
- To transfer skills to forecasters from South Africa as well as southern Africa to understand the improvements to the products and their usefulness (through training sessions and/or workshop presentations).
- To make the improved RDT and CRR products operationally available to all forecasters in South Africa as well as Southern African Development Community (SADC) via the internet.

1.5 Layout of the Report

In this chapter, the motivation and aims for undertaking this research project were given. A summarised version of the background of the RDT and the CRR products were provided. Chapter 2 will provide the differences in the two versions of the NWC SAF software (v2012 and v2013) and the results of the tests done to compare the two versions of the RDT and CRR software through case studies. In Chapter 3, the RDT and CRR products will be compared with and without including lightning data in the software to determine whether lightning data provides additional benefit. Chapter 4 will provide details on the implementation of the software, the transfer of skills to forecasters and skills development during the project. Chapter 5 will conclude the results and list recommendations for further work.

CHAPTER 2. COMPARISON AND CHANGES BETWEEN V2012 AND V2013 OF THE NWC SAF SOFTWARE

2.1 Introduction

The NWC SAF software (v2012) was installed and tested during 2013 and 2014 (as part of the WRC-funded project K5-2235/1). Towards the end of 2014, the latest version (v2013) became operational at the SAWS. Initial validation results of the v2012 showed that the RDT could successfully identify and track rapidly developing thunderstorms over South Africa and southern Africa (De Coning et al., 2015).

The aim of this chapter is to show the differences between the two versions of the software and to test v2012 and v2013 on the RDT and CRR products for a number of case studies to determine if there is an improvement in the newer version.

2.2 Improvements and Changes to the RDT Product

The improvements from v2012 to v2013 for the RDT product are as follows (NWC SAF Documentation, 2013d):

- The RDT product of v2013 includes the detection of overshooting tops for each cloud system. An overshooting top is the part of the thunderstorm that penetrates the troposphere due to strong updrafts. This is usually seen as a good indication of a more severe thunderstorm (Bedka, 2011). As a first step, the brightness temperature difference between IR108 and WV062 is used to select possible candidates. Then, these are confirmed as overshooting tops by also using the VIS06 channel and the NWP tropopause temperature.
- A very small improvement was made in determining the phase of the storm.
- A small improvement was also made to the calculations of the estimated speed of a storm cell. The new method uses weighed gravity centres of cloud systems to estimate the displacement between two times (NWC SAF Documentation, 2013d).

When the initial installation of the v2012 software package was done, the output was in BUFR1[1] format. To display the product, this had to be converted to different hierarchical data formats (HDFs). When v2013 was installed to run operationally, it soon became apparent that these conversions took considerable time on the local servers – to such an extent that the processing of data and the display of the RDT could not happen within 15 minutes (before the next data set arrived). The developers mentioned in their documentation (NWC SAF Documentation, 2013b) that if the output format is BUFR3, then the size of the file is reduced significantly, since all the non-convective elements are taken out before the display processes start. In order to save computer processing time, it was thus decided to use the BUFR3 format for the operational version of the v2013 software.

After some communication with the developers of the RDT product at Météo-France, adjustments were also made to the configuration file of the RDT. The developers found that using the RDT product in regions where lightning is not used as part of the input data sets, a few settings could be made to “force” the identification of a rapidly developing or significant convective cell. Two such forcing settings were added to the configuration file of the v2013 software, namely:

- A setting for high RRs: The CRR is one of the inputs to the RDT product. If an RR of more than 8 mm/hour is estimated by the CRR, this could indicate a significant/convective cell.
- A setting for very cold cloud top temperatures: The developers recommended adding a forcing setting of a significant convective cell if the cloud top temperatures (one of the other input fields to the RDT) are less than −70°C.

The developers further recommended that the settings for warmest and coldest temperature, which are used to identify the cloud cells, be set to 0°C and −80°C, respectively, since these are the optimal values for the mid-latitudes. In v2012, these were set to 5°C and −75°C, which are more commonly used in the higher latitudes, such as the European region.

[1] Binary Universal Form for the Representation of Meteorological Data

In the v2012 of the software, only growing and mature storms were considered convective in nature; thus, only these two phases of the storms were displayed and used in the validation of the RDT product. In the v2013 of the software, decaying storms are included in the convective category. This agrees with the principle of lightning occurrence as well, since significant cloud-to-ground (CG) lightning occurs in the mature as well as decaying phases of the storm, as indicated Figure 1. In the operational version of the RDT software (v2013), growing, mature and decaying storms are displayed, and used in the validation against lightning occurrence.

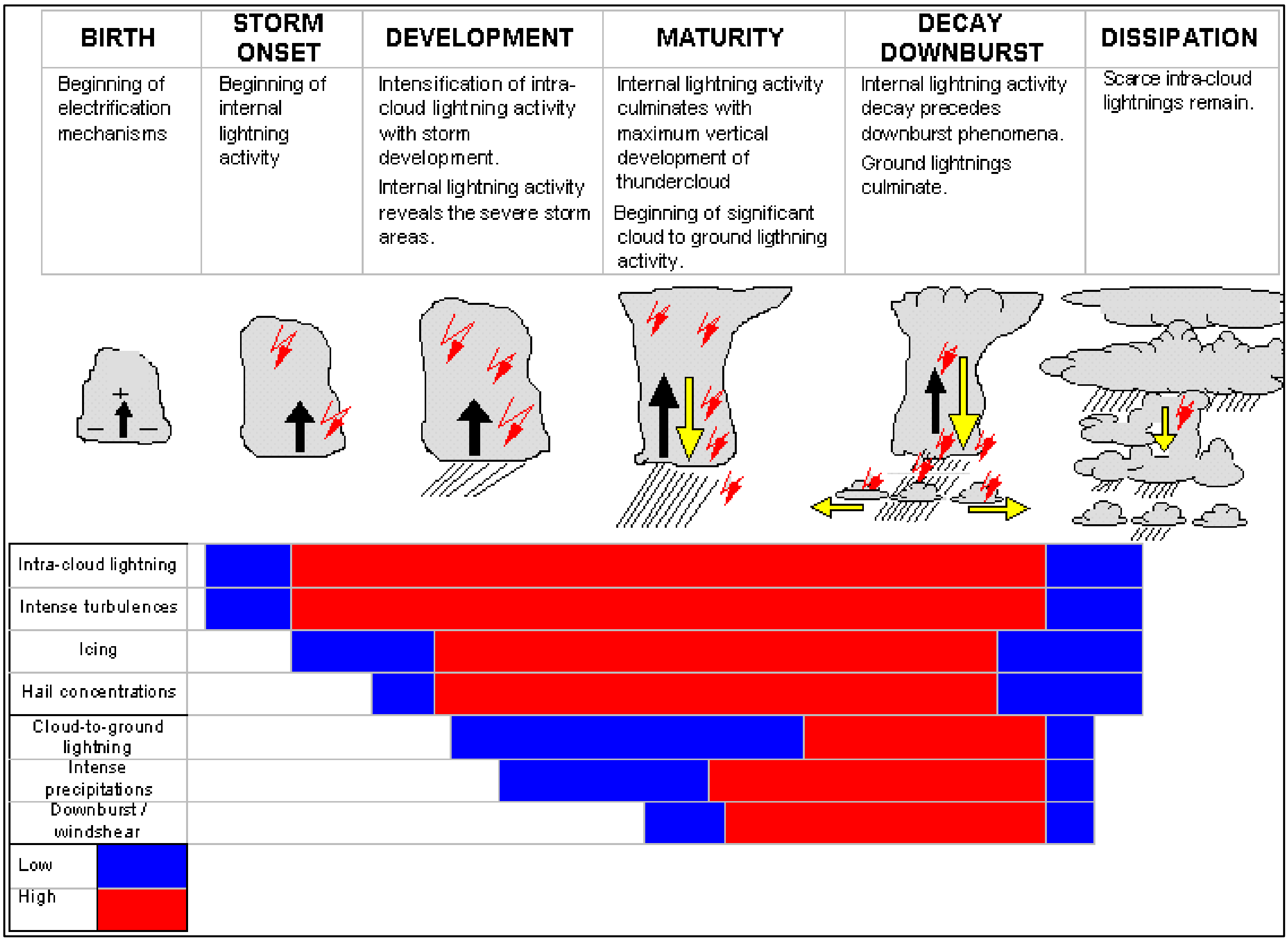

Figure 1: Relationship between convection and lightning (from Price, 2008)

2.3 Validation Report on the Performance of the RDT Product (by Météo-France)

Table 1 lists the contingency table scores (Wilks, 1995) that will be used extensively in both the validation of the RDT and CRR products (table adapted from Forecast Verification, n.d.):

Table 1: Definition of scores used for validation in this report

Score	Answers the question:	Range	Perfect score
POD	What fraction of the observed ‘Yes’ events were correctly forecast?	0 to 1	1
FARatio	What fraction of the predicted ‘Yes’ event actually did NOT occur?	0 to 1	0
False Alarm Rate (FARate)	What fraction of the observed ‘No’ events were incorrectly forecast as ‘Yes’?	0 to 1	0
Hanssen–Kuipers Score (HKS)	How well did the forecast separate the ‘Yes’ events from the ‘No’ events?	−1 to 1	1
Heidke Skill Score (HSS)	What was the accuracy of the forecast relative to that of random chance?	0 to 1	1

Score	Answers the question:	Range	Perfect score
TS	How well did the forecast ‘Yes’ events correspond to the observed ‘Yes’ events?	0 to 1	1
Equitable Threat Score (ETS)	How well did the forecast ‘Yes’ events correspond to the observed ‘Yes’ events (accounting for hits due to chance)?	−0.3 to 1	1

From the Validation Report for RDT (NWC SAF Documentation, 2013f), the following summarises the validation of the v2013 of the RDT algorithm:

- The validation of RDT v2013 was limited to a few case studies. Since no major modification has been made to the discrimination scheme, the previous versions’ statistics were considered still valid.
- With the version 2011 of the software, an objective validation of PGE11 was done over Europe from April to October (northern hemisphere summer). The lightning activity issued from the European Cooperation for Lightning Detection (EUCLID) database was used as ground truth.
- Considering moderate lightning activity, the overall POD was found to be between 74% and 77%. When convective cells at single time steps were considered, the POD was smaller (65%) with a FARatio of ±20%.
- The developer of RDT concluded that the product provides an accurate depiction of convective phenomena from triggering phase to mature stage. The RDT polygons point out the area of interest on a satellite image. It provides useful information on triggering and mature phases of storms. The subjective and objective evaluations exhibit that convection can be diagnosed before lightning activity occurs.
- Known problems and limitations: The tuning was done during a summer period and focused on moderate RDT objects with moderate lightning activity. The statistical scores during winter times could be worse.

Thus, no specific validation was done to compare the version 2011 or v2012 to the v2013 of the RDT product by the developers.

2.4 Improvements and Changes to the CRR Product

The improvements from v2012 to v2013 for the CRR product were as follows (NWC SAF Documentation, 2013c):

- Without changing the physical base of the algorithm, the calibration matrices used before were substituted by analytical functions. Tuning and validation of these analytical functions were done against radar rainfall data from the European radar networks.

2.5 Validation Done by the Developers for the CRR Product

From the Validation Report for CRR (NWC SAF Documentation, 2013e), the following is a summary of the validation of the v2013 of the CRR algorithm:

- An extensive validation of the CRR product was conducted using data corresponding to convective events that occurred during 2008 over Spain, and during 2009 over Hungary.
- Results of the validation against Hungarian radar rainfall fields are very similar to the result validation obtained from the Spanish radars.
- The root mean square error (RMSE) values obtained in v2013 for instantaneous RR are less than 3.3 mm/h, which are within the target set by the NWC SAF. For hourly rainfall accumulations, RMSE values obtained in all validations are less than 2.5 mm, which are within the target set by the NWC SAF.

Table 2 and Table 3 summarise the validation of the instantaneous RRs of the latest CRR version (NWC SAF Documentation, 2013e):

Table 2: Mean, mean error (ME), mean absolute error (MAE) and RMSE of the CRR v2010 and v2013 as calculated by the developers

Algorithm	N	Mean (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
V2010					
3 channels used (matrices)	850 761	0.73	0.10	1.10	2.71
2 channels used (matrices)	681 556	0.81	−0.10	1.11	2.33
V2013					
3 channels used (function)	846 153	0.60	0.47	1.18	2.81
2 channels used (function)	868 860	0.63	0.81	1.55	3.19

Table 3: POD, FAR and critical success index (CSI) of CRR v2010 and v2013 as calculated by the developers

Algorithm	FAR (%)	POD (%)	CSI (%)
V2010			
3 channels used (matrices)	17.4	42.2	38.7
2 channels used (matrices)	29.7	34.0	29.8
V2013			
3 channels used (function)	30.6	58.1	45.9
2 channels used (function)	44.6	54.4	37.8

- Known errors and limitations: The CRR product is based on a calibration method that requires the availability of a training set of precipitation data. This was derived from radar rainfall information to derive the relationship between satellite RR and radar RR.
- Regarding the radar data: The drop size distribution, used to obtain the radar RR (mm/h) from the radar reflectivity (dBZ), has been assumed to be the Marshall–Palmer type throughout the calibration and validation procedures. No operational method has been applied to adjust the radar rainfall intensities using rain gauge measurements.
- According to the feedback of the users, the CRR product provides useful information as a complement to radar rainfall products that allows the forecasters to identify RR in convective storms.

In South Africa, the local version of the UM is used as NWP input to the NWC SAF software. The CRR uses all levels in the vertical of the NWP, but also uses 925 hPa for the purpose of the humidity correction, which is to adjust the RR according to the amount of moisture that is available in the atmosphere. Since the local version of the UM does not have the 925 hPa level, this correction cannot be done and might have a negative impact on the rainfall intensity of the CRR. This has to be kept in mind in the validation statistics obtained from the case studies over South Africa.

2.6 Results of RDT Cases to Compare V2012 to V2013

Twenty-five cases were used to compare the different versions of the software. These cases were chosen between September and March, which covers the convective summer season, and all available data sets of MSG and NWP were used. Validation of the RDT could be done using: a) visual comparison with radar images (where possible) or satellite images, and b) an object-orientated validation methodology against lightning data.

The RDT algorithm is an object-orientated methodology. To validate these objects against point measurements of lightning requires an object-orientated methodology, which was also followed by the developers (NWC SAF Documentation, 2013f). Feature-based or object-based approaches identify different attributes (such as position and size) to each individual pair of forecast-observed 'objects' (Ebert, 2008). Contingency table verification statistics can again be calculated using new definitions for hits, misses and false alarms according to the identified objects. The R-software module (The R Project for Statistical Computing, n.d.) that can do this validation is called SpatialVx (Package 'Spatial Vx', c2014). This package was used to do an object-orientated validation of the RDT of v2012 (De Coning et al., 2015) and will again be used in the following validation results.

The RDT product was objectively evaluated against CG lightning data from the SALDN. The SALDN detects lightning over the country with a theoretical detection efficiency of 90% – meaning that 90% or more of all CG lightning is detected. To compensate for areas outside this 90% detection efficiency range, a mask was applied to the evaluation domain so that only accurate lightning data was used for the evaluation. The SALDN detects only CG lightning (lightning that strikes the Earth's surface) and thus does not capture the intra-cloud (IC) lightning and cloud-to-cloud (CC) lightning (Gijben, 2012). IC lightning is found predominantly during the developing phase of a thunderstorm, while in the mature phase of a storm the maximum IC lightning occurs together with a significant amount of CG (Figure 1). This can have a negative impact on the validation statistics calculated in the cases over South Africa since IC lightning data is not available.

All lightning activity was considered in the 10 minutes before until 10 minutes after each RDT time step. Since the RDT product is aimed at identifying intense or rapidly developing storms or parts of storms, one would expect that the moderate to intense lightning events would correspond best with the RDT polygons and the less intense lightning events might fall outside the RDT polygons. For all cases, the seven hours from 11:00 Coordinated Universal Time (UTC) to 18:00 UTC [13:00–20:00 South African Standard Time (SAST)] were used as these hours are usually the most convective part of the day. This approach was used in the calculation of all statistical scores and will be shown in the respective graphs provided in this chapter.

2.6.1 Results of the 25 cases

Figure 2 illustrates the HSS for all 25 cases that were evaluated. The average HSS per day for all 25 days for the v2012 of the software was 0.71; for the v2013 of the software the average was slightly higher at 0.74. For the cases indicated by a yellow star, the v2013 had a higher HSS than the v2012. A blue cross indicates the cases where the v2012 of the software performed better.

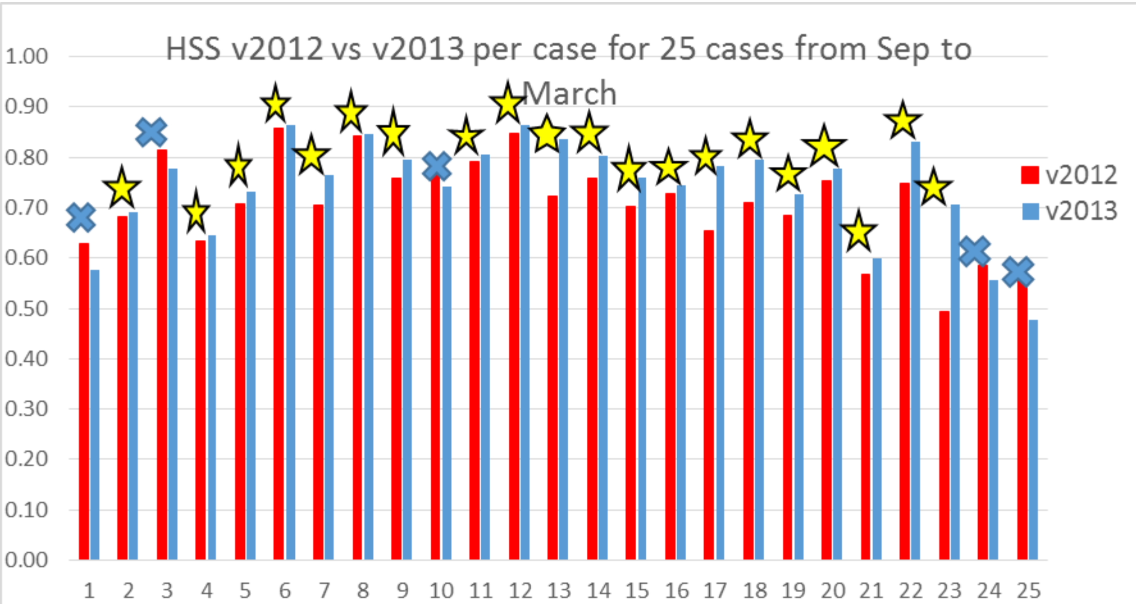

Figure 2: HSS of the 25 cases validated against lightning data for v2012 (red bars) and v2013 (blue bars)

Figure 3 compares the POD and FAR for the two versions of the software for the 25 cases. POD is indicated by bars and FARatio indicated by dashed lines. On average for all 25 cases, the POD was 5% better with the v2013 of the software than the v2012. The FAR of v2013 was slightly higher than the v2012 (3%). For most cases, the v2013 performed better than the v2012 as indicated by the yellow stars. These scores are similar to the scores calculated by the developers.

