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South African Weather Service operational satellite based precipitation estimation technique: applications and improvements

E. de Coning and E. R. Poolman

South African Weather Service, Private Bag X097, Pretoria, 0001, South Africa

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Correspondence to: E. de Coning (estelle.deconing@weathersa.co.za)

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Abstract

Extreme weather related to heavy or more frequent precipitation events seem to be a likely possibility for the future of our planet. While precipitation measurements can be done by means of rain gauges, the obvious disadvantages of point measurements are driving meteorologists towards remotely sensed precipitation methods. In South Africa more sophisticated and expensive nowcasting technology such as radar and lightning networks are available, supported by a fairly dense rain gauge network of about 1500 gauges. In the rest of southern Africa rainfall measurements are more difficult to obtain. The availability of the local version of the Unified Model and the Meteosat Second Generation satellite data make these products ideal components of precipitation measurement in data sparse regions such as Africa. In this article the local version of the Hydroestimator (originally from NOAA/NESDIS) is discussed as well as its applications for precipitation measurement in this region. Hourly accumulations of the Hydroestimator are currently used as a satellite based precipitation estimator for the South African Flash Flood Guidance system. However, the Hydroestimator is by no means a perfect representation of the real rainfall. In this study the Hydroestimator and the stratiform rainfall field from the Unified Model are both bias corrected and then combined into a new precipitation field which can feed into the South African Flash Flood Guidance system. This new product should provide a more accurate and comprehensive input to the Flash Flood Guidance systems in South Africa as well as southern Africa. In this way the southern African region where data is sparse and very few radars are available can have access to more accurate flash flood guidance.

1 Introduction

There is mounting evidence that changes in the earth's climate system will result in more frequent extreme weather events and the possibility exists that the likelihood of temperature extremes, heat waves, and heavy precipitation events will continue to increase (IPCC, 2007). Extreme weather events need to be anticipated not only in the time scale of months or seasons, but also on a day to day basis. The importance of early warning systems to warn the public of these types of weather events therefore becomes more and more critical.

When forecasters have to issue forecasts and warnings for the first 12 h of a forecast, they use the latest data from remote sensing tools such as radar and satellite, as well as observational data, to analyze and forecast smaller scale weather features. The World Meteorological Organisation (WMO) organized a series of sub-regional demonstration projects to improve severe weather forecast services in countries where sophisticated remote sensing forecast systems are not currently used (mostly developing countries). Such a project is currently running from South Africa and is called the Severe Weather Forecast Demonstration Project (SWFDP). The goals of this project include: improvement of the lead time of warnings, improved communication between global, regional and National Meteorological Centres (NMC), improved interaction of NMC with disaster management authorities before and during severe weather events (Poolman et al., 2008). One of the gaps identified in the project was that whereas the SWFDP succeeded in improving forecasting systems in the developing countries, there is a serious lack of nowcasting systems, particularly for severe convective storms.

The need to improve very short range and nowcasting services thus applies to the whole southern African region, specifically with regard to convective storm development and evolution. However, there are marked differences between the technologies available to support such services in the various countries of southern Africa. Most southern African countries are heavily reliant on satellite technology due to the limited number of surface and upper-air observations and the limited availability of numerical model output. These countries do not have access to weather radar or lightning information, nor the systems to integrate the data and products from various sources. South Africa, on the other hand, has a radar network and a lightning detection network, as well as the means to integrate, display and manipulate these various data sets. Although the approach to be followed for the southern African region outside of South

Africa has to be distinctly different from the possibilities for South Africa itself, some of the techniques developed for South Africa might also be useful within the region.

In this article the enabling technologies for satellite based precipitation estimation will be discussed in Sect. 2. Section 3 deals with the measurement of precipitation in South Africa, where a brief background of the Hydroestimator (HE) will also be given. In Sect. 5 the performance of the HE will be discussed and compared to the measurements made by rain gauges. Section 5 will describe the role remote sensing of precipitation can play in the South African Flash Flood Guidance (SAFFG) system. In this section a new combined precipitation estimation field will be discussed which should enhance the flash flood guidance produced by the SAFFG. A summary and conclusion will be provided in Sect. 6.

2 Enabling technology for precipitation measurement in South Africa

2.1 Meteosat Second Generation satellite data

Both South Africa and Africa as a whole have had access to the European Geostationary Meteosat Second Generation (MSG) satellite image data and derived products since 2005. The first satellite of the series, then known as MSG, was launched on 28 August 2002 by the European Space Agency on behalf of EUMETSAT (European Organization for the Exploitation of Meteorological Satellites). By 29 January 2004 the satellite, now known as Meteosat-8, was in full operation, allowing access to its data on a routine basis throughout Europe, Africa and the Middle East (Morgan, 2002). MSG-2 (Meteosat Second Generation-2) is the follow-on to MSG-1 and was launched on 21 December 2005. The two ton, spin stabilized craft carries the same instruments as MSG-1 (Spinning Enhanced Visible and InfraRed Imager or SEVIRI and Geostationary Earth Radiation Budget or GERB) and provides the same products. The satellite was renamed Meteosat-9 when it became operational in June 2006 (MSG-2 successfully launched, 2005).

This satellite offers a choice of twelve channels to use individually or in combination for various purposes, including nowcasting of convection. For eleven of the twelve channels, image pixels are sampled every 15 min at intervals of 3 km over the entire area. The High Resolution Visible (HRV) channel has a sampling distance of just 1 km, with the east-west scan limited to half of the full earth disc.

With MSG it is possible to provide images, day and night, of clouds and cloud systems at nearly every scale. It is also possible to look at the clouds and learn about their internal processes and states, e.g. cloud droplet size can be inferred, surface fog may be detected even at night, vegetation growth monitored and many more. A number of applications have also been developed to make use of these new capabilities for nowcasting, especially for the detection and prediction of severe weather (Morgan, 2002).

2.2 Radar

Until the end of 2009 the South African weather radar network consisted of ten C-band and two S-band radar systems located across the country. This network has been used extensively in support of weather predictions, storm identification and aviation applications (de Coning et al., 2010). The spacing of these radars is not ideal for observing stratiform rain because such systems are relatively shallow, resulting in the radar beam overshooting the echo tops at long ranges. Convective storms, however, have relatively deep vertical dimensions allowing them to be observed, at least partially, at longer ranges. Despite the obvious advantages of this system, it still lacked Doppler capabilities. The South African Weather Service (SAWS) is currently in the process of migrating to S-band (2.8 GHz) radar systems. The S-band radar signals undergo far less attenuation than that of the C-band signals. These new radars have sensitive Doppler capabilities with which it is possible to detect the internal wind structure of storms, which will make better nowcasting of severe storms possible. Several initiatives are also envisaged to use the better radar data for radar based precipitation estimates in the near future. The rest of southern Africa gave very few radars available.

