VERIFICATION OF GLOBAL AND REGIONAL INSTABILITY INDICES ACROSS SOUTH AFRICA AGAINST RADIOSONDE DATA

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Abstract

Statistical analysis was done on the K-index, Lifted index and Total precipitable water content values obtained from Global and Regional Instability Index (GII, RII and AveRII) products, by comparing these values to the same observed values obtained from radiosonde data. The GII product forms part of the Meteosat Second Generation (MSG) Meteorological Product Extraction Facility (MPEF) products, which are derived at the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). The RII and AveRII products were developed locally and are based on the GII product. Results obtained here indicate that all three products' show good linear association and accuracy when compared to the observed index values. Of the three products tested, the GII product outperforms the RII and AveRII products, with the highest correlation coefficient and lowest mean absolute error values.

INTRODUCTION

South Africa is prone to a large number of summer convective storms. These storms may become severe resulting in heavy rainfall leading to flashfloods, hail, or very strong winds, all of which can cause damage to property and may lead to loss of life (Tyson & Preston-Whyte, 2000). Furthermore, research has shown that these convective storms over South Africa produce a large amount of cloud-to-ground lightning (Gill, 2008). Other studies by Kruger (2006) indicates that over certain areas of South Africa there is an increase in the number of days where relatively high or extreme rainfall amounts occur. These higher extreme rainfall values could be associated with convective activity. It is thus particularly important to forecast convective events ahead of time, so that the appropriate warnings can be issued, allowing individuals to take the necessary precautions.

One of the ways in which early forecasting of convective storms can occur, is by referring to instability indices. Instability indices, such as the K-index (KI) and the Lifted Index (LI), as well as the total precipitable water (TPW) content, are used to help identify areas of atmospheric instability and available moisture. These indices are traditionally derived from radiosondes and Numerical Weather Prediction data by referring to the atmospheric profiles of the temperature and humidity. This can provide some indication on the vertical stability of the atmosphere at the specified time. A new method to obtain instability indices is through the use of the Global Instability Index (GII) (the products are provided for the entire MSG field of view) as well as the Regional Instability Index (RII) (which is a regional product that provides these products over southern Africa). The GII product forms part of the Meteosat Second Generation (MSG) Meteorological Product Extraction Facility (MPEF) products, which are derived at the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) (EUMETSAT, 2007).

Studies have been conducted using GII as a nowcasting or short-range weather forecasting tool (Koenig, *et al*.2006, Pajek *et al*., 2008; Koenig & de Coning, 2009). It is therefore important to verify the accuracy and reliability of these GII and RII products. This will be done by comparing the various indices (as mentioned below) to the same indices computed from radiosonde data for 5 stations across South Africa.

BACKGROUND ON MSG, GII AND RII

The MSG satellite is spin stabilized and has a high temporal, spatial and spectral resolution, with the primary instrument being the Spinning Enhanced Visible and Infrared Imager (SEVIRI). For further information on all the available MSG products, please refer to the EUMETSAT website (www.eumetsat.int).

The Global Instability Index (GII) and the Regional Instability Index (RII) are airmass parameters which indicate the stability of the clear atmosphere (Schmetz *et al*., 2002). As a result, the GII (as well as the RII) is only available when clear skies exist at the time of calculation. This is significant during the summer months, when afternoon clouds are widespread over certain parts of southern Africa. The GII product is derived globally and disseminated to users, while the RII is a product that was developed locally based on the GII product. The GII product is a combination of ECMWF model and MSG satellite data, with a resolution of 1° x 1° (approximately 15 x 15 MSG pixels and (45 x 45km) and has been operational at the South African Weather Service (SAWS) since October 2005 (Koenig & de Coning, 2008). In addition, SAWS also runs the RII product specifically developed for southern Africa. It is based on a combination of the South African version of the Unified model and MSG satellite data. The resolution is 0.1° x 0.1° (approximately 3 x 3 MSG pixels and (9 x 9km)), which is a much higher resolution than the GII product.

Due to the fact that the horizontal resolutions of these 2 parameters vary greatly, it was decided to adjust the dimensions incorporated by the RII in order to compare the GII and the RII products to each other. Therefore an average RII (AveRII) product has been computed by using a combination of the South African version of the Unified model and MSG satellite data (such as the RII), but for an area of roughly 45 x 45 km (i.e. 15 x 15 MSG pixels), making this an average value over the entire area. The AveRII is thus spatially analogous to the GII. The same adjustments could not be made for the GII, as this product is only disseminated to the users, whereas the RII is a local product and can therefore be adjusted as needed.

The GII, RII and AveRII products consist of 4 instability indices, as well as the TPW (EUMETSAT, 2007). The 4 instability products include the KI, LI, the KO index and the Maximum Buoyancy. In this research, only the KI, LI and the TPW content were assessed and therefore only these 3 parameters will be discussed. The 3 indices are defined as (EUMETSAT, 2007):

(1) $KI = (T^{obs(850)} - T^{obs(500)}) + TD^{obs(850)} - (T^{obs(700)} - TD^{obs(700)})$;

(2) $LI = (T^{obs(500)} - T^{\text{Lifted from surface}(500)})$;

(3) TPW: Vertically integrated water vapour concentration.

Here, T is the Temperature and TD is the Dewpoint Temperature at the specified height.