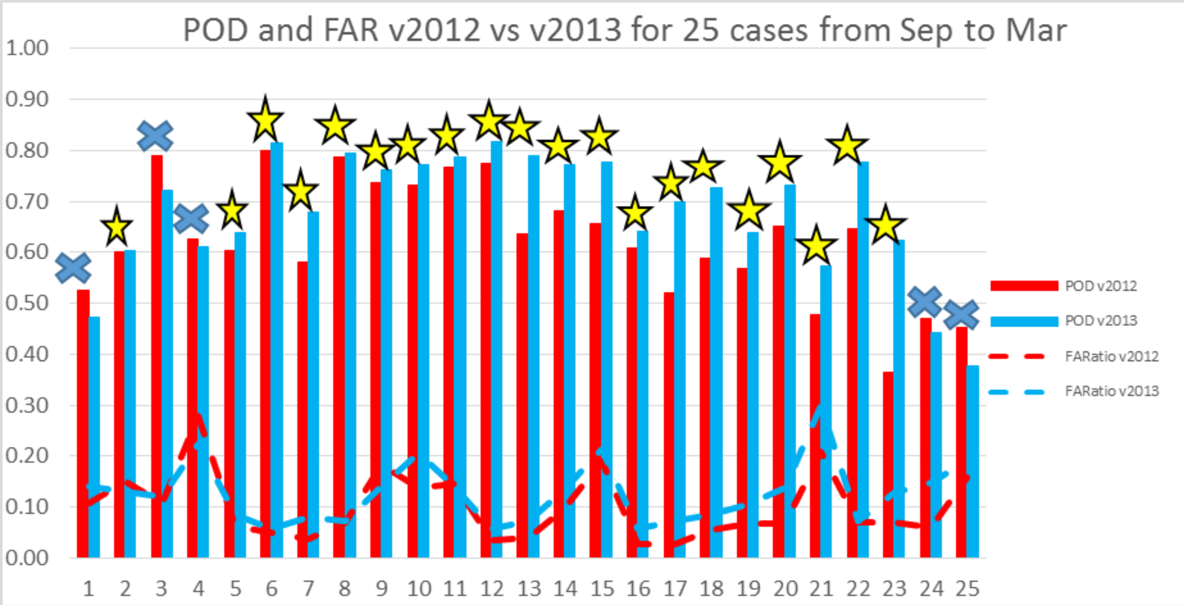

Figure 3: POD and FARatio of the 25 cases validated against lightning data for v2012 (red) and v2013 (blue)

Figure 4 compares the HSS, POD and FAR for all 25 cases for the different times of the day. The POD is indicated by bars, the FARatio is indicated by red lines, and the HSS is indicated by green lines. The HSS is between 0.7 and 0.8 for all hours from 11:00 UTC to 18:00 UTC. The POD of v2013 is better than the POD of v2012 for all times. The FAR is similar or slightly higher for v2013. From this graph it is clear that the RDT validates well against the occurrence of lightning for all relevant hours, with a slight decrease in performance in the later hours of the day.

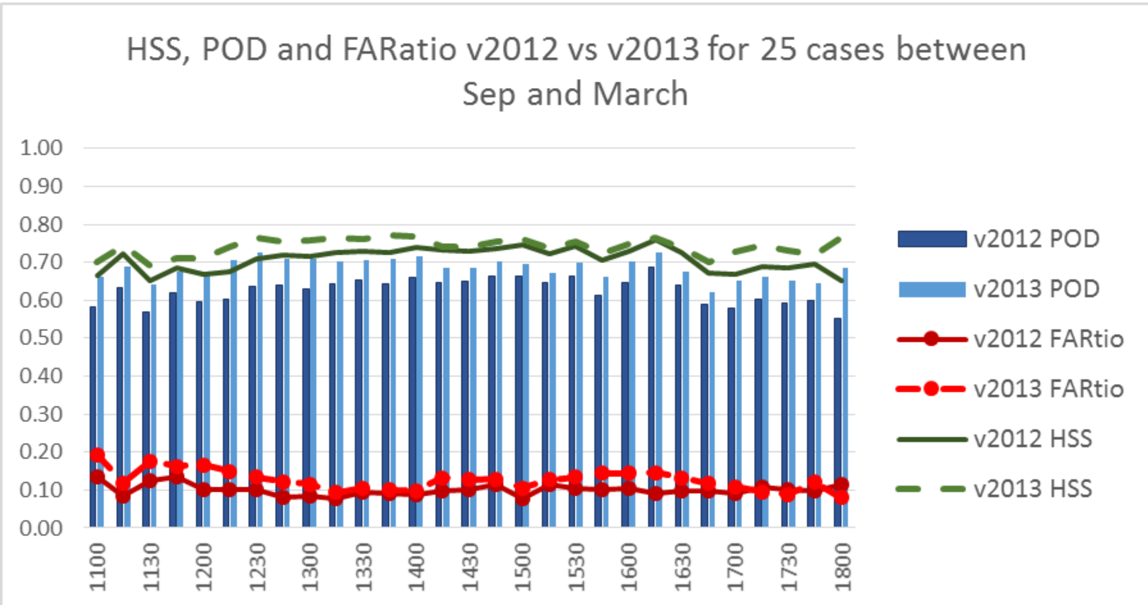

Figure 4: POD, FARatio and HSS of the 25 cases validated against lightning data for the v2012 (darker colours and solid line) and v2013 (lighter colours and dashed line)

2.6.2 Discussion of a few cases

2.6.2.1 Case 1: 9 November 2012

Figure 5 compares the RDT of v2012 and v2013 for 12:45 UTC on 9 November 2012. The RDT v2012 (left) identified growing, mature and decaying storms in similar regions as v2013 (right), except for the storm over the Eastern Cape (yellow arrow) where v2012 did not identify a storm while v2013 did. This storm was associated with lightning and, thus, v2013 performed slightly better than v2012. An average of all the time steps for this case indicates that the POD was slightly higher with v2013 (0.82) than with v2012 (0.8), the FAR was similar, and the HSS the same (0.86).

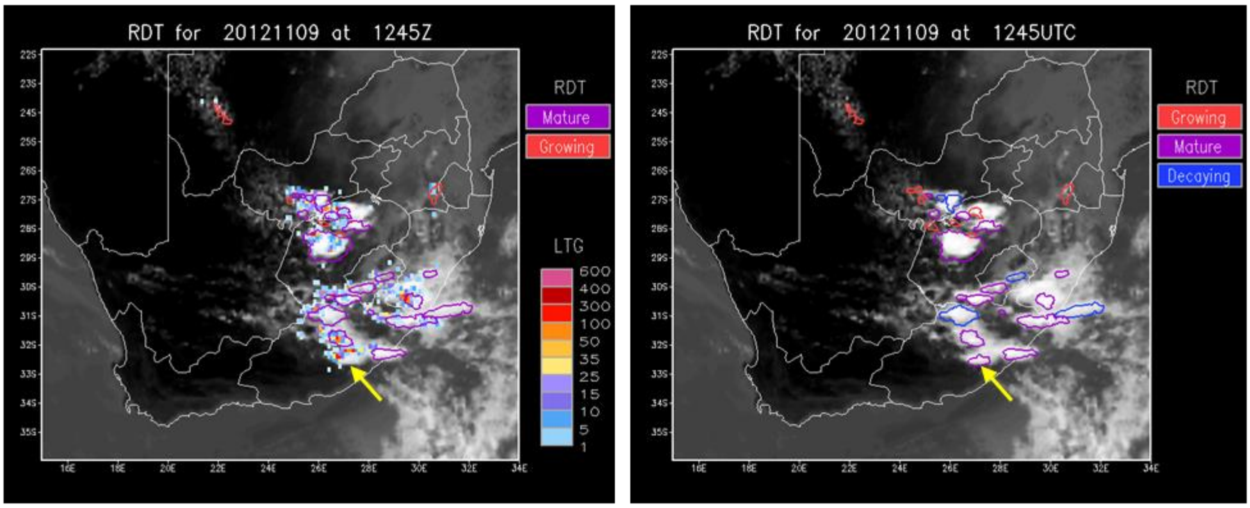

Figure 5: RDT v2012 (left) and RDT v2013 (right) for 9 November 2012 at 12:45 UTC

2.6.2.2 Case 2: 6 September 2012

Figure 6 compares the RDT of v2012 and v2013 for 15:30 UTC on 6 September 2012. The RDT objects corresponded well with the lightning objects, except for the circled area. The RDT (v2013 and v2012) identified growing storms in the circled area, but no CG lightning occurred in these storms. Very little CG lightning is seen in growing convective storms and it is thus possible that small, growing storms did occur in this area. RDT v2012 identified a mature storm over the northern parts of Limpopo province that was associated with the occurrence of CG lightning; however, this was missed by v2013. The POD average for all the time steps of this case was slightly lower for v2013 (0.47) than for v2013 (0.53). The HSS was 0.63 for v2012 and 0.58 for v2013.

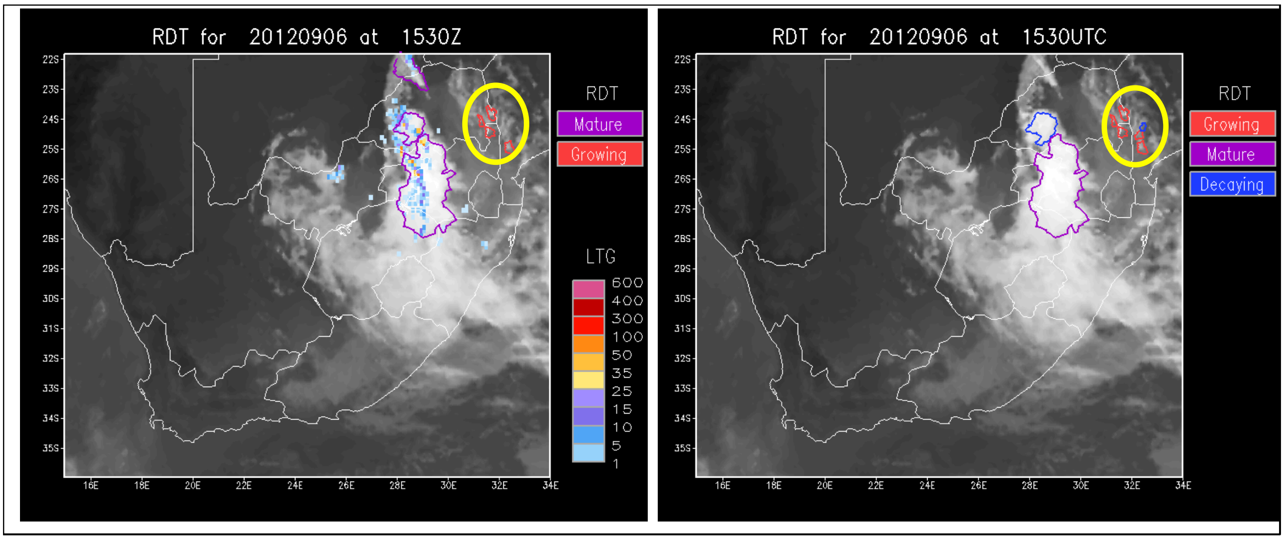

Figure 6: RDT v2012 (left) and RDT v2013 (right) for 6 September 2012 at 15:30 UTC

2.6.2.3 *Case 3: 10 December 2012*

Figure 7 compares the RDT of v2012 and v2013 for 11:30 UTC on 10 December 2012. The RDT v2013 identified more storms than the v2012 (indicated in the red circles) where lightning also occurred. The POD and HSS averages for all time steps of this case were 0.58 and 0.70 for v2012, and markedly better for v2013 at 0.68 and 0.77, respectively.

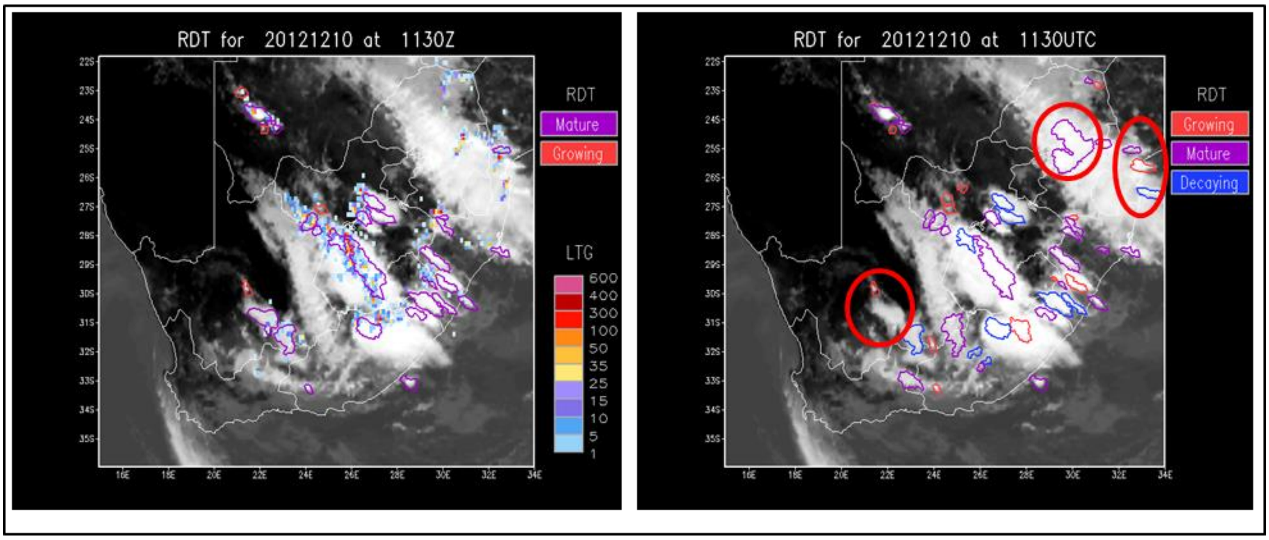

Figure 7: RDT v2012 (left) and RDT v2013 (right) for 10 December 2012 at 11:30 UTC

2.6.3 Summary of the results of the RDT validation

Twenty-five cases between September and March (convective season) were used to validate the v2012 and v2013 of the RDT product over South Africa. Statistical scores were calculated using the CG lightning data from the SALDN for each time step between 11:00 UTC and 18:00 UTC. In most cases, the RDT v2013 outperformed the RDT v2012. The POD and HSS were better for v2013, while the FAR was slightly higher (worse) for v2013 than for v2012. When the different time steps were compared, it was evident that both v2012 and v2013 performed well at all hours of the day, with a slight decrease in performance towards the latter part of the period. Small changes could be seen when images for individual times were compared (v2012 to v2013), but in general, the results show a slight improvement due to the minor updates in the latest version of the software.

2.7 Results of CRR Cases to Compare V2012 to V2013

Twenty cases were used to compare the different versions of the software against daily rainfall totals from rain gauges. These cases were chosen between September and March – in the convective season dominated by convective rainfall in South Africa. The rain gauge network over the country includes 199 automatic weather stations, 169 automatic rainfall stations, 1214 rainfall stations, and 199 synoptic stations. All available data was used to calculate daily rainfall totals from 06:00 UTC to 06:00 UTC.

The International Precipitation Working Group (IPWG, n.d.) is one of the working groups of the Coordination Group for Meteorological Satellites. The aim of this working group is to highlight the opportunities and challenges for quantitative precipitation measurements on a global scale. Through the work of the IPWG, precipitation estimates from various satellite and NWP products are compared in a standardised method against ground-truth data sets. Ground truth can either be surface rain gauges or radar rainfall fields. All the comparisons are done on a 0.25° × 0.25° grid resolution for a 24-hour period. The verification methodology is applied in various regions of the world by the participating members (Ferraro et al., 2013; Kidd et al., 2007).

The SAWS has been hosting a validating website for the South African region since March 2013. Various daily accumulations of model and satellite precipitation products are available on the South African IPWG validation webpage: http://rsmc.weathersa.co.za/IPWG/ipwgsa_qlooks.html (De Coning, 2013b). The same methodology used by the IPWG was used to validate the CRR v2012 and CRR v2013 to daily rainfall totals measured by the rain gauges. Three thresholds were used to determine the performance for light to heavier falls, namely, 1 mm, 10 mm and 20 mm.

2.7.1 *Results of the CRR case studies*

Figure 8 shows the average statistical scores for daily rainfall from CRR v2012 and CRR v2013 compared to the rain gauge totals. CRR v2012 are indicated in the lighter bars and CRR v2013 in the darker bars for three thresholds, namely, 1 mm (red), 10 mm (blue) and 20 mm (green). For all scores, the CRR v2013 performed better; however, the FARatio for the 10 mm threshold was slightly worse than the CRR v2012.