2.3 Unified model

The Unified Model is the suite of atmospheric and oceanic numerical modelling software, developed and used at the UK Met Office since 1991. The Met Office maintains a suite of versions at particular resolutions that it encourages collaborating partner institutions to use. At the SAWS, the Unified Model runs operationally at a horizontal resolution of 12 km and is scheduled to run twice daily to provide hourly numerical forecasts of atmospheric conditions for up to 48 h ahead. The domain of the Unified Model run on South African computers is between 0.48° N and 44° S, and 10° W and 56° E, with an East/West resolution of 0.11° and a North/South resolution of 0.1112°.

3 Measurement of precipitation

3.1 South African rain gauge network

The SAWS rain gauge network is depicted in Fig. 1. Rainfall is measured by about 1500 rain gauges for 24 h periods from 06:00 to 06:00 UTC, and is then is listed as the day total in climatological records. In 2009 an additional eighty Automatic Rainfall Systems (ARS) have been installed providing rainfall information in real-time. Despite the obvious advantage of being able to measure rainfall in 5 min intervals, this type of precipitation measurement is still too sparse to provide a comprehensive picture of hourly rainfall over the country.

3.2 Satellite precipitation estimations – the Hydroestimator

Measuring precipitation is one of the most difficult observational challenges of meteorology as a result of the high variability with geography and time. Although rain gauges provide a direct measurement of rainfall, rain gauge networks are far too coarse to capture all the rainfall, especially at smaller scales. Rain gauges are unevenly distributed and, most importantly, they provide point source data and not a representation of a spatial domain (Kondragunta, 2007). Radars can be used to provide an indirect measurement of rainfall, but then the radars need to cover the entire area of interest, be well correlated and have a good radar rainfall relationship. Due to the expensiveness of procuring and maintaining radars they are a scare commodity in Africa and thus not a feasible option for this purpose. Although satellite based estimates of rainfall are not as accurate as gauges or radar, its major advantage is the high temporal resolution and spatial coverage, even over oceans, in mountainous regions and sparsely populated areas where rainfall is not measured. Thunderstorms and flash floods often occur and move in between gauges and other surface based networks and thus cannot be detected properly. In such cases satellite-derived rainfall can be a “critical tool for identifying hazards from smaller-scale rainfall and flood events” (STAR Satellite Rainfall estimates, http://www.star.nesdis.noaa.gov/smcd/emb/ff/index.php).

Satellite precipitation estimates (SPE) offer an excellent way to compensate for some of the limitations of other sources of quantitative precipitation estimations. However, the relationship between satellite-measured radiances and rainfall rates is less robust than that between radar reflectivities and rainfall rates. SPE should thus not be considered as a replacement for radar estimates and gauges but as a complement (Scofield and Kuligowski, 2003).

Scofield (2001) described the status and outlook of operational satellite precipitation algorithms for extreme precipitation events. Since 1978, SPE for flash floods have been produced using data from the Geostationary Operational Environmental Satellite (GOES). They combine manual effort and computer algorithms with the main application to alert forecasters and hydrologists of the potential for heavy precipitation and flash floods. Due to the interactive nature of this method, these SPE cover limited areas over limited periods of time and take a significant amount of time to produce. To address these problems, the National Environmental Satellite, Data and Information Service (NESDIS) developed an automated SPE algorithm for high-intensity rainfall called the Autoestimator (AE). The original AE, developed by Vicente et al. (1998), computes rain rates from 10.7 µm brightness temperatures based on a curve that was derived from more than 6000 collocated radar and satellite pixels. The dependence of the initial AE on radar was a significant problem, because one of the advertised strengths of satellite QPE (Quantitative Precipitation Estimation) is its usefulness in regions for which radar and/or rain gauge coverage is unavailable. Another version of the AE, called the Hydroestimator (HE) has been developed which can be used outside of regions of radar coverage without compromising accuracy. The HE is mainly dependent on temperature (the higher the cloud, the colder the temperature and the greater the rain rate). Scofield and Kuligowski (2003) described the following features in the HE which were improvements on the AE.

The definition of a "raining pixel" was adjusted to include only those pixels with an IR10.8 brightness temperature below the average value of the surrounding region. In this way the overestimation of rain area seen in the Autoestimator (AE) has been significantly reduced.

The rain rate curve used for the AE was adjusted according to the difference between the brightness temperature of the pixel and that of the pixels in the surrounding area. The highest rain rates are given to the pixels that are the coldest relative to their surroundings.

The dependence on Precipitable Water (PW) and Relative Humidity (RH) has been separated. PW was used to adjust the rain rate curve (higher PW means higher rain rate). RH was used to determine an amount which has to be subtracted from the calculated rain rate (drier low levels suggest that the rain will evaporate, i.e. the rain rate will be lowered). These adjustments have been beneficial in the handling of stratiform rain events with embedded convection as well as wintertime precipitation associated with lower PW.

In general, experience and validation studies (Kuligowski et al., 2001) have shown the following tendencies in the behaviour of infrared based Satellite Precipitation Estimates (SPE):

- SPE tend to overestimate rainfall intensity and spatial coverage of the storm when it is slow moving and has a cold top.

- SPE tend to underestimate rainfall from warm topped mesoscale convective systems.
- SPE are less accurate spatially in regions of strong vertical wind shear.
- SPE do not handle rain bursts early in the life cycle of mesoscale convective systems well.

Comments by analysts at the NESDIS Satellite Analysis Branch (SAB) who work with the HE on an operational, real time basis (R. J. Kuligowski, personal communication, 2009) include:

- The HE works best for convective events.
- Stratiform events might be over/underestimated.
- Very cold tops with significant Cirrus debris might be overestimated.
- Warm cloud tops are often underestimated.
- Rainfall totals over 1 to 6 h should be most reliable, while 24 h totals might be too high.

Input files for the HE consist of the IR10.8 channel brightness temperatures of the MSG satellite and model output fields of the SAWS local version of the Unified Model, including: Profiles of the temperature and humidity on 19 levels, from 1000 to 100 hPa, every 50 hPa, Surface pressure and 700 hPa wind field. Before the actual HE code is run, parallax and zenith angle corrections are made. The parallax correction helps to position the rainfall cores more accurately, which plays an important role in smaller scale storms (Vicente et al., 2002). The HE is available in the same domain as the local version of the Unified model (i.e. between 0.48° N and 44° S and between 10° W and 56° E). Most of the code is very similar to the original NOAA code, but with two exceptions: (a) Cloud top minimum temperature, which is hard coded to 213 K in the original code, is replaced by the tropopause temperature, taken from the given profile and (b) for the box averages, minima and standard deviations, the final rain rate is calculated only from the larger box (100×100 pixels), which was found to give somewhat smoother fields (Koenig, 2007).

Despite the simplicity of this precipitation estimation algorithm, it is still used in many countries around the world. There are, of course, more accurate and also more involved precipitation algorithms available, but the requirements for these algorithms are beyond the capabilities in South and southern Africa. In southern Africa a precipitation estimator independent of radars was required and thus the HE suited the need. During September 2007 a local version of the Hydroestimator was installed and tested at the South African Weather Service and has been running operationally ever since. An example of how in-house developed software (SUMO at http://old.weathersa.co.za/SUMO/) displays the Hydroestimator together with the IR10.8 channel is show in Fig. 2.

3.3 Accumulation products for the HE

An important part of the warning process for flooding and/or flash flooding is knowledge of the amount of rain which fell in the previous time periods, from one hour to several hours. In regions where rain gauges are sparse a satellite based accumulation of precipitation can go a long way to help a forecaster to know where a lot of rain has fallen recently. Accumulation products of the HE have been developed for 1 h, 3 h, 6 h, 24 h, 10 days and 1 month. These products are updated operationally on a rolling time average basis on the Regional Specialized Meteorological Centre (RSMC) webpage (http://old.weathersa.co.za/RSMCLoginServlet). This website was developed to aid National Meteorological Centres (NMC) of southern African countries with numerous guidance products in the SWFDP project, such a model output as well as warnings for possible floods, strong wind etc. It is password protected for use only by southern African). An example of the HE accumulation products is shown in Fig. 3.

4 Performance of the HE

4.1 Evaluation of the HE as part of the IPWG programme

The International Precipitation Working Group (IPWG) is one of the working groups of the Coordination Group for Meteorological Satellites (CGMS). The work done in this group concentrates on "operational and research satellite based quantitative precipitation measurement issues and challenges" (http://www.isac.cnr.it/~ipwg). Statistical evaluation performed on the HE in the United States show that the HE is performing very well with a correlation between the HE and the rain gauges of more than 0.7 in some examples. More information on the HE and its performance can be obtained from Kuligowski et al. (2005). In South Africa similar studies have only just started and have not been done for a substantial amount of data. It has been established that similar trends exist, but extensive research in this regard is still ongoing. The HE is the only precipitation estimator which is available for operational use, every 15 min. It is envisaged that the HE will also perform well over the southern Africa region as soon as it has been tuned to local conditions.

4.2 Examples of 24 h rain gauge totals versus 24 h HE totals over South Africa

Two examples (Figs. 4 and 5) are shown comparing the 24 h rain gauge totals to the 24 h totals from the HE. Both of these examples are during the summer season, when mostly convective precipitation occurs. Only rain gauges from South Africa are available and therefore the domain for comparison is confined to the areas within the borders of South Africa. A factor to bear in mind is that the HE tends to overestimate 24 h totals, as mentioned earlier.

The rain gauge totals for this day (Fig. 4a) show the rainfall mainly over the North West, Gauteng and Mpumalanga provinces. Amounts do not exceed 20 to 30 mm (light orange). The HE (Fig. 4b) shows less rain over North West, similar amounts of rain over Gauteng and totals reaching more than 70 mm in Mpumalanga. There is also an indication of more than 30 mm in the southern part of Limpopo which is not reflected by the gauge data. The amounts of rainfall given by the HE are generally too high.

For this day the rain gauge totals (Fig. 5a) show widespread rain, except in the Northern Cape. The highest totals were recorded in the South Western Cape, on the east coast, in the northern parts of KwaZulu-Natal and Limpopo province. Spatially, the HE looks similar (Fig. 5b), but the rainfall in the southern Free State was not detected by the HE. The HE put the highest emphasis in the Limpopo Province, with rainfall totals close to 100 mm which is too high in comparison to the gauges. The higher gauge totals in the south-western Cape and on the coast of KwaZulu-Natal were not reflected by the HE.

From these examples it should be clear that the HE differs substantially in intensity from the measurements by the rain gauges when using a 24 h accumulation. The aerial extent of where precipitation occurs is reasonable. The HE performs best for convective events and thus rainfall from stratiform weather systems might not be detected by this algorithm. This might explain some of the discrepancies in the second example. Despite the problems identified here, the HE can give forecasters a regular (every 15 min) update on where convective precipitation is occurring and this information can form part of the nowcasting process.

5 Applications and improvements for the South African Flash Flood Guidance system

5.1 The South African Flash Flood Guidance (SAFFG)

Flooding events in recent years around the country, and particularly in the Western Cape and KwaZulu-Natal, dramatically demonstrated the devastating impact of flash floods on the country. In response to this the SAWS and the National Disaster Management Centre (NDMC) embarked on a collaborative project for the development and implementation of a flash flood warning system in flash flood prone regions in October

2008 called the South African Flash Flood Guidance (Poolman, 2010). The development of the SAFFG system was tested during the first half of 2010 and rolled out operationally in October 2010.

The SAFFG system is a hydro-meteorological modelling system combining in real-time meteorological information, such as quantitative rainfall estimation from weather radars, satellite and rain gauges, with hydrological modelling of the soil moisture conditions and resultant flash flood potential in 1633 small river basins (on average 50 km^2) in five flash flood prone regions over South Africa. The SAFFG uses the quantitative rainfall estimates of the previous 24 h from radar, satellite and rain gauges to pre-calculate every hour the necessary hydrological information of each relevant small river basin (soil moisture, subsequent run-off) to determine the amount of rain needed over the basin that will lead to bank full at the outlet of the river, i.e. start of flooding. When this value is compared in real time to the amount of rain falling over each basin (as estimated from real-time monitoring rain gauges, radar and satellite) river basins in danger of flash flooding can be quickly identified. The SAFFG depends heavily on the quality of QPE products from radar and satellite as input to the hydrologic models. It is therefore very important to improve the rainfall estimation from radar and satellite information as a primary input into the hydrological modelling.

The WMO is developing a similar flash flood guidance system (called the SADC SARFFG) aiming for implementation over seven southern African countries in 2011. The SADC SARFFG system will cover the rest of South Africa and six other countries where there are no radar coverage. This system will therefore depend primarily on satellite QPE as precipitation input for modelling soil moisture and flash flood guidance over large parts of southern Africa.

Hourly rainfall estimates is a vital input parameter into the SAFFG hydro-meteorological modelling system. At present hourly accumulations of the HE is used for this purpose. One of the weak points of the HE is the overestimation on very short (about 1 h) and also on longer (more than 24 h) time scales. The first step isto estimate the bias of the HE and to adjust the field provided to the SAFFG. Another disadvantage of the HE is that it is mainly aimed at estimation of convective precipitation and it sometimes misses stratiform rain events where the cloud tops are not so high.

One aspect of the Unified Model which usually evaluates well with reality is the handling of synoptic scale weather features such as frontal systems. The stratiform rainfall which accompanies the passage of frontal systems is an easier field to predict than the convective precipitation accompanying thunderstorms. The stratiform precipitation field from the Unified Model will be compared to gauges measurements in a novel way and then bias-corrected. Consequently it will be used in combination with the bias-corrected HE field to supply the SAFFG with more comprehensive precipitation estimation to cover not only the convective events, but also the stratiform events more accurately.