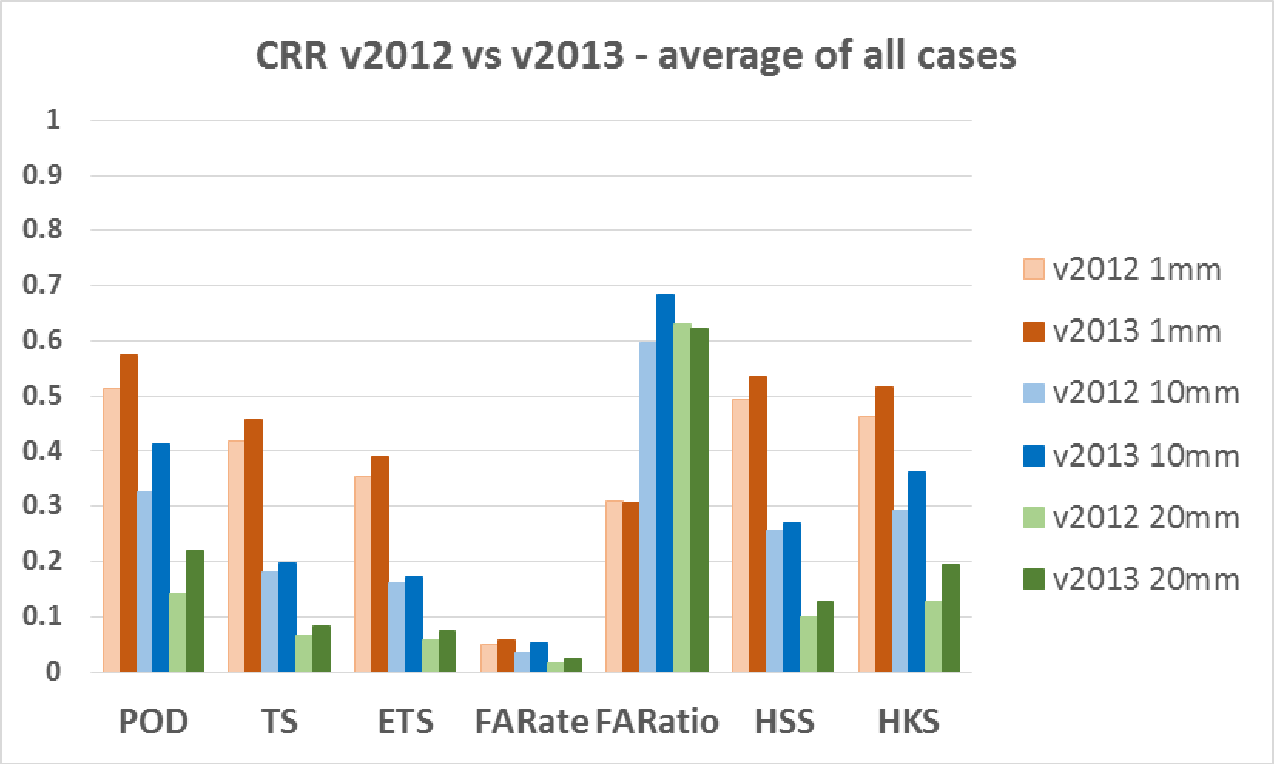

Figure 8: Average POD, TS, ETS, FARate, FARatio, HSS and HKS for CRR v2012 compared to CRR v2013 on a daily basis for all 20 cases

Table 4 gives the MAE, ME and the bias for all 20 cases. The MAE of v2013 is worse than v2012. The ME of v2013 is positive (0.39) compared to a negative ME of v2012 (−0.142). The bias reflects that for the 1 mm to 20 mm thresholds, the v2013 is worse than v2012 and tends to overestimate intensity.

Table 4: MAE, ME and bias for 1 mm, 10 mm and 20 mm thresholds

	MAE	ME	Bias 1 mm	Bias 10 mm	Bias 20 mm
CRR v2012	1.64	-0.142	0.7276	0.352	1.07
CRR v2013	1.90	0.390	0.8328	1.456	1.72

Figure 9 shows the POD, FARatio and HSS per case for the 1 mm threshold. In some cases, the scores are very similar, but in most cases, the v2013 outperformed the v2012 for the 1 mm threshold. The POD and FARatio for the 1 mm threshold are similar to the POD and FARatio calculated by the developers.

POD is shown by blue bars, FARatio by green bars, and HSS by red lines for CRR v2012 compared to CRR v2013 on a daily basis for all 20 cases. CRR v2012 values are indicated in the lighter bars and CRR v2013 in the darker bars/line for the 1 mm threshold.

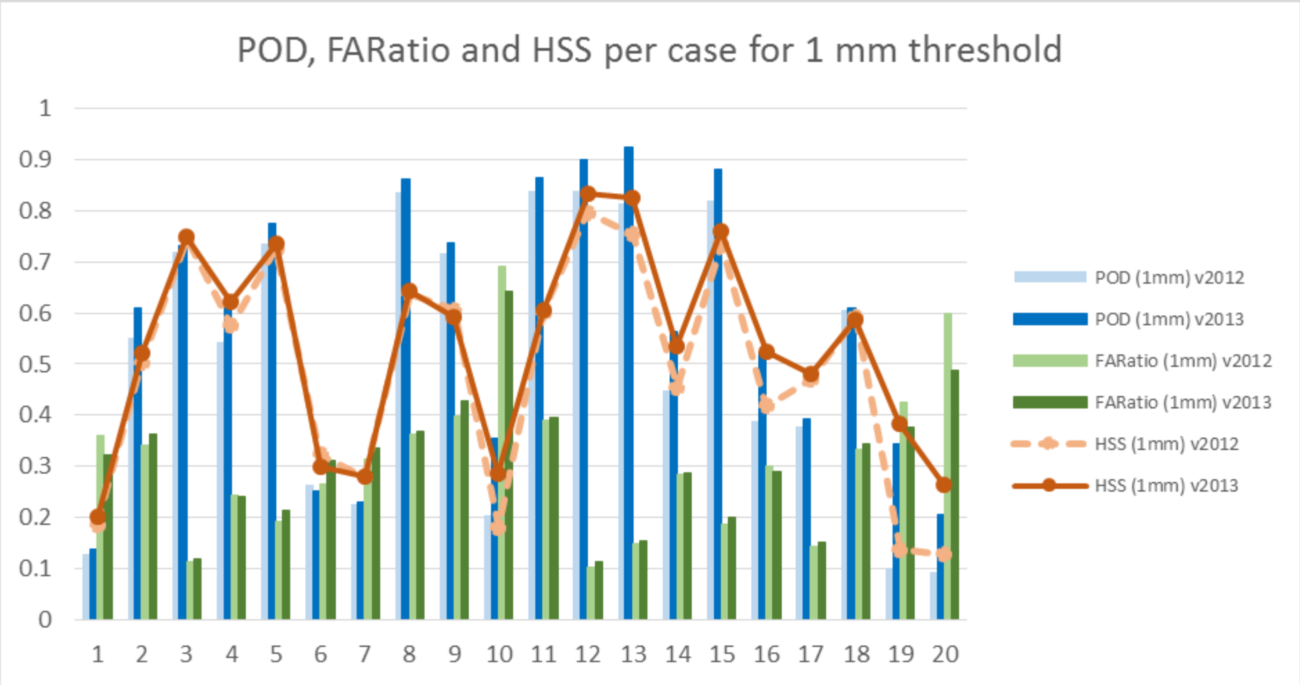

Figure 9: POD, FARatio and HSS (red lines) for CRR v2012 (lighter bars) compared to CRR v2013 (darker bars/ line) for the 1 mm threshold on a daily basis for all 20 cases

2.7.2 Discussion of a few cases

2.7.2.1 Case 1: 16 March 2015

On 16 March 2015, a cold front swept over the southern coastal regions and adjacent interior, while a surface trough was situated over the central and northern parts, extending to a coastal low-pressure system over the extreme east, ahead of the surface front. Daily rainfall totals from the rain gauges (Figure 10, top left) indicate that precipitation occurred along the south and south-eastern coastal regions, which is consistent with the passage of a surface cold front.

Precipitation was also recorded over the eastern half of the country to the east of the surface trough, with high rainfall totals indicated for the central interior of KwaZulu-Natal (KZN). Both CRR v2012 and CRR v2013 indicated marginal rainfall totals over the corresponding area (Figure 10, bottom). This indicates that the CRR algorithm does not handle stratiform rainfall associated with frontal systems well at all. The convective rainfall occurrence over the interior was handled better. For the 1 mm threshold on this day, the HSS was 0.32 for v2012 and 0.30 for v2013.

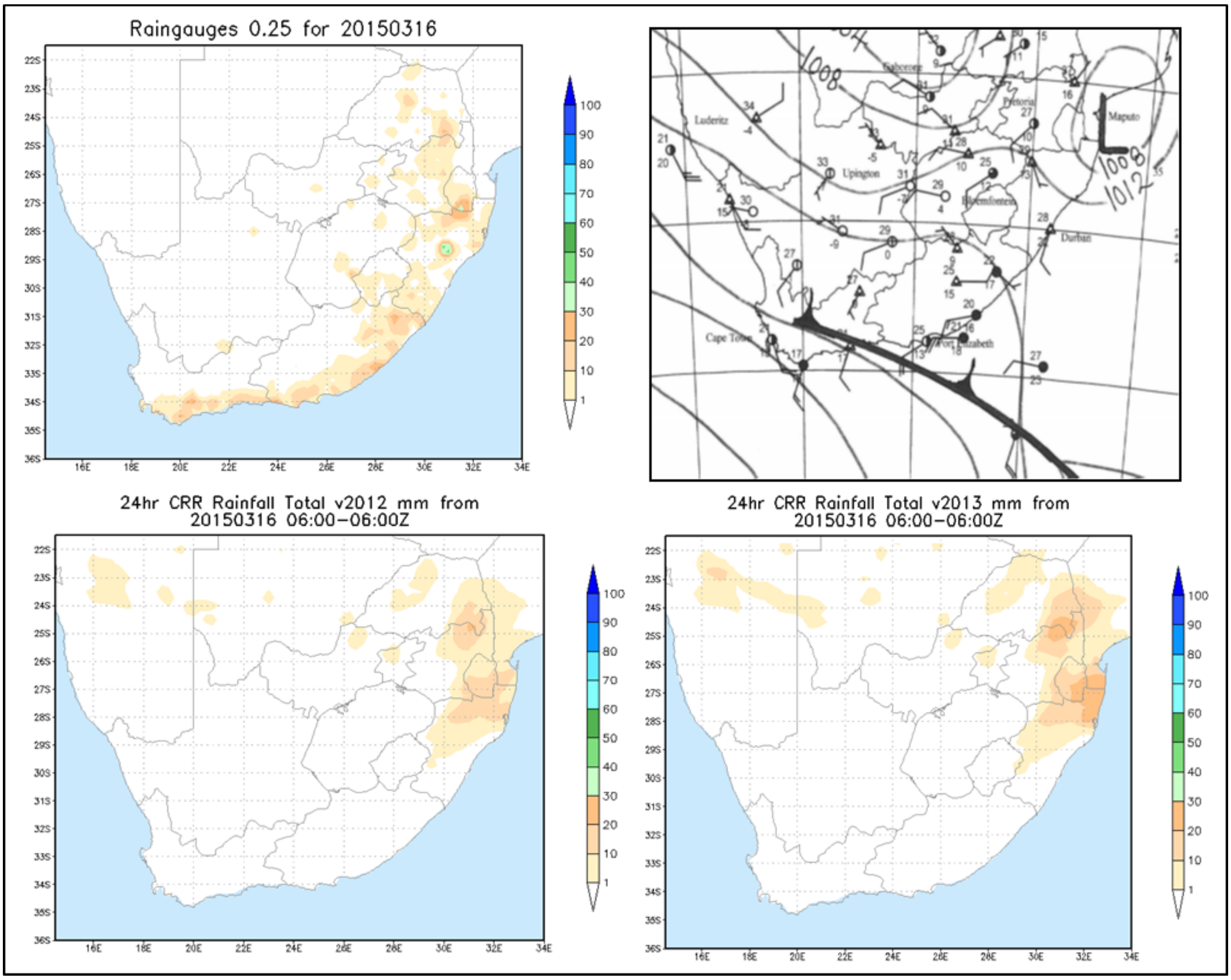

Figure 10: Daily rainfall total as measured by the rain gauges (top left), synoptic circulation pattern (top right), daily rainfall total as estimated by CRR v2012 (bottom left) and daily rainfall total as estimated by CRR v2013 (bottom right) for 16 March 2015

2.7.2.2 Case 2: 19 November 2013

On 19 November 2013 (Figure 11), a more typical summer convection situation dominated the country. Heavier falls were recorded over the Free State and North West provinces, which were captured well by the CRR algorithm. The lighter falls in the Eastern Cape and Western Cape were estimated well, but the light rain along the Cape West Coast was not captured by the CRR algorithm. For the 1 mm threshold on this day, the HSS was 0.50 for v2012 and 0.52 for v2013, while the same scores for the 20 mm threshold were 0.32 and 0.34, respectively. The CRR v2013 performed better than the CRR v2012 on this day.

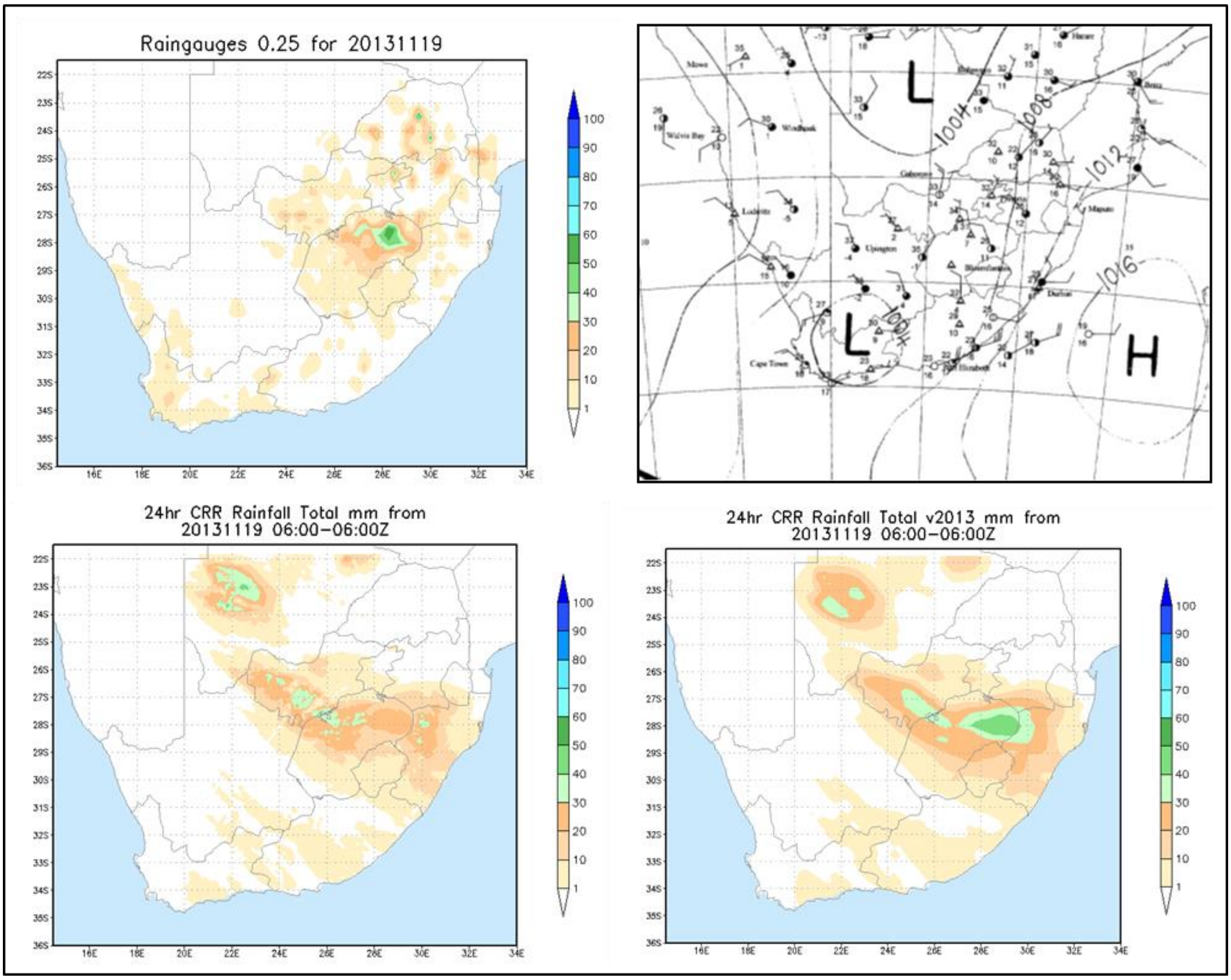

Figure 11: Daily rainfall total as measured by the rain gauges (top left), synoptic circulation pattern (top right), daily rainfall total as estimated by CRR v2012 (bottom left) and daily rainfall total as estimated by CRR v2013 (bottom right) for 19 November 2013

2.7.2.3 Case 3: 23 March 2015

On 23 March 2015 (Figure 12), widespread thunderstorms occurred over the central parts of the country, while heavier falls were recorded over the southern interior. The intensity of these events was not captured well by either version of the CRR. For the 1 mm threshold on this day, the HSS was 0.75 for v2012 and 0.82 for v2013, while the same scores for the 10 mm threshold were 0.31 and 0.42, respectively. The CRR v2013 performed better than the CRR v2012 on this day.

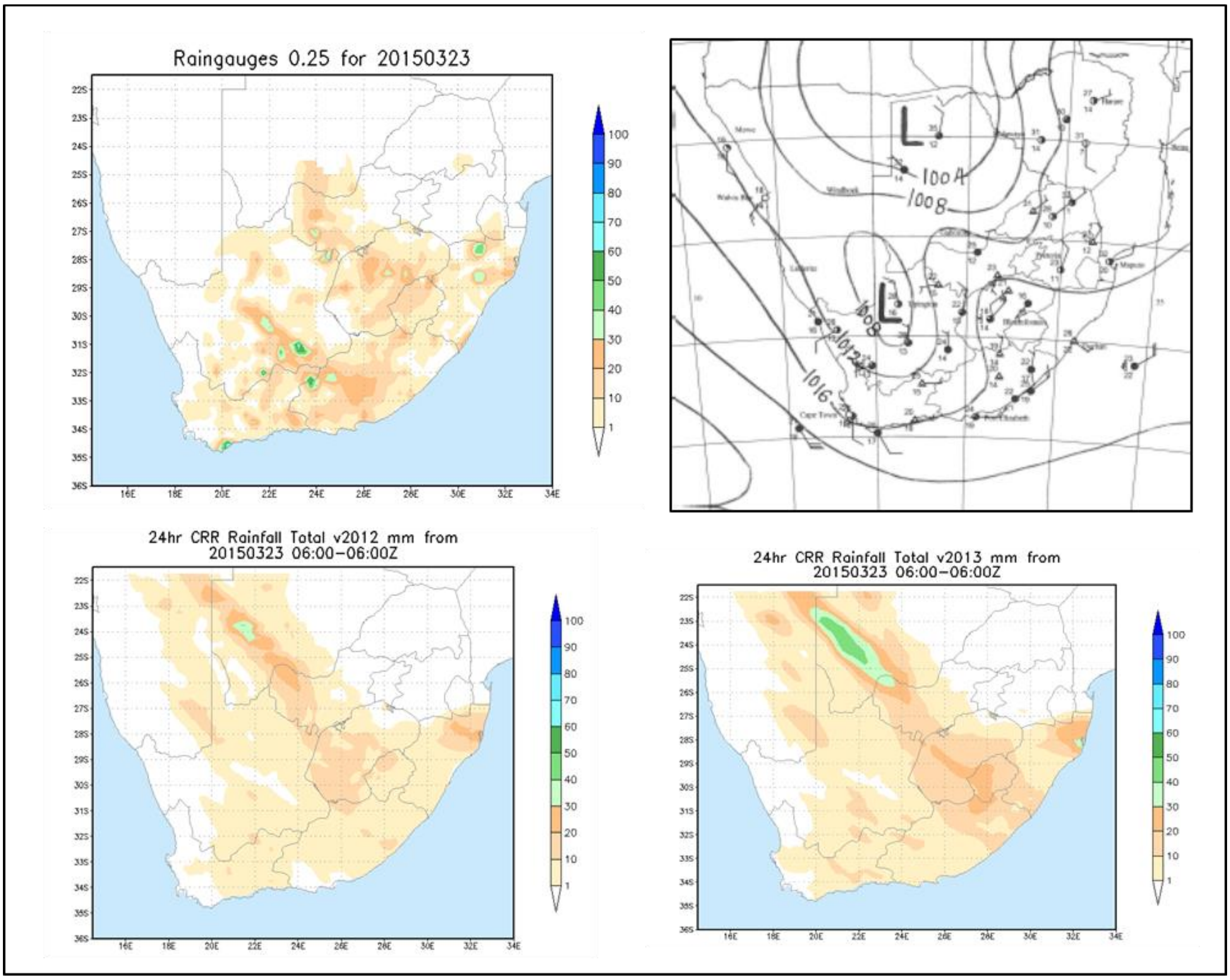

Figure 12: Daily rainfall total as measured by the rain gauges (top left), synoptic circulation pattern (top right), daily rainfall total as estimated by CRR v2012 (bottom left) and daily rainfall total as estimated by CRR v2013 (bottom right) for 23 March 2015

2.7.3 Summary of results of CRR validation

Twenty cases between September and March (convective season) were used to validate the v2012 and v2013 versions of the CRR product over South Africa. Statistical scores were calculated using the daily rainfall totals from the rain gauges as ground truth. In most cases, the CRR v2013 was very similar or slightly better than the CRR v2012. Three thresholds were used to validate the CRR algorithms, namely, 1 mm, 10 mm and 20 mm.

On average the POD, HKS and HSS were all better for v2013, while the FAR was slightly higher (worse) for v2013 than for v2012, for all three thresholds. The bias scores indicate the CRR v2013 overestimates the intensity of the rainfall, more so than v2012. Adjustments to the intensity of the CRR algorithm could improve when the 925 hPa level of the NWP will be added when the new UM becomes operational since the absence of this level negatively affects the intensity of rainfall as moisture correction cannot be done. Small changes could be seen when images for individual days were compared (v2012 to v2013), but in general, the results are very similar with slight improvements due to the minor updates in the latest version of the software.

CHAPTER 3. DIFFERENCES AND IMPROVEMENTS BETWEEN RDT AND CRR PRODUCTS WITH AND WITHOUT LIGHTNING DATA AS INPUT

3.1 Introduction

The latest version of the NWC SAF software (v2013) is currently operational at the SAWS. In Chapter 2, tests were conducted to show that v2013 performs slightly better than v2012 for the RDT product. The statistics for the CRR, however, did not show a significant improvement and v2013 tends to overestimate the intensity of daily rainfall more so than for v2012.

Another capability of the NWC SAF software suite is to add ancillary data as input to the system. One option is to add lightning data over the South African domain to the software for the calculation of the CRR and RDT. By using lightning data as input to these products, cloud systems, which were previously missed (based on satellite and NWP alone), can be identified. As lightning activity is related to convection, this information could possibly also benefit the CRR product. In this chapter, the RDT and CRR products were validated against radar data when lightning data was used/not used as input data to the processes.

3.2 Settings and Assumptions for Including Lightning Data in the RDT Product

According to the Product User Manual (NWC SAF Documentation, 2013d), lightning data can be added to the RDT input data set to characterise the electrical activity inside thunderstorms in order to force the identification of convective systems missed by satellite and NWP alone but contains significant amounts of lightning.

To include lightning data in the processing for RDT, a few settings are made in the configuration file on recommendation of the developers:

- A period of 600 seconds (10 minutes) before and after each RDT time step is used as the time window for lightning data to be included in the calculation.
- Three satellite pixels are set as the distance between the satellite cell and the lightning flash with which it is associated.

The RDT product without lightning data added to the software was validated against the occurrence of lightning in Chapter 2. When lightning data is used as input to the process, it cannot be used as validation tool again. For this reason, the RDT product was validated against radar data (where available) for the same 25 cases mentioned in Chapter 2.

3.3 Settings and Assumptions for Including Lightning Data in the CRR Product

According to the CRR Product User Manual (NWC SAF Documentation, 2013c), the inclusion of lightning activity to the CRR product is useful as lightning relates to convection. In the development, only CG lightning flashes were used as measured by European ground-based lightning detection network. To incorporate this information into the CRR product, an RR was assigned to every lightning flash depending on:

- The time interval ($\Delta\tau$) between the lightning event and scanning time of the processing region centre.
- The location of the lightning.
- The spatial density of lightning in a time interval.

Once the lightning-based precipitation pattern was computed, it was compared to the CRR precipitation pattern in order to obtain the final product. This final product contains the highest RR of the two. The CRR lightning algorithm and the coefficients applied have been derived for Spain using the lightning information from their lightning detection network. It is recommended that users in different countries adapt these lightning coefficients for their specific regional climate. As a start, we used the settings as provided by Spain. In communication with the developers it was indicated that including lightning data would mostly affect the intensity of the RR. A study on the relationship between lightning flashes and RR for the South African domain will be considered at a later stage (not included in this project). On recommendation of the developers, a setting was made in the configuration file to include lightning data 15 minutes before the CRR time step. This ensured that lightning data was included in the CRR product. The CRR products with and without lightning as input were all validated against daily rainfall totals from the rain gauges over South Africa on a 0.25° resolution, in the same manner and for the same cases as in Chapter 2.

3.4 Results of the RDT Case Studies With and Without Lightning Data As Input

Twenty-five cases were used to compare the RDT product with and without lightning data as input to the product against radar data. The first challenge regarding using radar data is radar availability. Unfortunately, radar data is not as readily available as lightning data, which made the validation more challenging. The areas covered by radars across the country varied from day to day and even from time to time during any day. To deal with these variations, the first step was to identify the radar systems that were available (or operational) between 11:00 UTC and 18:00 UTC of each of the case dates.

Table 5 shows the radar systems that were available for each of the 25 cases. The yellow blocks indicate that the radar data was available for the entire period, the red blocks indicate that the radar data was only available for certain times of the period, and the white blocks indicate where no radar data was available at all.

Table 5: Availability of radar data for the 25 cases

Cases		Radars																	
		Bloemfontein	Bethlehem	Cape Town	Durban	De Aar	East London	Ermelo	George	Irene	Ottosdal	Port Elizabeth	Polokwane	Skukuza	Umtata	Bloemfontein Azimuth	Irene Azimuth	Bethlehem Azimuth	East London Azimuth
Case 1	2011-12-31																		
Case 2	2012-09-06																		
Case 3	2012-10-09																		
Case 4	2012-10-17																		
Case 5	2012-10-20																		
Case 6	2012-11-08																		
Case 7	2012-11-09																		
Case 8	2012-12-10																		
Case 9	2013-01-19																		
Case 10	2015-03-15																		
Case 11	2015-03-16																		
Case 12	2015-03-17																		
Case 13	2015-03-18																		
Case 14	2015-03-19																		
Case 15	2015-03-20																		
Case 16	2015-03-21																		
Case 17	2015-03-22																		
Case 18	2015-03-23																		
Case 19	2015-03-24																		
Case 20	2015-03-25																		
Case 21	2015-03-26																		
Case 22	2015-03-27																		
Case 23	2015-03-28																		
Case 24	2015-03-29																		
Case 25	2015-03-30																		

Radar mosaic data was used for evaluation purposes, thus all the possible radars across the country were combined into a mosaic map. Figure 13 shows the radar availability mask if all radars are available. This is the maximum area that could be considered for evaluation purposes. The areas in red are covered by radar systems, and the areas in white fall outside the radar coverage mosaic. In order to take the missing data from non-operational radars into account, different masks had to be used over the country. Radar systems that were offline had to be removed from the mask, depending on the time and date. In essence, each case day and even different hours for a case day had a different mask.

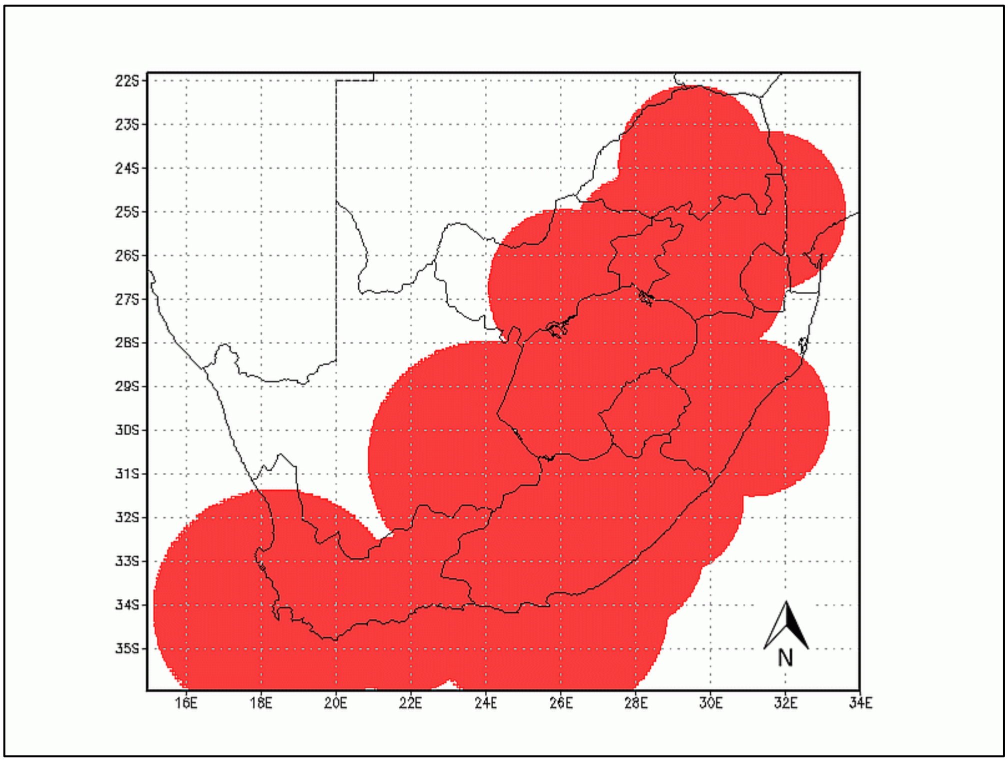

Figure 13: A map showing the maximum domain (red) that could be considered for the evaluation of the RDT; white areas indicate no radar coverage

The second challenge when using radar data is that the scanning interval of the radars changed from five-minute intervals to six-minute intervals. For the older (2011, 2012 and 2013) case days, the interval of radar mosaic data was every five minutes, while the intervals of the 2015 cases were every six minutes. The interval of RDT data, which relates to satellite data, on the other hand is every 15 minutes. As a result, the maximum radar reflectivity in the 10 minutes before and after the RDT time (two radar time steps before and two radar time steps after the RDT time) was used to evaluate the older cases.

For the newer (March 2015) cases, the six-minute interval radar data does not correspond so well with the RDT times. For these cases, when the RDT timestamp was 00 (on the hour) or 30 minutes past the hour, the radar data for the six minutes following the RDT time was used. When the RDT timestamp was 15 or 45 minutes past the hour, the radar data for the six minutes surrounding the RDT time (three minutes before and after RDT) was used.

Figure 14 shows a graphical representation of the times considered. The red numbers show the RDT time steps. The left image shows that data in the 10 minutes before and after the RDT time steps (red, blue, green and yellow zones) was used for the older cases. The image on the right shows that radar data for the six minutes following the 00- and 30-minute RDT time steps (blue zones), and three minutes before and after the 15 and 45-minute RDT time steps (green zones) were used for the newer cases.

For all cases, the seven hours from 11:00 UTC to 18:00 UTC (13:00–20:00 SAST time) were used, similar to the cases in Chapter 2.

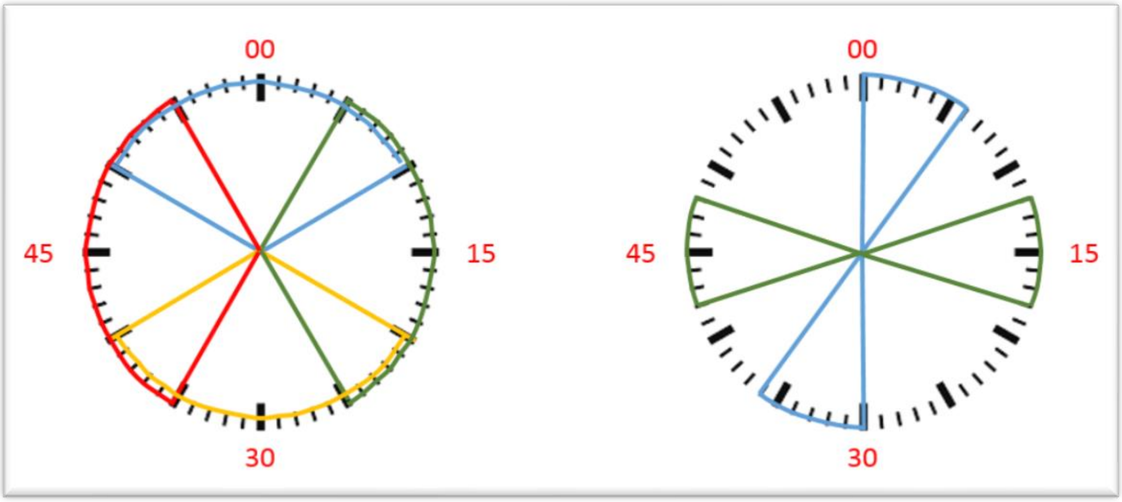

Figure 14: Graphical representation of the radar periods considered in relation to the RDT times (red). The image on the left is for the older 2011, 2012 and 2013 cases, while the image on the right is for the newer 2015 cases

When radar data is considered, 30 dBZ is usually seen as the threshold to start tracking thunderstorms. A reflectivity value of 30 dBZ indicates light rain or drizzle, 40 dBZ indicates moderate rain, and 50 dBZ indicates heavy rain. At reflectivity values above 50 dBZ, hail is likely (Storm Identification, n.d.).

Using an object approach, most cell-tracking algorithms define such an object as an area where the reflectivity exceeds a threshold: 35 dBZ, 40 dBZ and 45 dBZ are most typically used (Dixon & Wiener, 1993). The RDT product is aimed at identifying intense rapidly developing storms or parts of storms. RDT can also distinguish between growing, mature and developing storms. In order to consider all the phases of the storms in the evaluation of the RDT product, radar reflectivities greater and equal to 35 dBZ were used to exclude less significant storms and align with the RDT principle of rapidly developing and/or intense parts of thunderstorms.

The threshold of 35 dBZ was also recommended by Météo-France: “35 dBZ is the first threshold we use to follow radar-detected convection” and “our aeronautical end-user define the 36 dBZ as ‘moderate convection’” (Moisselin, 2016). The RDT polygons were thus validated against all radar reflectivity areas greater or equal to 35 dBZ.

The RDT algorithm is an object-orientated methodology to identify and track thunderstorms by means of polygons for different phases of convective storms – triggering, growing and mature. These polygons were validated to the 35 dBZ and higher reflectivity polygons in an object-orientated methodology, similar to the method described in Chapter 2.

3.4.1 Results of 25 RDT cases validated against radar data, with and without lightning data

Figure 15 illustrates the HSS for all 25 cases where RDT was evaluated against radar (excluding and including the lightning data as input). The HSS has a perfect score of 1 (Wilks, 1995). The average HSS per day for all 25 days for the RDT product without lightning data included was 0.61, while for the RDT product with lightning data included the average HSS was 0.66. By including lightning data in the RDT input data, HSS improved by 5%. For the cases indicated by a yellow star, the RDT with lightning included in the input data set had a higher HSS than the RDT where lightning data was not included. A blue cross indicates the cases where the RDT without lightning data included in the input data set performed better or the same. From the 25 cases, 21 performed better when lightning data was included, three marginally poorer, and one case had the same result.