5.2 Addressing the overestimation of the HE

Data from the HE were archived and available for analysis since January 2008. The HE from January 2008 until December 2009 was used to determine the average ratio between the HE and the rain gauges. Due to the fact that this is a very short "climate" to base findings on, it was decided to use two six month periods instead of individual months for all calculations. It was clear that the months from November to April and May to October, respectively, had similar ratios and thus November to April will be termed the "summer" months and May to October will be termed the "winter" months.

In Fig. 6 the two year rainfall total for the winter months are shown in (a) and the two year rain gauge total in (b). Figure 7 is similar for the summer months. The average of the ratio for the summer months (November to April) is 1.3 and the average for the winter months (May to October) is 2.1. The HE is thus overestimating by a factor 1.3 in summer and a factor of 2.1 in winter. At this point it then seems that if 75% (∼1/1.3) of the HE is used in summer months and 50% (∼1/2.1) in winter months, the HE totals and rain gauge totals might be more aligned.

5.3 Combining the HE and the stratiform rainfall field from the UM

Before the UM stratiform field can be combined with the bias-corrected HE, it would only be fair to evaluate and/or bias correct this field as well. The evaluation of the stratiform rainfall field provided by the Unified Model can be done using the rain rate of the automatic rain gauges and attempting to identify those periods in which the rain rate approximates that expected from stratiform rainfall. Unfortunately, there are not enough of these gauges operational over the country yet.

An alternative solution is to use the ratio of the UM stratiform field to the UM total rainfall field to establish what percentage of the rainfall is stratiform compared to the total rainfall totals. Figure 8 show this ratio for the months from May to October and November to April. This was calculated using the hourly UM derived rainfall fields from January 2008 to December 2009. It is evident that the frontal systems contribute more to stratiform rainfall during the winter months in the southwestern parts of the country. During the summer months stratiform rainfall also occur along the northeastern escarpment of the country. If these winter and summer ratios are applied to the rain gauge totals for the summer and winters of the same two year period, a pseudo stratiform observation can be calculated (Fig. 9). In Fig. 10 the UM stratiform fields for winter and summer are shown. Comparing Figs. 9 and 10 it is evident that the precipitation field provided by the model also over estimates, but less so than the HE. Calculating the ratio of the UM stratiform field over this pseudo stratiform observation in areas where more than 150 mm were recorded in this two years period (i.e. in regions where stratiform rainfall makes a significant contribution), provides a bias-correction for the UM stratiform field of 1.25 (~80%) for winter months and 1.4 (~70%) for summer months.

If the maximum value of the bias-corrected HE (as mentioned in Sect. 5.1) and the bias-corrected UM stratiform rainfall field is used at each grid point, the combined products will be a rainfall field which not only reflect the convective precipitation, but also the stratiform rainfall field. This should be a more comprehensive rainfall field input to the SAFFG and thus also provide better input into a warning for flash floods.

Ten case days were used to calculate some statistical values. These include: 17 and 18 June 2008, 4 and 5 February 2009, 9 February 2009. 22 and 23 February 2010, 4 and 5 April 2010 and 27 May 2010. Two examples will be shown, 18 June 2008 and 4 February 2009 (Figs. 11 and 12, respectively). In each figure the top left panel shows the stratiform rainfall field from Unified Model, the top right panel shows the HE precipitation estimation, the bottom left panel shows the combined rainfall product and the bottom right panel indicates the rainfall measured by the rain gauges. All of these products are 24 h rainfall totals.

From the winter time example (Fig. 11) it is clear that the stratiform rainfall produced by the Unified Model (a) captures the rainfall on the east coast and also the convection embedded in the frontal passage over the central parts of the country. The HE (b) missed the rainfall on the east coast of South Africa and over estimated the convection over the northern interior. In the combined precipitation product (c), the stratiform precipitation along the east coast is evident as well as the convection captured by the HE, but bias-corrected to be more realistic. The combined field correlates well with the rain gauges (d) in aerial extent as well as intensity.

In the summer case (Fig. 12) it is clear that stratiform precipitation on the eastern highveld of was captured by the Unified Model (a). Convective precipitation was seen by the HE (b) over the northeastern part of the country and further northwestward. Both of these are included in the combined field (c) while the over estimation of the HE (top right) is corrected to be more realistic compared to the gauges (d). Rainfall along the east coast was not captured by either the UM or the HE.

Figure 13 shows the third example from 4 April 2010. The Unified Model stratiform rainfall field (a) had small amounts of rain with the most focus on the southeast coastal regions. The HE (b) predicted much more rain, especially over the northeast parts of the country. The combined precipitation product (c) diminished the extreme rainfall amounts predicted by the HE and is also much closer to the rain gauges (d) measurements for this time period.

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In Fig. 14 a comparison of the average number of grid points with more than 1 mm of rainfall for the ten cases is shown. It is clear that the combined product has a number of grid points closer to the number measured by the rain gauges than the two individual products. In Fig. 15 the same comparison is done for grid points with more than 50 mm of rainfall and the combined product is closest to the rain gauges. Finally, in the average correlation for the ten cases between the rainfall measured by the rain gauges and the three different products are shown in Fig. 16. A correlation of 0.33 is found between the gauges and the combined product which is statistically significant at a 99% level for the number of grid points for these ten cases.

From these examples it is clear that the improvement in the precipitation field not only eliminates the over estimation of the HE, but the stratiform events are also captured better. Advantages of the combined rainfall field therefore include a better aerial coverage as well as more realistic rainfall totals. Providing such a field to the SAFFG would certainly be beneficial.

6 Summary and conclusion

In this article the satellite based precipitation measurement called the hydroestimator (HE) for southern Africa was described. The HE is based on a single channel (IR10.8) from MSG and mainly uses the temperature of cloud tops to estimate precipitation rate every 15 min. It also uses some moisture fields from the local version of the Unified Model. Although improvements have been incorporated into the HE to avoid the possibility of getting rain from high level Cirrus clouds, but to include lower clouds which can cause precipitation, it is still considered to be mainly useful for convective precipitation. The HE has been available through the SUMO software which displays satellite data since September 2007.

Accumulation products of the HE have also been developed for 1 h, 3 h, 6 h, 24 h, 10 days and a month and these products are available on the RSMC webpage on an operational basis. Thus far the HE seems to provide a reasonable estimation of convective precipitation on a real time basis, every 15 min. Shortcomings of the HE include the over estimation of precipitation amounts and the lack of coverage of some stratiform events.