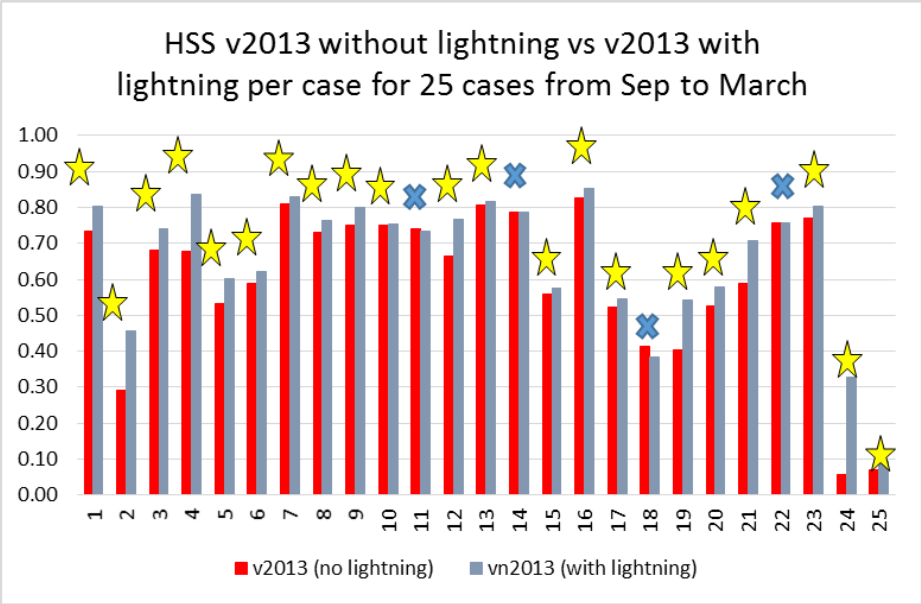

Figure 15: HSS of the 25 cases validated against radar data without (red bars) and with (blue bars) lightning data included in the input data

Figure 16 compares the POD and FARatio for the RDT product with and without lightning data included in the software for 25 cases. On average, the POD for all 25 cases was 6.6% better with lightning data included in the input data set. The FARatio when lightning data was included was marginally higher than when lightning data was not included in the RDT (0.1%). For most cases, the RDT with lightning data included performed better compared to when no lightning data was included in the input data set (indicated by yellow stars).

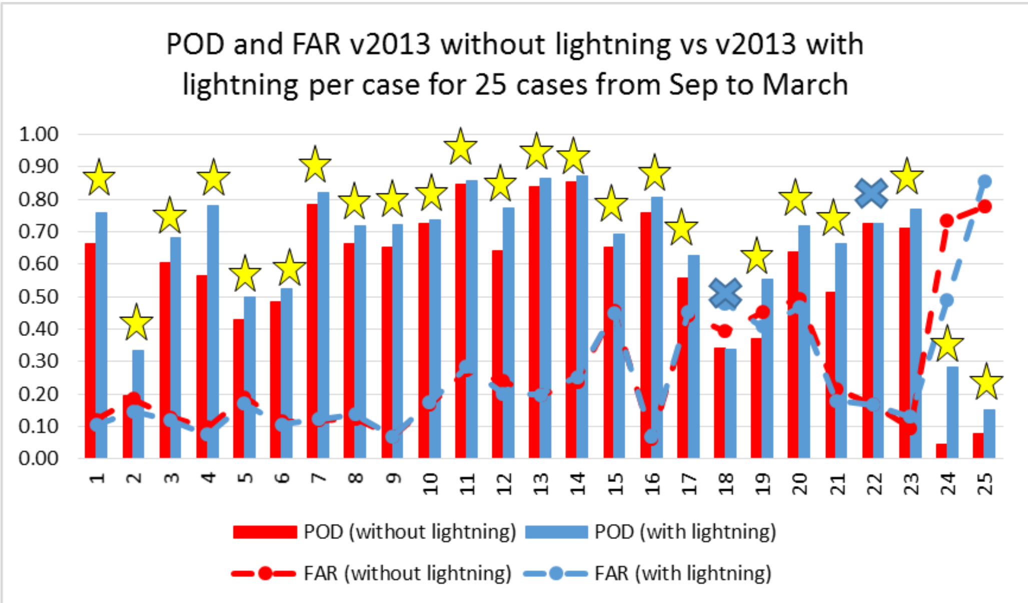

Figure 16: POD and FARatio for 25 cases validated against radar data for the RDT product without (red) and with (blue) lightning data added in the software

Figure 17 compares the HSS, POD and FARatio for all 25 cases for the different times of the day. The HSS is between 0.5 and 0.8 for all hours from 11:00 UTC to 18:00 UTC and shows an improvement to the RDT product for all time steps when lightning data was included in the input. The POD when lightning data was included in the input data set is better for all times and the FAR is similar with/without lightning data included. From this graph, it is clear that the RDT validates well against radar for all relevant hours, and shows an improvement when lightning data is added to the input data set.

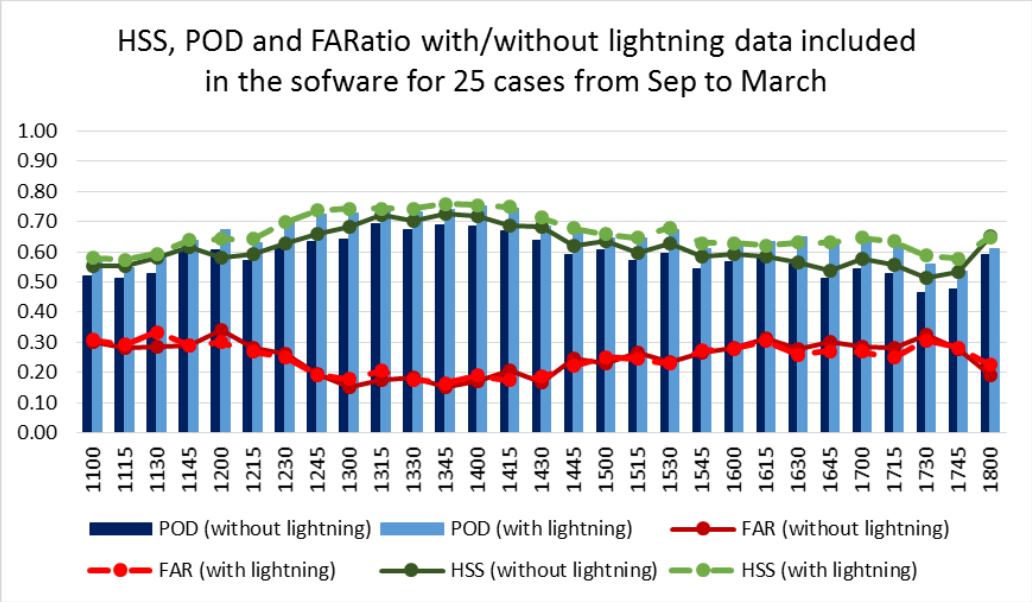

Figure 17: POD, FARatio and HSS for 25 cases validated against radar data for the RDT without lightning data included (darker colours and solid line) and RDT with lightning data included (lighter colours and dashed line)

3.4.2 Discussion of a few cases

3.4.2.1 Case 1: 17 October 2012

Figure 18 shows the RDT with (right) and without (left) lightning data included in the input data set at 17:00 UTC on 17 October 2012. Radar reflectivity for the same time is shown on the bottom of the image. It is clear that the two RDT images are similar, but a few additional storms were detected when lightning data was included (top right). The storms indicated by the green and yellow arrows were not identified by RDT without lightning data included in the input (top left), but were identified when lightning data was used as input (top right).

The radar image indicates that the more intense storms did occur over these areas. Another difference between the RDT images is that the phase of some of the storms changes when lightning data was included. This is especially true for storms that were classified as decaying and were reclassified as mature storms with the inclusion of lightning data.

An average of all the time steps for this case indicates that the POD was higher when lightning data was included in the input (0.78) compared to when no lightning was added (0.57), the FAR slightly better (0.07 compared to 0.09), and the HSS also higher (0.84 compared to 0.68).

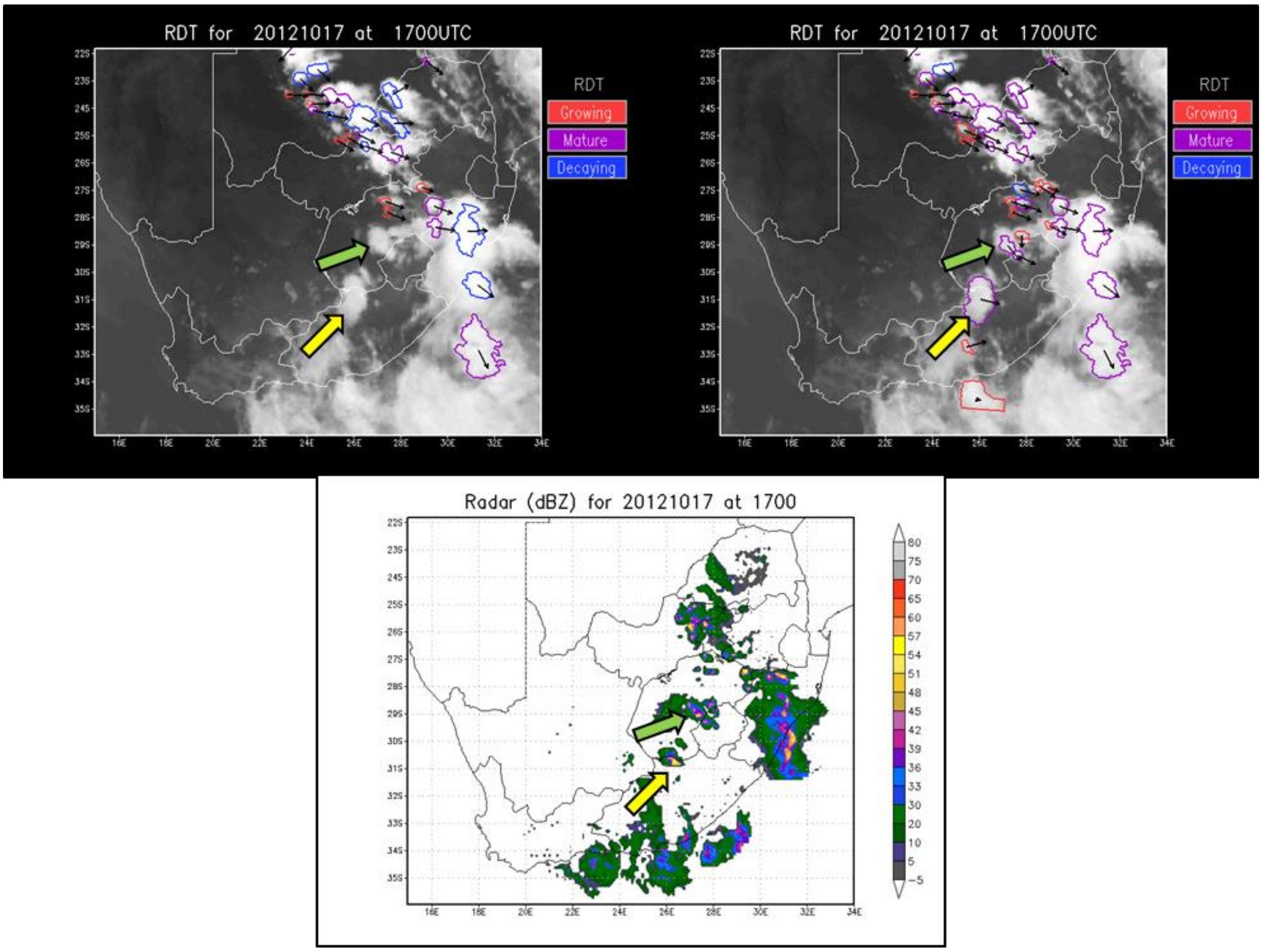

Figure 18: RDT without (left) and RDT with (right) lightning data included in the input data set compared to radar reflectivity (bottom) for 17 October 2012 at 17:00 UTC

3.4.2.2 Case 2: 20 October 2012

Figure 19 compares the RDT without (left) and RDT with (right) lightning data added to the input data for 17:00 on 20 October 2012 with the radar reflectivity image for the same time. The two RDT images are similar, except that a few additional storms were identified when lightning data was included.

The grey and yellow arrows show that these storms were also visible on the radar image. The average of all the time steps for this day indicate that there was a 7% improvement in the POD (0.5 vs 0.43), a 2% improvement in the FAR (0.17 vs 0.19), and a 7% improvement in the HSS score (0.6 vs 0.53) when lightning data was included in the RDT software.

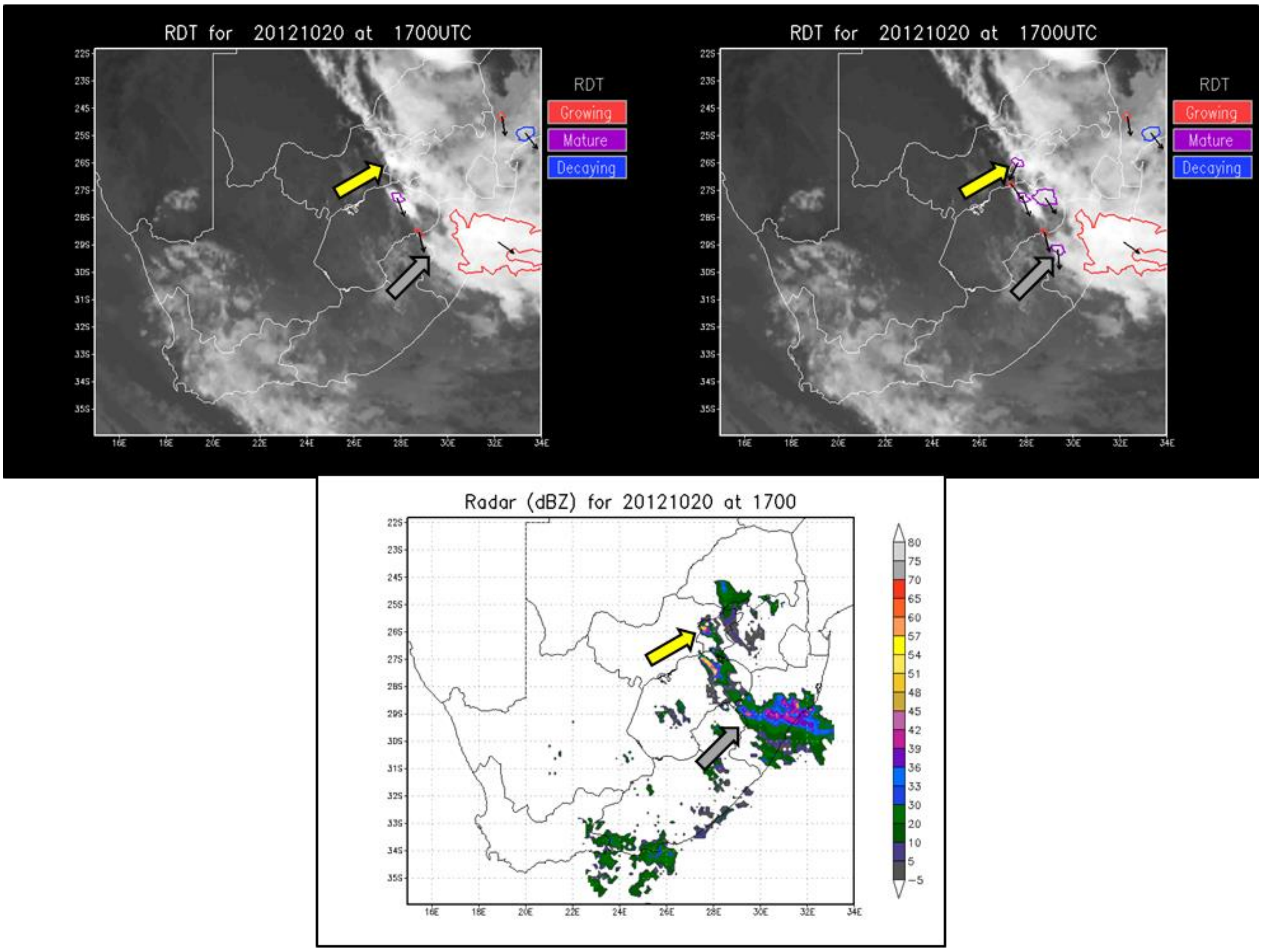

Figure 19: RDT without (left) and RDT with (right) lightning data included in the software compared to radar (bottom) for 20 October 2012 at 17:00 UTC

3.4.2.3 *Case 3: 21 March 2015*

Figure 20 shows the RDT without lightning included (left), RDT with lightning included (right) and the radar image (bottom) for 13:00 UTC on 21 March 2015. Additional storms were again identified when lightning data was included in the input and some of the storm phases changed. An intense storm over the Free State, as indicated by the yellow arrow, was identified when lightning data was included. This intense storm can be seen on the radar image. The average of all time steps for this day shows that the POD score improved by 5% (0.81 vs 0.76), the FAR increased slightly (0.067 vs 0.062) and the HSS improved by 2% (0.85 vs 0.83) when lightning data was added to the software.

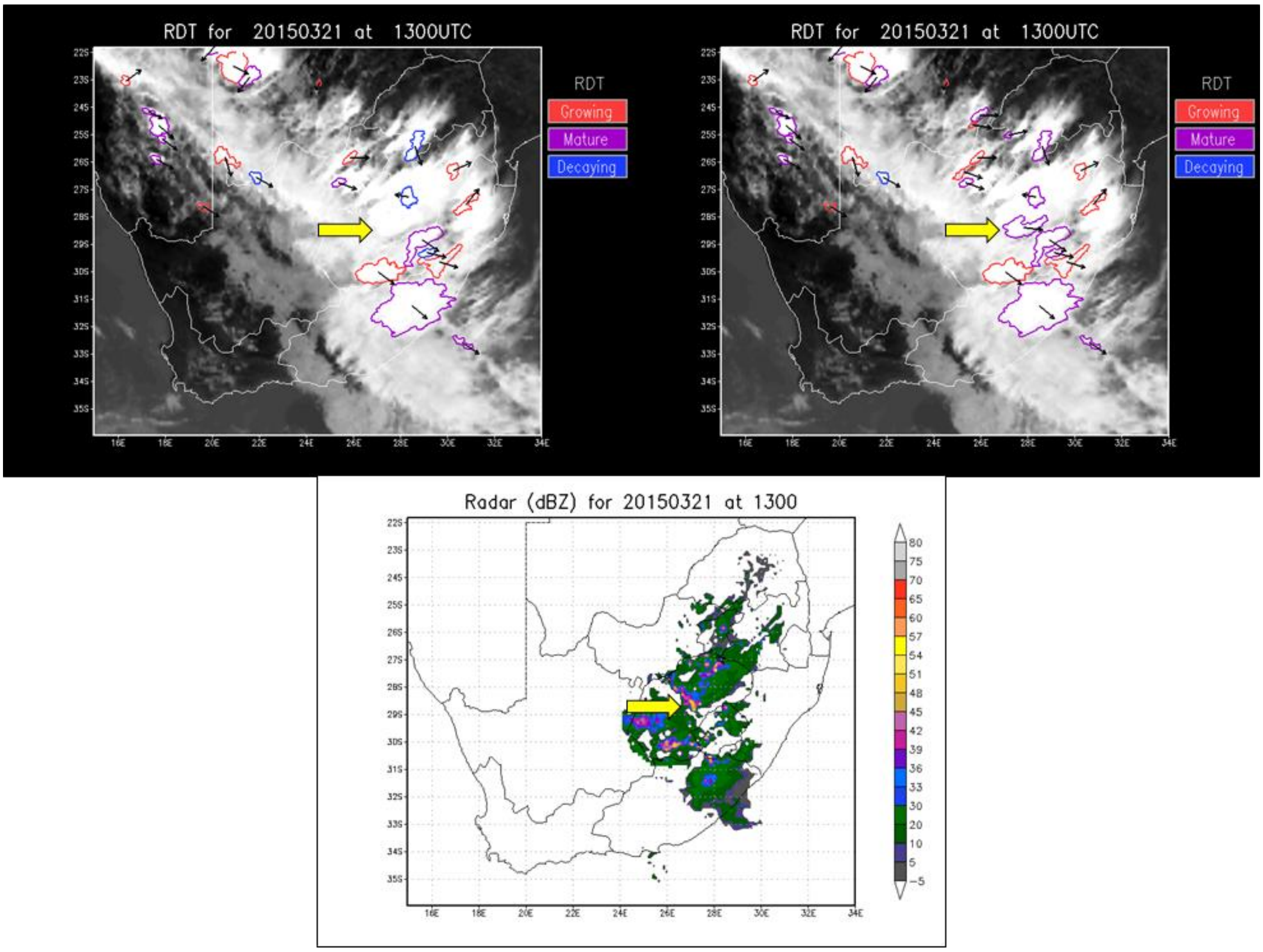

Figure 20: RDT without (left) and RDT with (right) lightning data included in the input data compared to radar reflectivity (bottom) for 21 March 2015 at 13:00 UTC

3.4.3 Summary of RDT cases

Twenty-five cases between September and March (convective season) were used to validate the RDT with and without lightning data included in the input data set over South Africa. Statistical scores were calculated using radar reflectivity data from the SAWS radar network of more than 35 dBZ as ground truth for each time step between 11:00 UTC and 18:00 UTC. In most cases, the RDT with lightning data added outperformed the RDT when no lightning data was added. The POD improved by 6.6%, the HSS by 4.6% and the FAR by 0.1%.

Changes could be seen when images for individual times were compared (RDT with and without lightning data added as well as radar). In a large number of the cases, the inclusion of lightning data in the input data set identified storms that were not at first identified when lightning was not added. The inclusion of lightning data also resulted in some of the storm phases being reclassified. This was mostly true for decaying storms that were reclassified as mature storms when lightning data was added.

3.5 Results of the CRR Case Studies With and Without Lightning Data As Input

The same 20 cases were used to compare the NWC SAF software with and without lightning data as input against daily rainfall totals from rain gauges. The same methodology (as described in Chapter 2) used by the IPWG (n.d.) was used to validate the CRR with and without lightning data as input to daily rainfall totals measured by the rain gauges. Three thresholds were used to determine the performance for light to heavier falls, namely, 1 mm, 10 mm and 20 mm.

3.5.1 Results of 20 cases with and without lightning data as input

Figure 21 shows the average statistical scores for daily rainfall from CRR with and without lightning data input when compared to rain gauge totals. For all scores, the CRR with lightning data as input performed better; however, the FARate and FARatio scores were slightly worse when lightning data was included.

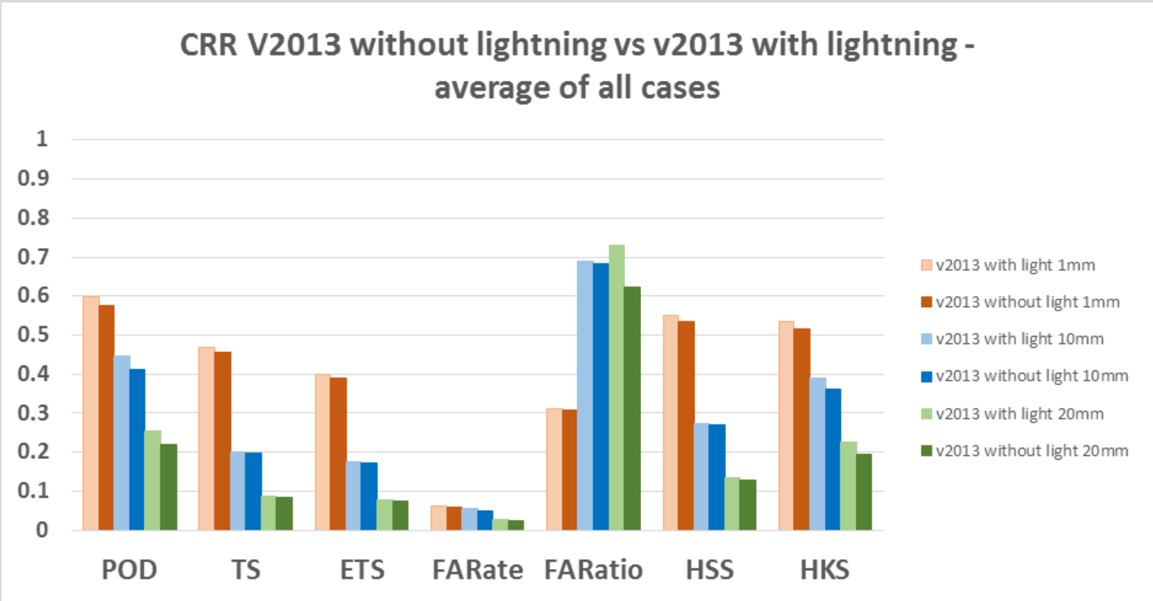

Figure 21: Average POD, TS, ETS, FARate, FARatio, HSS and HKS for CRR with (lighter bars) and without lightning data (darker bars) as input compared to rain gauge data on a daily basis for all 20 cases. Three thresholds were tested, 1 mm (red), 10 mm (blue) and 20 mm (green)

Figure 22 shows the POD and HSS per case for the 1 mm threshold. In some cases, the scores are very similar, but for most, the CRR with lightning outperformed the CRR without lightning for the 1 mm threshold.

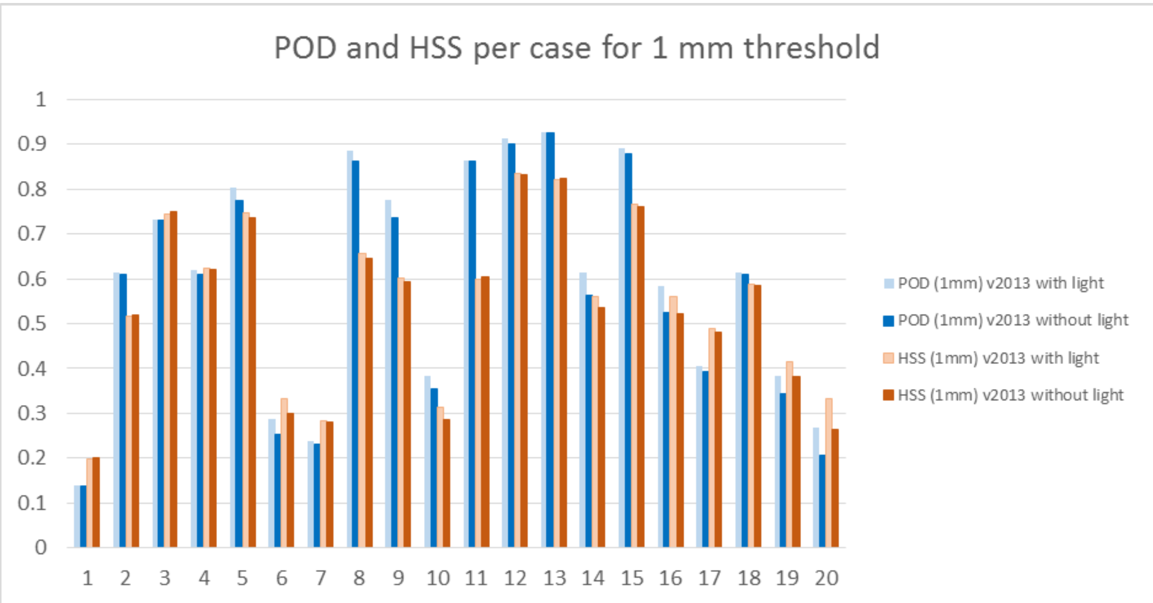

Figure 22: POD (blue bars) and HSS (red bars) for CRR with (lighter bars) and without lightning (darker bars) compared to rain gauges on a daily basis for all 20 cases for the 1 mm threshold

Table 6 gives the MAE, ME and the bias for all 20 cases. The MAE, ME and bias when lightning data was included are slightly worse than CRR without lightning data.

Table 6: MAE, ME and bias for 1 mm, 10 mm and 20 mm thresholds

	MAE	ME	Bias 1 mm	Bias 10 mm	Bias 20 mm
CRR with lightning data	1.9807	0.5534	0.8694	1.5902	1.9897
CRR without lightning data	1.9022	0.3900	0.8328	1.4560	1.7266

3.5.2 Discussion of a few cases

3.5.2.1 Case 1: 16 March 2015

On the 16 March 2015, daily rainfall totals from the rain gauges (Figure 23, top left) indicate that precipitation occurred along the south and south-eastern coastal regions, which is consistent with the passage of a surface cold front. Higher rainfall totals were indicated for the central interior of KZN. The rainfall total patterns are very similar. For the 1 mm threshold on this day, the HSS was 0.30 excluding lightning data and 0.333 including lightning data.

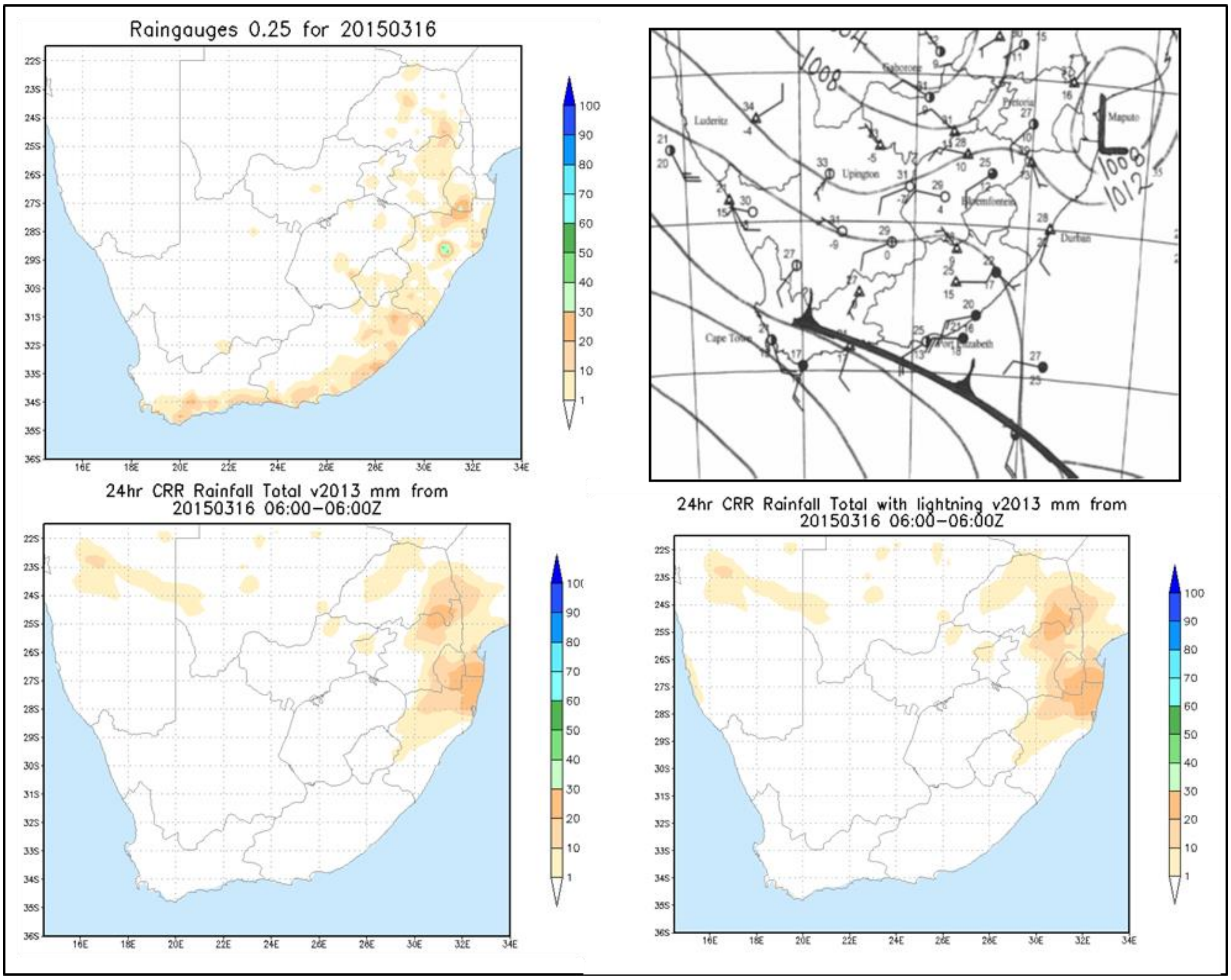

Figure 23: Daily rainfall total as measured by the rain gauges (top left), synoptic circulation pattern (top right), daily rainfall total as estimated by CRR without lightning data (bottom left) and daily rainfall total as estimated by CRR with lightning data (bottom right) for 16 March 2015

3.5.2.2 *Case 2: 19 November*

On 19 November 2013 (Figure 24), heavier falls were recorded over the Free State and North West provinces and this was captured well by the CRR algorithm. The rainfall patterns were very similar. For the 1 mm threshold on this day, the HSS was 0.517 with lightning data and 0.52 without lightning data. The same scores for the 10 mm threshold were 0.298 (excluding lightning data) and 0.35 (including lightning data), respectively.

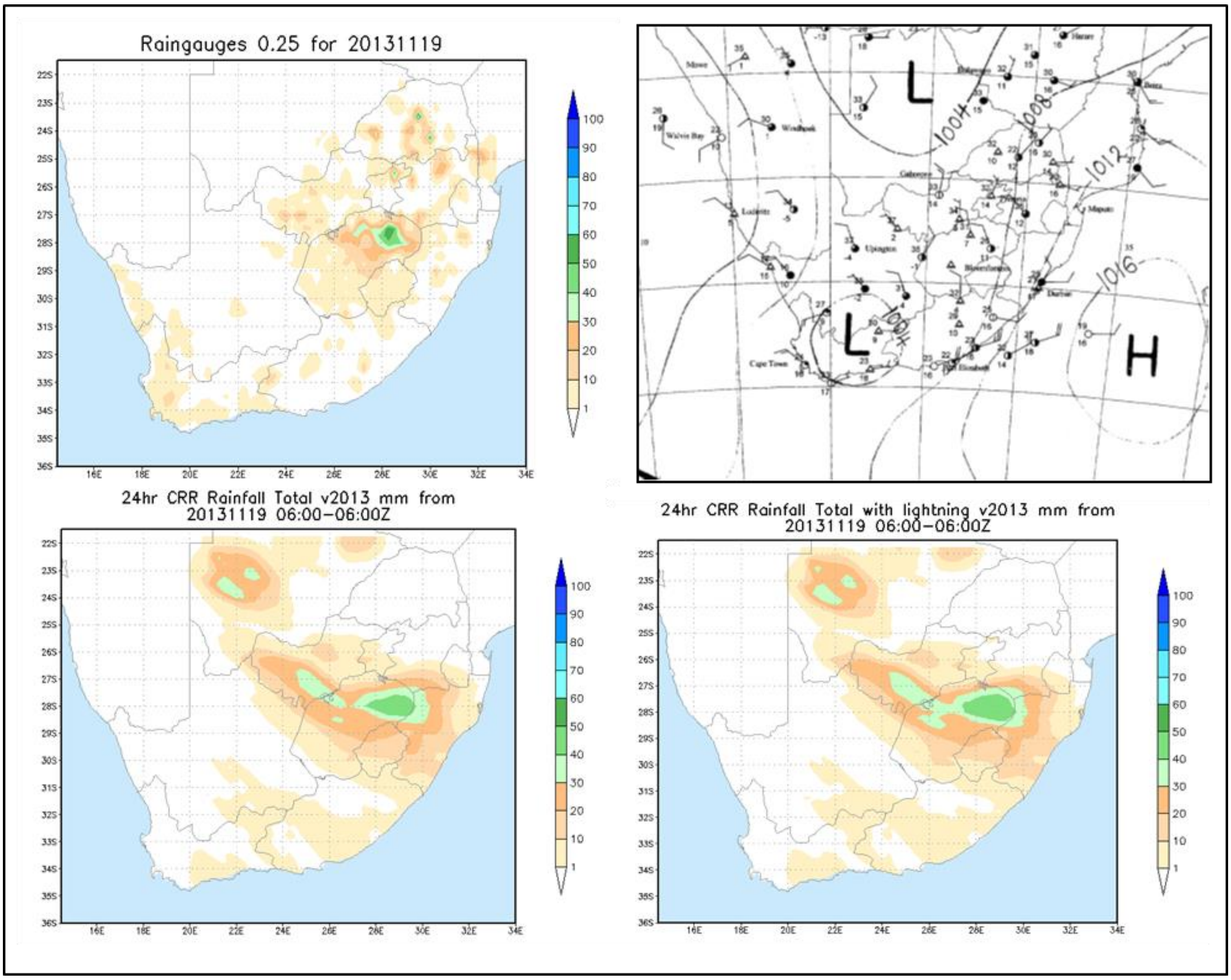

Figure 24: Daily rainfall total as measured by the rain gauges (top left), synoptic circulation pattern (top right), daily rainfall total as estimated by CRR excluding lightning data (bottom left) and daily rainfall total as estimated by CRR including lightning data (bottom right) for 19 November 2013

3.5.2.3 Case 3: 23 March 2015

On 23 March 2015 (Figure 25), widespread thunderstorms occurred over the central parts of the country, while heavier falls were recorded over the southern interior. An increase in rainfall intensity was visible over KZN when the lightning data was included in the CRR algorithm. For the 1 mm threshold on this day, the HSS was 0.819 for CRR with lightning data and 0.82 for CRR without lightning data. For the 10 mm threshold, the CRR was better when the lightning data was included (0.447 compared to 0.426). Very small differences occurred, but in general, the patterns are the same.