The SAFFG uses both radar rainfall and satellite based rainfall input in order to provide a warning map for flash floods. The quality of the input fields determines the accuracy of the warnings which can be provided. For the South African region radar rainfall fields can aid in the process of creating these warning maps, but for the rest of southern Africa the flash flood guidance will depend solely on the satellite based fields. In order to provide the warning system with a more comprehensive and accurate satellite precipitation based input field, a new combination product was developed. The new product aims to combine the strengths of the HE and the stratiform precipitation field from the Unified Model (UM). The respective bias corrections of the HE as well as the UM stratiform field were determined over a two year period and these bias corrected products were combined into a new precipitation estimation field. The combined product provided a better correlation with the rain gauge measurements for the ten cases which were used. It is envisaged that this product will add value to the SAFFG and the SARFFG when it becomes operational in 2010 and 2011, respectively.

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Fig. 1. Distribution of rain gauges in South Africa.

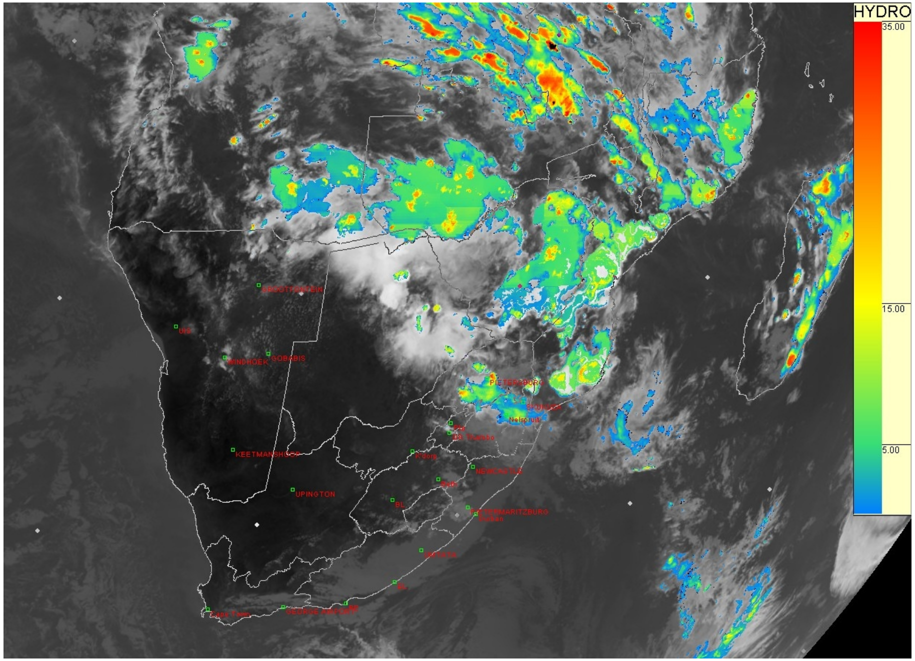

Fig. 2. Hydroestimator as depicted together with MSG Channel 9 (IR10.8) in SUMO on 28 January 2010 at 15:00 UTC.

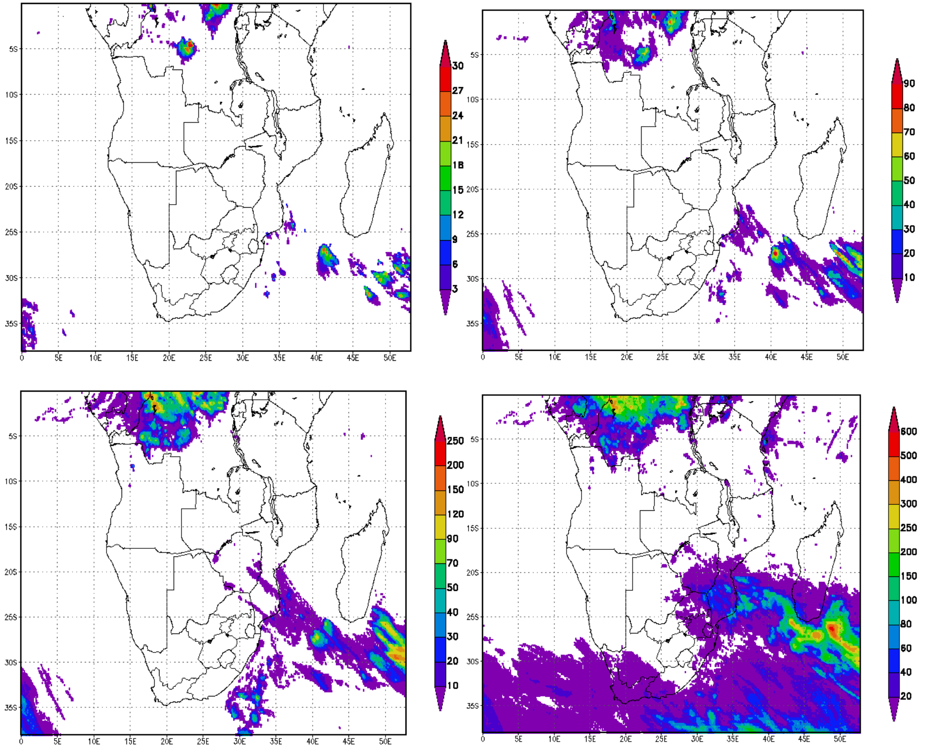

Fig. 3. Examples of the accumulation products of the HE are shown; 1 h **(a)**, 6 h **(b)**, 24 h **(c)** and 10 days **(d)** for 1 June 2010.

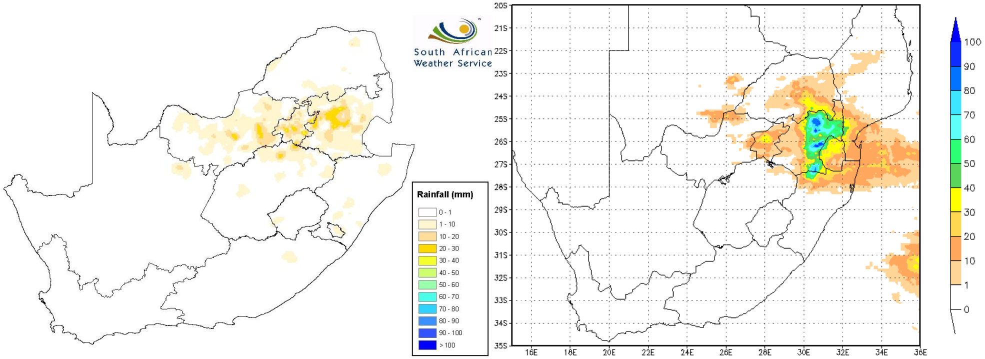

Fig. 4. Rainfall totals over 24 h from rain gauges **(a)** and HE **(b)** for 18 October 2008.

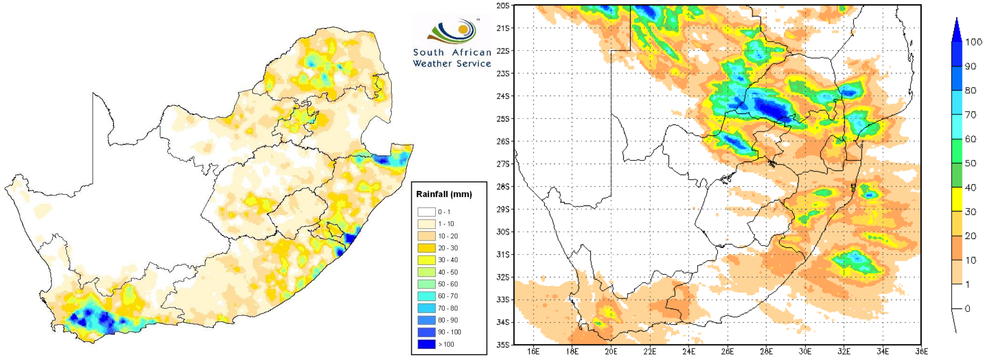

Fig. 5. Rainfall totals over 24 h from rain gauges **(a)** and HE **(b)** for 12 November 2008.

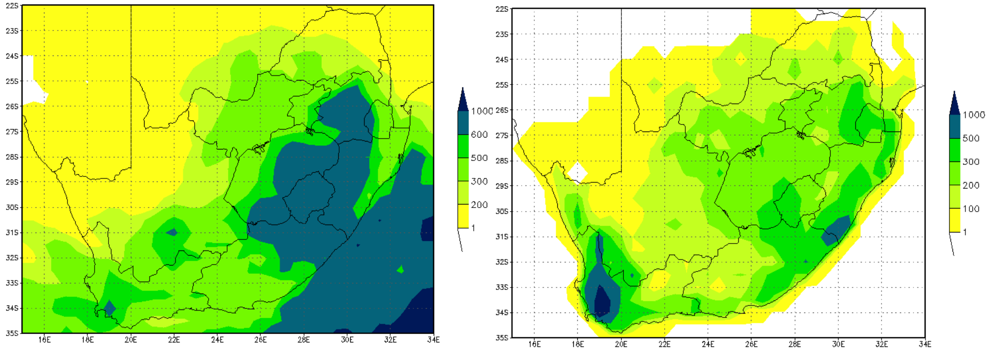

Fig. 6. HE winter rainfall for 2008 and 2009 **(a)** and rainfall measured by the gauges in the winters of 2008 and 2009 **(b)**.

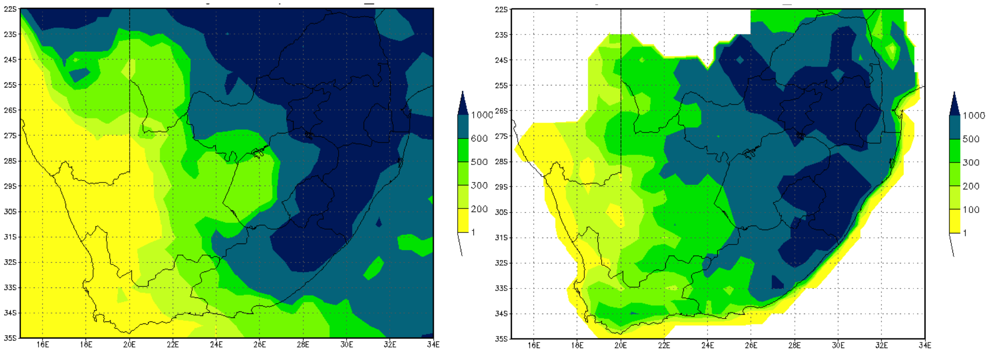

Fig. 7. HE summer rainfall for 2008 and 2009 **(a)** and rainfall measured by the gauges in the summer of 2008 and 2009 **(b)**.

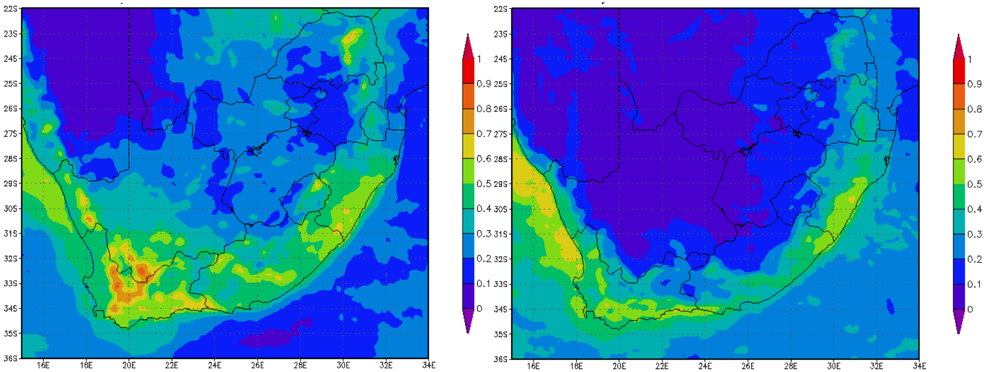

Fig. 8. Ratio of UM stratiform rainfall over UM Total rainfall for winter months **(a)** and summer months **(b)** for 2008 and 2009.

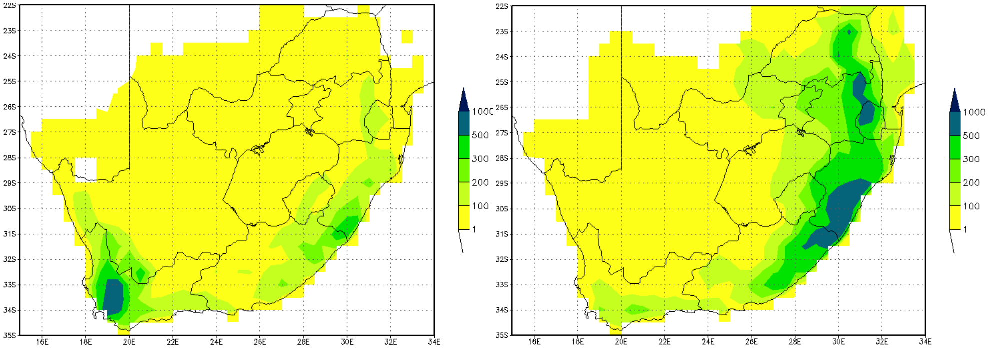

Fig. 9. Pseudo stratiform rainfall from gauges for winter months **(a)** and summer months **(b)** for 2008 and 2009.