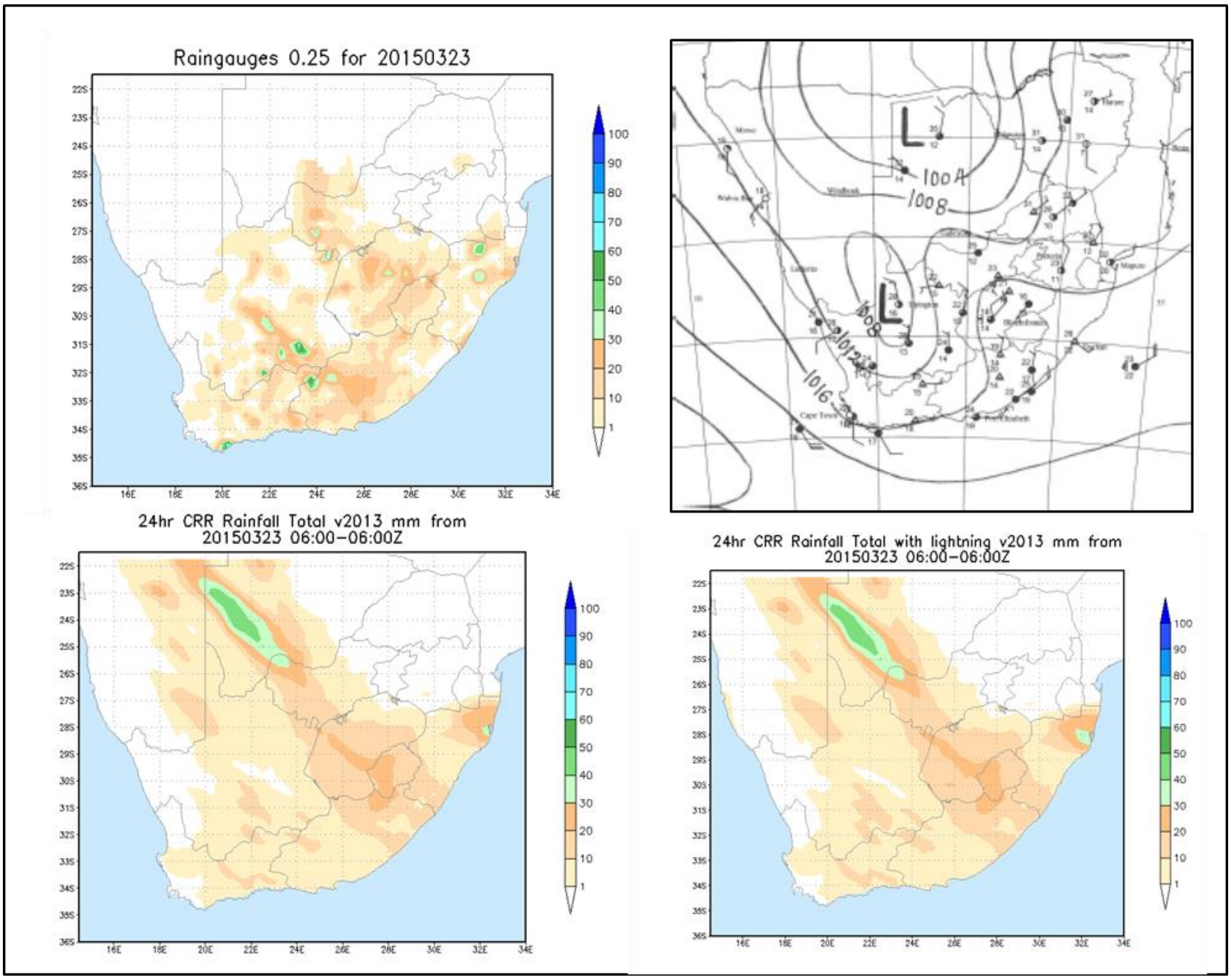

Figure 25: Daily rainfall total as measured by the rain gauges (top left), synoptic circulation pattern (top right), daily rainfall total as estimated by CRR without lightning data (bottom left) and daily rainfall total as estimated by CRR with lightning data (bottom right) for 23 March 2015

3.5.3 Summary of CRR cases

Twenty cases between September and March (convective season) were used to validate the CRR product with and without lightning data as input over South Africa. Statistical scores were calculated using the daily rainfall totals from the rain gauges as ground truth. In most cases, the CRR with lightning data was very similar or slightly better than the CRR without lightning data. Three thresholds were used to validate the CRR algorithms, namely, 1 mm, 10 mm and 20 mm.

On average, the POD, HKS and HSS were all slightly better when lightning data was included, while the FAR was slightly higher (worse) for all three thresholds. The bias scores indicate the CRR with lightning overestimates the intensity of the rainfall, more so than when lightning data was not included. Adjustments to the intensity of the CRR algorithm could improve when the 925 hPa level of the NWP will be added when the new UM becomes operational since the absence of this level negatively affects the intensity of rainfall as moisture correction cannot be done. Small changes could be seen when images for individual days were compared (with and without lightning input), but in general, the results are very similar.

3.6 Summary and Conclusion on the Comparison Between the RDT and CRR Products When Lightning Data is Included/Excluded as Input Data

The goal of this chapter was to compare the RDT and CRR products with and without lightning data as input. The RDT algorithm was compared for 25 cases. The results indicate that in general for most cases the RDT with lightning data added as auxiliary data to the software performed better than RDT without lightning added. The CRR algorithm was compared for 20 cases and the results indicate that in general for most cases the CRR was slightly better when lightning data was included than without lightning data. Including the lightning data into the CRR algorithm, however, leads to more overestimation of the intensity of the rainfall. The CRR algorithm performs best for convective rainfall cases (as the name indicates). Stratiform rainfall associated with the passage of a cold front or ridging high-pressure system is not captured well by this algorithm.

It is recommended that lightning data be added to the RDT product. When lightning data is added as auxiliary data to the algorithm, the RDT product shows an improvement of about 5% compared to when lightning is not included. The addition of lightning data to the software also reclassifies some of the storm phases that seems more correct when compared to radar data.

It is recommended that the lightning should not be included in the CRR algorithm at this point in time due to the enhanced overestimation in the intensity of rainfall. Possibilities to improve the CRR in the future would include:

- Including the 925 hPa level in the NWP input (to be able to do a humidity correction).
- Improving the UM resolution (as planned by SAWS).
- Establishing the relationship between RR and lightning occurrence over South Africa to adjust the parameters that are currently set for European conditions.

CHAPTER 4. IMPLEMENTATION, APPLICATIONS AND CAPACITY BUILDING

The latest version of the software (v2013) is currently operational at the SAWS. In Chapter 3, the results of the tests conducted showed that adding the lightning data as input to the RDT and CRR products has a positive impact on the RDT and very little improvement on the CRR. The next step was to implement the lightning data into the operational creation of the RDT product.

4.1 Implementation and Applications of the RDT Product with Lightning Data

According to the RDT Algorithm Theoretical Basis Document (NWC SAF Documentation, 2013b), including lightning data in the RDT product "greatly contributes to the diagnosis of convection". This was also confirmed with the results of Chapter 3.

To include lightning data in the processing for RDT, a few settings were made in the configuration file on recommendation of the developers:

- A period of 600 seconds (10 minutes) before and after each RDT time step is used as the time window for lightning data to be included in the calculation.
- Three satellite pixels are set as the distance between the satellite cell and the lightning flash with which it is associated.
- An RDT polygon is associated with 15 or more lightning strokes.

Since February 2016, lightning data has been provided on an operational basis to be used by the algorithm calculations. Scripts run every 15 minutes to prepare the lightning data. This involves copying the most recent lightning data to the relevant directory, sorting the data to select the correct times to be used for the RDT time step, and converting the data into the correct format needed by the processing software. Since February 2016, lightning data has been included in the input data of the RDT operationally and this is showing favourable results. Future improvements will be considered when the new high-resolution UM is added to the software and when the new updated version 2016 of the NWC SAF software package is installed at SAWS. A few examples are shown:

4.1.1 Examples of the new operational RDT products for February 2016

4.1.1.1 Case 1: 14 February 2016

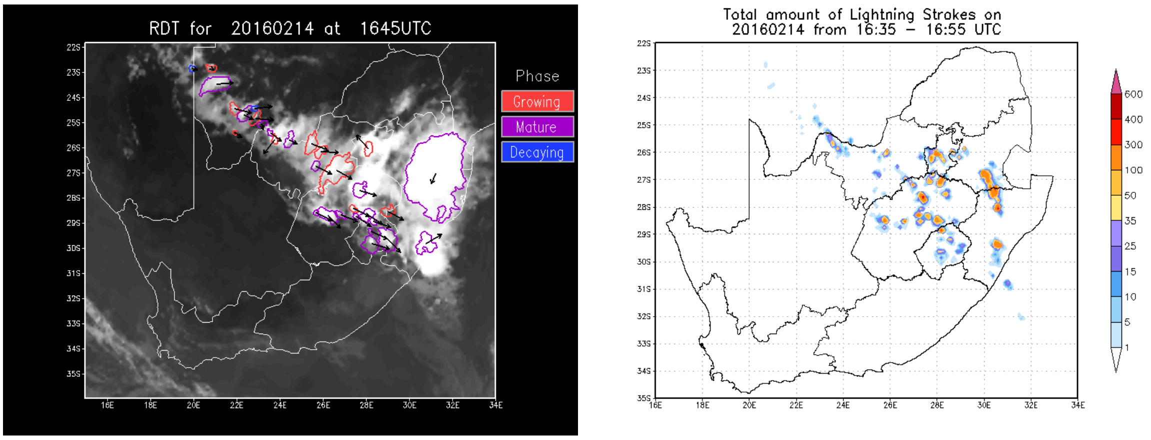

Figure 26: RDT with lightning data included in the software compared to lightning that was used as input for 14 February 2016 at 16:45 UTC

4.1.1.2 Case 2: 15 February 2016

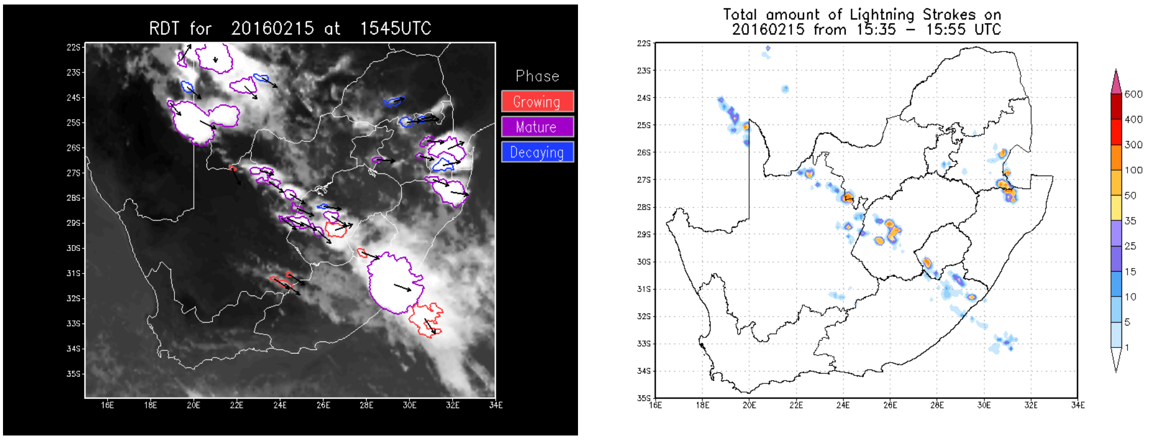

Figure 27: RDT with lightning data included in the software compared to lightning that was used as input for 15 February 2016 at 15:45 UTC

4.1.1.3 Case 3: 16 February 2016

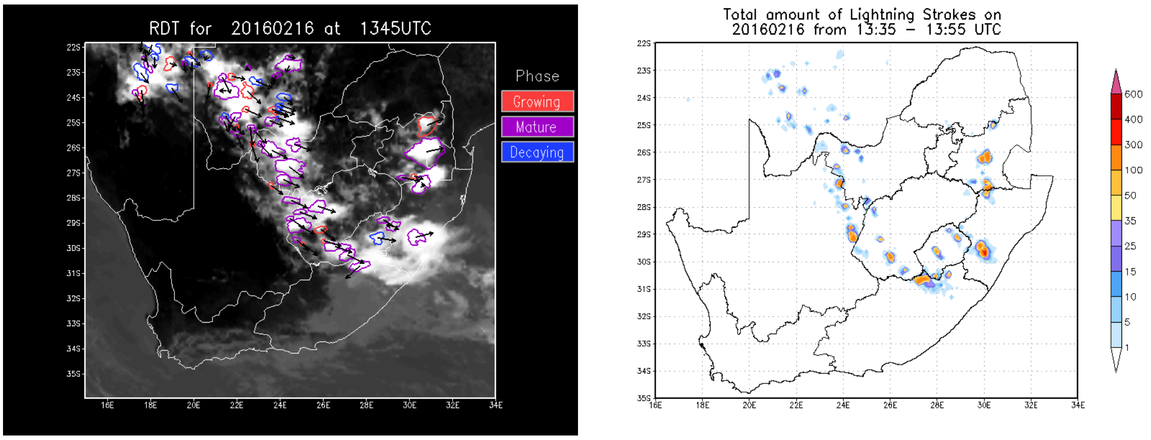

Figure 28: RDT with lightning data included in the software compared to lightning that was used as input for 16 February 2016 at 13:45 UTC

4.1.1.4 Case 4: 17 February 2016

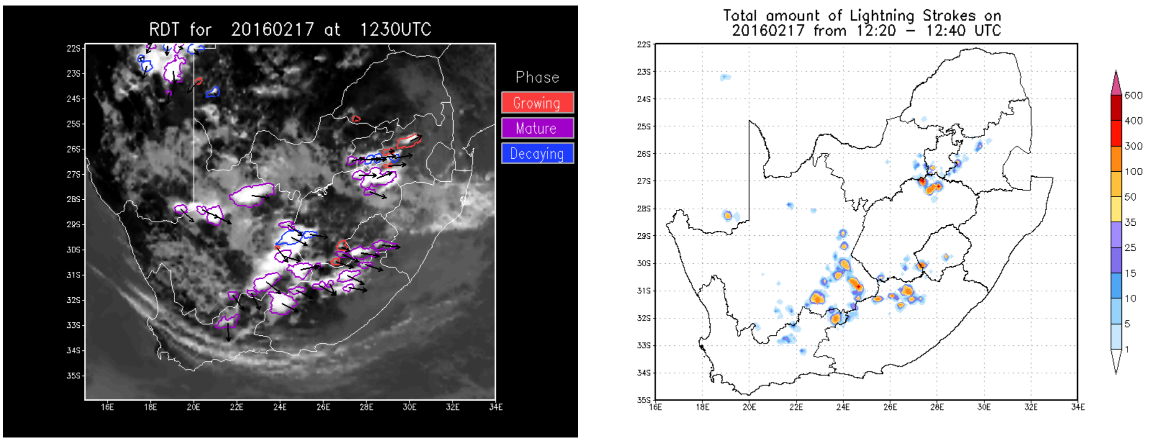

Figure 29: RDT with lightning data included in the software compared to lightning that was used as input for 17 February 2016 at 12:30 UTC

4.1.1.5 Case 5: 18 February 2016 at 12:45 UTC

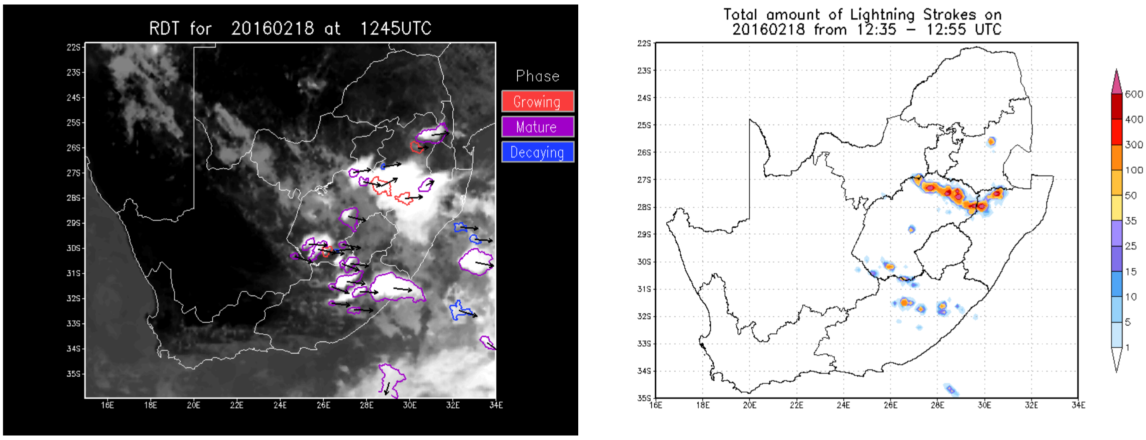

Figure 30: RDT with lightning data included in the software compared to lightning that was used as input for 18 February 2016 at 12:45 UTC

4.2 Capacity Building with Forecasters from South Africa and Southern Africa

Forecasters in South Africa and southern Africa have been informed about the progress made on the implementation of the latest NWC SAF products in several ways:

Refresher course to operational forecasters (November 2015)

Identification and Tracking of Thunderstorms Using Satellite Data – RDT (6 November 2015) – A refresher lecture on the background and usefulness of the RDT product with examples was presented to operational forecasters from Pretoria and the regional offices via teleconference. These presentations showed the latest improvements to the products and some case study examples.