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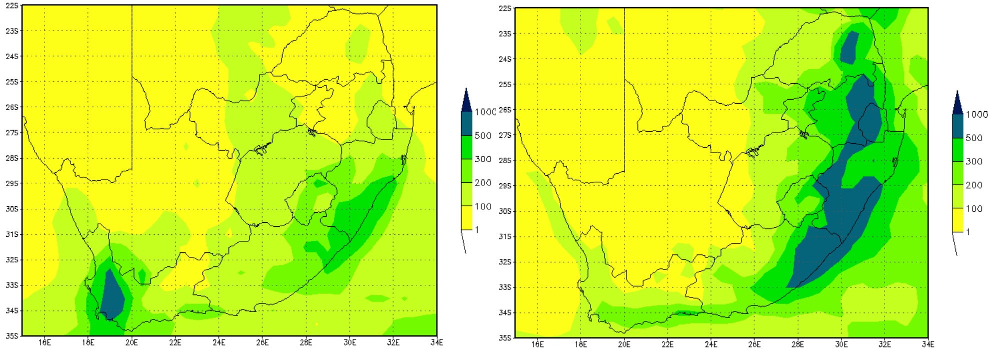

Fig. 10. UM stratiform rainfall for winter months **(a)** and summer months **(b)** for 2008 and 2009.

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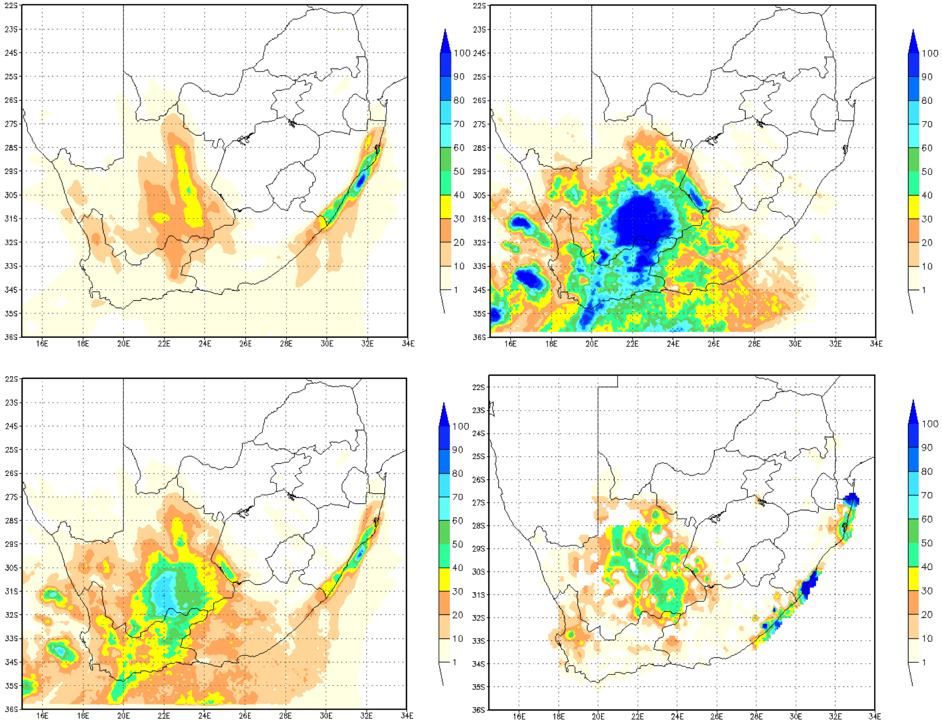

Fig. 11. Unified Model stratiform precipitation total for 24 h **(a)**, Hydroestimator precipitation total for 24 h **(b)**, the combined product from HE and UM for 24 h **(c)** and the total rainfall as measured by the rain gauges **(d)** for 18 June 2008.

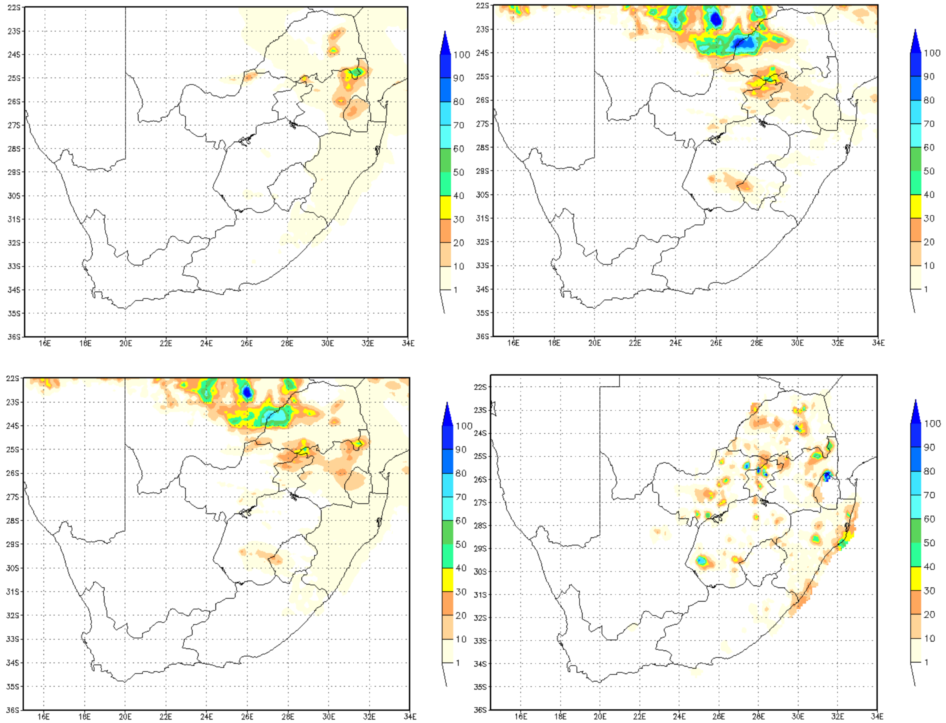

Fig. 12. Unified Model stratiform precipitation total for 24 h **(a)**, Hydroestimator precipitation total for 24 h **(b)**, the combined product from HE and UM for 24 h **(c)** and the total rainfall as measured by the rain gauges **(d)** for 4 February 2009.