Severe Weather Forecasting Demonstration Project training event (12 November 2015)

Presentations were done during the Severe Weather Forecasting Demonstration Project (SWFDP) training event to forecasters from the SADC region on 12 November 2015. This was the annual training event for the SWFDP. This event was attended by forecasters from 15 African countries including South Africa, Lesotho, Botswana, Swaziland, Angola, Seychelles, Zimbabwe, Zambia, Tanzania, Namibia, Madagascar, La Reunion, the Democratic Republic of the Congo, Malawi and Mozambique.

During the 2015 event, several examples of the RDT case studies and the operational product were shown. An advantage is that the RDT product was operationally available on the Regional Specialised Meteorological Centre (RSMC) website, which is available to all southern African countries. The programme content (all the presentations) is available on the RSMC website (RSMC, n.d.).

Refresher course to aviation forecasters (March 2016)

A refresher course on satellite-based nowcasting tools at SAWS, including the background and usefulness of RDT and CRR products, was presented to aviation forecasters at OR Tambo International Airport on 10 March 2016.

Workshop on current and new nowcasting tools (September 2016)

A workshop dedicated to nowcasting tools was held in September 2016. Representatives of all regional forecasting offices in South Africa were invited. At this workshop, various nowcasting tools were discussed and demonstrated, amongst which were the RDT and CRR product with examples and validation. The workshop was held at the SAWS headquarters in Pretoria and was attended by eight forecasters from the Regional Offices: OR Tambo, Bloemfontein, Cape Town, Port Elizabeth, Durban and Pretoria Head Office. The Regional Training Centre was also represented with five forecaster interns.

SWFDP training event (27 October 2016)

Presentations were done during the SWFDP training event to forecasters from the SADC region on 27 October 2016. This was the annual training event for the SWFDP. This event was attended by forecasters from 13 African countries including South Africa, Lesotho, Swaziland, Mauritius, Seychelles, Comoros, Zimbabwe, Tanzania, Namibia, Madagascar, the Democratic Republic of the Congo, Malawi and Mozambique.

During the 2016 event, several examples of the RDT case studies and the operational product were shown. The RDT product was operationally available on the RSMC website, which is available to all southern African countries, and could be used to demonstrate the usefulness of the products. A new interactive display of the RDT available to southern African countries was also demonstrated at the event and was received with great enthusiasm. The programme content (all the presentations) is available on the RSMC website (RSMC, n.d.).

4.3 Presentations at National Level

The research work done on the products of the Nowcasting Satellite Application Facility (specifically the RDT and CRR) was presented at the following national events:

- Use of Satellite Data in Nowcasting to the World Meteorological Organization (WMO) Meeting of the CCl Task Team on the use of remote sensing data for Climate Monitoring. "Remote sensing: Using Geostationary Satellite Data for Nowcasting (0–2 hours)" (10–12 June 2015). Pretoria.
- An information session with aviation clients on the use of satellite data to track thunderstorms. "Satellite-based Products for Nowcasting" (20 April 2015). South African Airways offices.
- A refresher on the background and usefulness of the RDT product with examples, an online presentation through the WMO Regional Training Centre for SADC forecasters. "Identification and Tracking of Thunderstorms Using Satellite Data – RDT" (29 October 2015). Pretoria.
- SWFDP training event (12 November 2015). Pretoria.
- SWFDP training event (27 October 2016). Pretoria.
- The RDT products were presented at the South African Society for Atmospheric Scientists (SASAS) conference. "Recent Improvements to the Rapidly Developing Thunderstorm Product: The Addition of Lightning Data" (31 October 2016 to 1 November 2016). Cape Town.

4.4 Presentations at International Level

The use of satellite-based tools for nowcasting purposes is widely acknowledged for developing countries where radar systems are not necessarily available. The use of various satellite-based tools, including the RDT and CRR products, was presented at various international events:

WMO Aviation Research Demonstration Project (24–25 June 2015): A Presentation to Demonstrate the Uses of Satellite-based Tools for Aviation Nowcasting in South Africa

Estelle de Coning was a speaker at the Aviation Research and Development Project (AvRDP) kick-off meeting held in Shanghai, China, from 24 to 25 June 2015. At this meeting, satellite-based tools such as the RDT and CRR products from the NWC SAF software were demonstrated for the use by the aviation industry. The OR Tambo International airport is one of the airports in the AvRDP project.

WMO Nowcasting Meeting in Mwanza, Tanzania (17–20 August 2015): A Presentation on Satellite-based Tools for Data-sparse Regions such as Africa

Estelle de Coning was invited to take part in the WMO Nowcasting meeting that took place in Mwanza, Tanzania, from 17 to 20 August 2015. The purpose of this meeting was to develop a framework for nowcasting in the Lake Victoria region. Presentations on the use of the NWC SAF software, including the RDT and CRR products, were presented.

EUMETSAT Conference in Toulouse, France (20–25 September 2015): Using the Nowcasting SAF Products over South Africa and Southern Africa to Enhance Nowcasting Capabilities in Data-sparse Regions

Estelle de Coning was a keynote speaker of a paper presented at the EUMETSAT conference, which was held in Toulouse, France, from 20 to 25 September 2015, entitled: Using the Nowcasting SAF Products over South Africa and Southern Africa to Enhance Nowcasting Capabilities in Data-sparse Regions.

Eastern African WMO SWFDP Training Event in Addis Ababa, Ethiopia (19–20 November 2015)

A presentation on nowcasting products including the use of the RDT and CRR products was presented at the Eastern African WMO SWFDP training event in Addis Ababa, Ethiopia, from 19 to 20 November 2015. A practical session on the products was also given to forecasters to practise using the products in an operational setting.

WMO Task Team on Guidelines for Nowcasting in Shanghai, China (15–17 March 2016)

Estelle de Coning presented a presentation on satellite nowcasting at a WMO task team meeting on the development of guidelines for nowcasting techniques in Beijing, China, from 15 to 17 March 2016, entitled: Using the Satellite and NWP Blended Products for Nowcasting in Data-sparse Regions. As part of her presentation, the RDT and CRR products were presented.

WMO Nowcasting Symposium in Hong Kong, China (25–29 July 2016)

Estelle de Coning presented a presentation at the WMO WWRP International Symposium on Nowcasting and very short-range forecasts in Hong Kong from 25 to 29 July 2016, entitled: Nowcasting for Aviation Purposes in South Africa – A Case Study: Part 1 – Satellite and Radar-based Tools.

As part of the presentation, the RDT product and its use for aviation purposes was demonstrated.

4.5 Publications

SASAS 2016

Morné Gijben was the first author of a paper presented at the SASAS conference, which was held in Cape Town from 31 October to 1 November 2016, entitled: Recent Improvements to the Rapidly Developing Thunderstorm Product – The Addition of Lightning Data.

Reference to the extended abstract is as follows:

> Gijben M., Maseko B., Van Hemert L. and De Coning E. Recent Improvements to the Rapidly Developing Thunderstorm Product – The Addition of Lightning Data. 32nd Annual Conference of the South African Society for Atmospheric Science, 31 October to 1 November 2016, Cape Town. ISBN 978-0-620-72974-1.

Submission to Remote Sensing journal 2017

A paper entitled Using Satellite and Lightning Data to Track Rapidly Developing Thunderstorms in Data-sparse Regions was submitted to the Remote Sensing journal in January 2017 for possible publication.

4.6 Enrolment for MSc Study

Morné Gijben was enrolled for his MSc studies at the University of Pretoria in 2015 and 2016. He completed his degree with distinction and received his degree certificate on 1 September 2016. Morné Gijben would like to thank the WRC for allocating money to the project for skills development that could be used to pay the 2015 and 2016 registration fees at the University of Pretoria.

Bathobile Maseko started with her MSc degree in 2016 at the University of Potchefstroom and is currently in the process of registering for the 2017 academic year. Bathobile is making satisfactory progress with her degree and would like to thank the WRC for allocating money to the project for skills development that could be used to pay the 2016 registration fee at the University of Potchefstroom.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion of the Project

The aims of this research project were:

- To use and test the latest version of the nowcasting software (v2013) against the previous version (v2012) for the RDT and CRR products on a dedicated server at SAWS using information from the MSG satellite and model input from the local version of the UM.
- To include lightning data from the SALDN as auxiliary data to further enhance the accuracy of the products.
- To transfer skills to forecasters from South Africa as well as southern Africa to understand the improvements to the products and its usefulness (through training sessions and/or workshop presentations).
- To make the improved RDT and CRR products operationally available to all forecasters in South Africa as well as the SADC via the internet.

For the first aim of this project, the v2012 and v2013 of the RDT and CRR products were compared to see if there were differences between the two. Twenty-five cases between September and March (convective season) were used to validate the v2012 and v2013 versions of the RDT product over South Africa. The RDT was validated against lightning data for each time step between 11:00 UTC and 18:00 UTC. In most of the 25 cases, the RDT v2013 performed similarly to the RDT v2012 and showed indications of small improvements in the newer version. When the different time steps were compared, it was evident that both v2012 and v2013 performed well at all hours of the day, with a slight decrease in performance towards the latter part of the period. Small changes could be seen when images for individual times were compared (v2012 to v2013), but in general, the results show a slight improvement due to the minor updates in the latest version of the software.

For the CRR product, 20 cases between September and March (convective season) were used to validate the v2012 and v2013 versions of the CRR product over South Africa. Statistical scores were calculated using the daily rainfall totals from the rain gauges as ground truth. In most cases, the CRR v2013 was very similar or slightly better than the CRR v2012. The bias scores indicate that the CRR v2013 overestimates the intensity of rainfall, more so than v2012. Adjustments to the intensity of the CRR algorithm could improve when the 925 hPa level of the NWP will be added in the new UM. The absence of this level negatively affects the intensity of rainfall as the moisture correction cannot be done. Small changes could be seen when images for individual days were compared (v2012 to v2013), but in general, the results are very similar with slight improvements due to the minor updates in the latest version of the software.

The next aim of the project involved including lightning data into the RDT and CRR software over South Africa. Twenty-five cases between September and March (convective season) were used to validate the RDT with and without lightning data included in the input data set over South Africa. Statistical scores were calculated using radar reflectivity data of more than 35 dBZ from the SAWS radar network as ground truth for each time step between 11:00 UTC and 18:00 UTC. In most cases, the RDT with lightning data added showed signs of improvement compared to the RDT when no lightning data was added. The POD improved by 6.6%, the HSS by 4.6% and the FAR by 0.1%. Changes could be seen when images for individual times were compared (RDT with and without lightning data added as well as radar). In a large number of the cases, the inclusion of lightning data in the input data set identified storms that were not identified at first when lightning data was not added. The inclusion of lightning data also resulted in some of the storm phases being reclassified. This was mostly true for decaying storms that were reclassified as mature storms when lightning data was added.

For the CRR product, 20 cases between September and March (convective season) were used to validate the CRR product with and without lightning data as input over South Africa. Statistical scores were calculated using the daily rainfall totals from the rain gauges as ground truth. In most cases, the CRR with lightning data was very similar or slightly better than the CRR without lightning data. Three thresholds were used to validate the CRR algorithms, namely, 1 mm, 10 mm and 20 mm.

On average, the POD, HKS and HSS were all marginally better when lightning data was included, while the FAR was slightly higher (worse) for all three thresholds. The bias scores indicate that the CRR with lightning overestimates the intensity of the rainfall, more so than when lightning data was not included. Adjustments to the intensity of the CRR algorithm could improve when the 925 hPa level (or different level for South Africa) of the NWP will be added when the new UM becomes operational. The absence of this level negatively affects the intensity of rainfall as moisture correction cannot be done. Small changes could be seen when images for individual days were compared (with and without lightning input), but in general, the results are very similar.

Lightning data was made operational in the RDT algorithm calculations during February 2016. Scripts run every 15 minutes to prepare the lightning data. This involves copying the most recent lightning data to the relevant directory, sorting the data to select the correct times to be used for the RDT time step, and converting the data into the correct format needed by the processing software. The inclusion of lightning data in the product has been showing favourable results since it has been included.

Several occasions were used to demonstrate the RDT and CRR products to operational forecasters in South Africa as well as in the southern African region through workshops and the annual SWFDP training events. Positive feedback has already been received about this new nowcasting tool. Other African countries have expressed the need to share in the output of the RDT product.

The 2013 version of the NWC software was made operational at SAWS during the second half of 2014. The data is archived on a server at SAWS. The RDT images are available on a website to forecasters in South Africa, but also on the RSMC website for forecasters from our neighbouring countries. During 2016, a new interactive display was introduced and made available to all forecasters of South Africa and other southern African countries. This display plots the RDT product over a Google Maps™ background that allows users to zoom into different regions as well as see town names, roads, places etc. that will be highly beneficial for nowcasting. Forecasters have expressed their enthusiasm about this new display on several occasions. Satellite-based nowcasting tools such as the RDT product can be very useful to identify and track the more intense parts of thunderstorms in data-sparse regions.

5.2 Recommendations

The comparison between the v2012 and v2013 software shows that there is a small improvement in the performance of the RDT in the newer version of the software. The CRR product is similar between the two versions of the software with a very small improvement in the estimation of the location of the rainfall with v2013. The v2013, however, results in a slightly larger overestimation of the intensity of the rainfall from CRR. Adjustments to the intensity of the CRR algorithm could improve when the 925 hPa level of the NWP will be added when the new UM becomes operational. The absence of this level negatively affects the intensity of rainfall as moisture correction cannot be done. It is, however, recommended to use the newer v2013 of the software for both the RDT and CRR as the RDT shows an improvement, while the CRR remains similar compared to v2012 of the software. The slightly larger overestimation of the intensity of rainfall by CRR will be addressed with the inclusion of the 925 hPa level in the new UM.

The developers of the NWC SAF software frequently releases updated versions of the software. A new 2016 version of the software was made available at the end of 2016. This new version should improve the performance of the products even further. One of the new improvements to the RDT product that will highly beneficial for nowcasting purposes is the addition of forecast tracks to the RDT product. This will mean that the RDT can now estimate the locations of storms over a period of 15 minutes, 30 minutes, 45 minutes and 60 minutes ahead. This could be highly beneficial for sending out warnings to the public and various sectors such as the aviation industry. It is recommended that the new 2016 version of the software should be tested at SAWS in the near future and that tests must be performed between the v2013 and new 2016 version of the software.

This study showed that inclusion of lightning as auxiliary data into the software is beneficial to the RDT product. When lightning data is added as auxiliary data to the algorithm, the RDT product shows an improvement of about 5% compared to when lightning is not included. The addition of lightning data to the software also reclassifies some of the storm phases that seems more correct when compared to radar data. For the CRR product, the inclusion of lightning data into the software yielded similar or slightly better results, but the intensity of the rainfall is overestimated slightly more than without lightning data. Based on the results it is recommended to add lightning data to the processing of the RDT product since it shows a 5% improvement in the performance of the product. For the CRR product, it is recommended that lightning should not be included in the algorithm at this point in time due to the enhanced overestimation. Future work could establish the relationship between

RR and lightning occurrence over South Africa in order to adjust the parameters used by CRR that are set for European conditions at the moment.

A new high-resolution version of the UM was introduced at SAWS and this should improve the performance of the NWC SAF products. A higher resolution model should provide a better representation of reality on a smaller scale. This will be more beneficial to resolve thunderstorms and should enhance the NWC SAF products. For the CRR product, the inclusion of the 925 hPa level will be especially useful since the software needs this level to perform a humidity correction on the rainfall calculation. This correction is currently not included in the CRR product. The 4 km resolution model will be introduced into the NWC SAF software during 2017 and it is recommended that tests be performed to determine the effects of this new model in the NWC SAF software.

When the next generation geostationary satellite for Europe and Africa [Meteosat Third Generation (MTG)] is launched in 2019/2020 by EUMETSAT in collaboration with the European Space Agency, a lightning imager will be on board the satellite that will provide lightning data for the entire European and African continent. This will be a valuable source of information for the data-sparse regions of Africa and could be included in the NWC SAF to provide improved products over the continent. As was demonstrated in this project, lightning data can improve the RDT product by about 5%. Thus, the data from the lightning imager on board MTG could improve the RDT over southern Africa by 5%. The new MTG satellite will also provide satellite data with an improved resolution that should further enhance the RDT and CRR products. It is recommended that when this satellite is launched, the new satellite and lightning data should be utilised in the processing of the NWC SAF products and tests should be conducted to determine how beneficial the new data is on the products.

It will also be beneficial to evaluate the RDT and CRR products over a longer period. Currently, 25 cases were considered for the RDT product and 20 cases for the CRR product. This limited number of cases have shown that there seems to be an improvement in the products, but in order to get a better idea, longer periods need to be considered. Future evaluations should ideally be performed over the different seasons and will be considered for future work. This will, however, all depend on data availability, storage space and computer resources.

This project highlights the importance of using satellite data (together with NWP and lightning information where available) to provide forecasters and various industries with valuable information on intense and rapidly developing thunderstorms. This work is especially applicable to data-sparse regions where very little observational data, such as radar data, is available. The geostationary MSG satellite provides data coverage over all African countries and products derived from satellite information, such as the RDT and CRR, could provide these data-sparse regions with an excellent second option for nowcasting purposes in order to save lives and prevent damage to property. It is recommended that the NWC SAF products must be used and made available to forecasters and industries in as many data-sparse countries as possible.

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