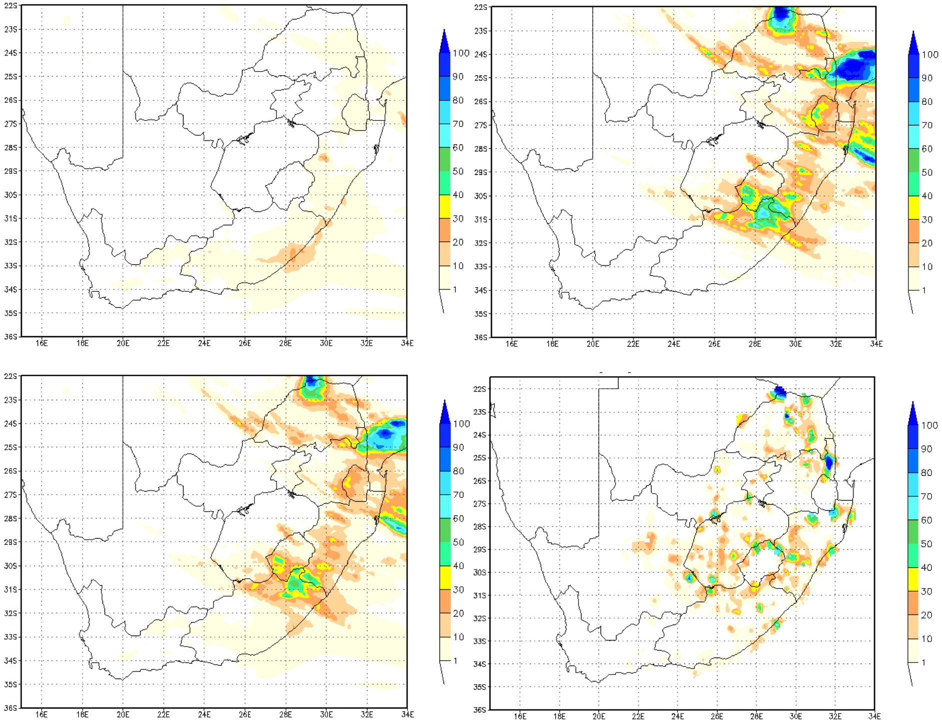

Fig. 13. Unified Model stratiform precipitation total for 24 h **(a)**, Hydroestimator precipitation total for 24 h **(b)**, the combined product from HE and UM for 24 h **(c)** and the total rainfall as measured by the rain gauges **(d)** for 4 April 2010.

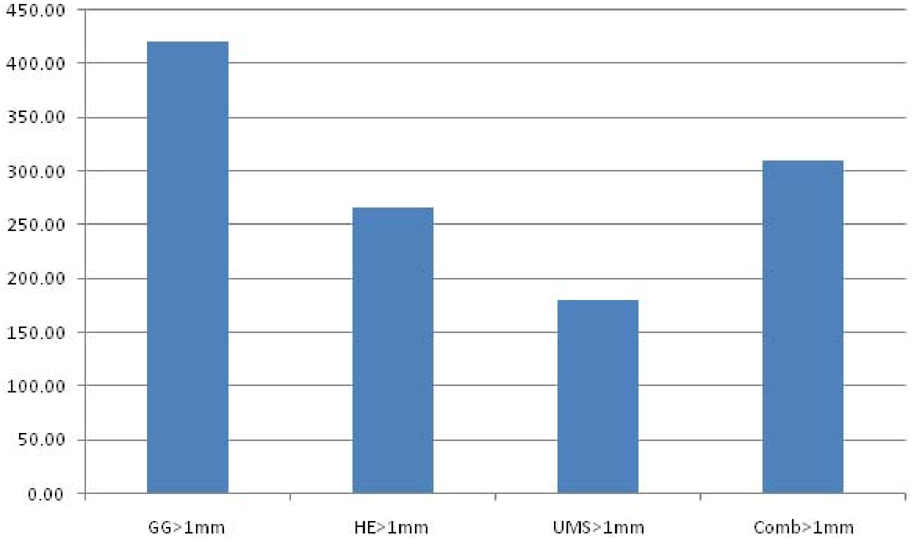

Fig. 14. Number of grid points with more than 1 mm precipitation for the ten cases. First bar is the rain gauges, second the Hydroestimator, third the Unified Model stratiform field lastly the combined precipitation estimation product.

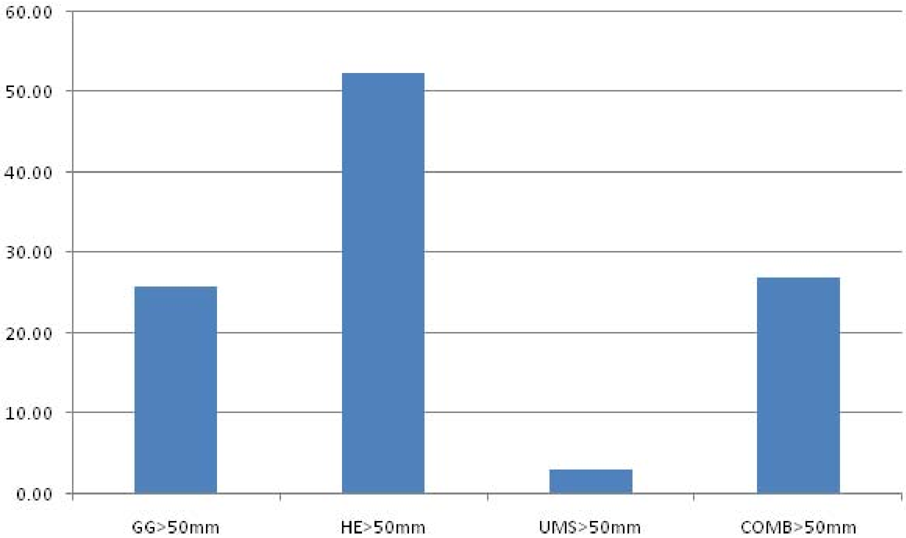

Fig. 15. Number of grid points with more than 50 mm precipitation for the ten cases. First bar is the rain gauges, second the Hydroestimator, third the Unified Model stratiform field lastly the combined precipitation estimation product.

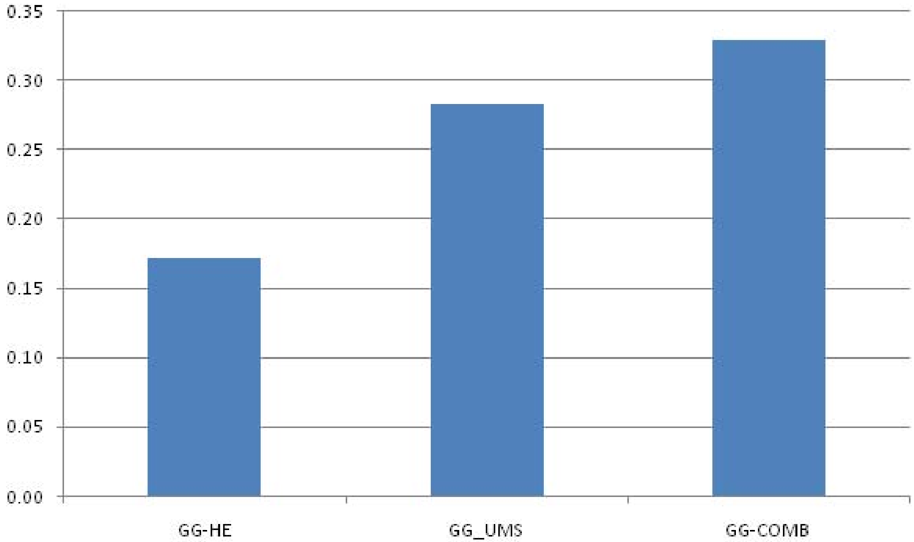

Fig. 16. Correlation between the gauges and the Hydroestimator, gauges and the Unified Model stratiform precipitation field and gauges and the combined precipitation estimation product for the ten cases.