A physical method is used for the retrieval of these airmass parameters from MSG SEVIRI data (EUMETSAT, 2007). This retrieval method uses a given set of channels and attempts to reconstruct a temperature and humidity profile from the satellite radiances or brightness temperatures (EUMETSAT, 2007). The set of channels used are Ch05 (WV6.2), Ch06 (WV7.3), Ch07 (IR8.7), Ch09 (IR10.8), Ch10 (IR12.0) and Ch11 (IR13.4). For an in-depth explanation on how this physical retrieval process works, please refer to the EUMETSAT (2007) baseline document.

As mentioned earlier, the GII and RII products (as well as the AveRII product) can only be calculated when the atmosphere is cloud-free. This leads to the fact that when there are already clouds or storms developing, there will be no GII or RII data available over those specific regions. Due to this, many of the studies done relate the GII and RII data from the early hours of the morning (when there is usually little or no clouds present) to thunderstorms developing later in that same day – thus giving a lead time of a couple of hours on storm development. This research does not verify how useful the indices used by the GII and RII products are. This research is focused on verifying how accurate and reliable the GII and RII products are as compared to radiosondes.

METHODS AND DATA

The stability indices from the GII and RII products are compared to the same instability indices from upper air sounding data for the period of 01 Dec 2007 to 30 Nov 2008. This period was divided into the 4 seasons, namely 01 Dec 2007-29 Feb 2008 (DJF); 01 March-31 May 2008 (MAM); 01 June-31 August 2008 (JJA); and 01 Sept-30 Nov. 2008 (SON). In South Africa, which his situated in the Southern Hemisphere, DJF is the summer season, MAM is autumn, JJA is winter and SON is spring. In previous research, proximity soundings were used to determine the pre-storm environments of tornadic and nontornadic mesocyclones (Craven & Brooks, 2008; Rasmussen & Blanchard, 1998; Brooks *et al*., 1994). These proximity soundings varied between 80km and 400km in range with Craven & Brooks (2008) also adding a 6-hour time period restriction on the launching time of the radiosondes. In this research, some adjustments and restrictions were also applied to the radiosonde data, as some of the observations displayed erroneous values. These adjustments will not be mentioned here due to a lack of space.

In South Africa, radiosondes are launched at 0000 and/or 1200 UTC at various stations (totaling 10 stations). Because of the fact that at some of the stations there are only morning (0000) or afternoon (12:00) soundings, a decision was made to only verify the stations that have both morning and afternoon soundings and that have a complete record of at least 12 consecutive months. Therefore, only 5 stations were used: Irene, Bloemfontein, Durban, Port Elizabeth and Cape Town (Figure 1, Table 1). Irene, Bloemfontein and Durban are stations that receive most of their rainfall during summer, with Irene and Bloemfontein experiencing late-afternoon thunderstorms during summer on a regular basis. Cape Town mostly receives rainfall during the winter months, as cold fronts, and associated storms, move over the area during this time. Port Elizabeth receives rainfall throughout the year, with cold fronts also moving over this station during the winter season.

Various statistical analysis methods were used on the data. For the statistical analysis, the GII, RII and AveRII index values were given the notation of “forecast values” and the observed radiosonde index values were labeled the “observation values”. To measure the degree of linear association between two variables (i.e. forecast and observation values), the correlation coefficient (r) was applied to the data (Murphy, 1988; Kachigan, 1991; Jolliffe & Stephenson, 2003). To measure the accuracy of the variables, which illustrates the correspondence between the variables, the mean absolute error (MAE) was calculated, which is less sensitive to large outlier values than the Mean Squared Error (MSE) (Jolliffe & Stephenson, 2003). In addition, the average bias was also calculated to verify whether the forecast values were under- or over-forecast. Various studies have evaluated satellite-derived retrievals and products to radiosonde index values using a combination (and more) of the above-mentioned statistical analysis methods (Fuelberg & Olson, 1991; Rao & Fuelberg, 1998; Ellrod *et al*., 2000; Schmit *et al*., 2002).

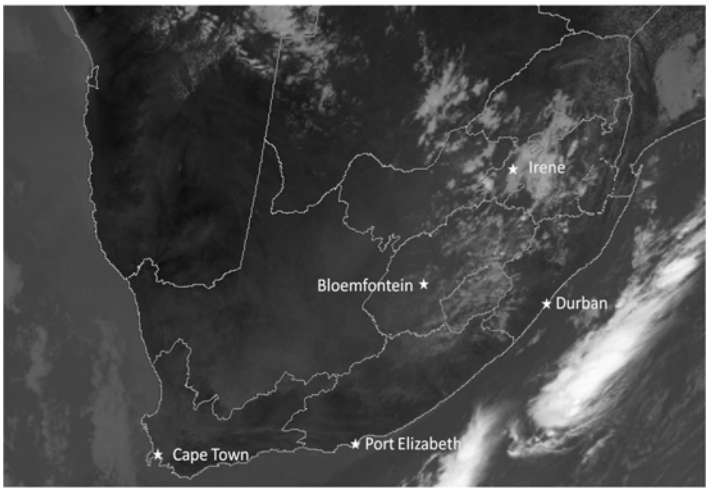

Figure 1**: MSG IR108 showing upper air sounding stations across South Africa on 27 May 2008 at 1200 UTC.**

	Latitude	Longitude	Height above Sea Level (m)
Irene	-25.92	28.22	1326
Bloemfontein	-29.10	26.30	1406
Durban	-29.97	30.95	14
Port Elizabeth	-33.98	25.62	61
Cape Town	-33.97	18.60	42

***Table 1*: Latitude, longitude and height above sea level for the 5 stations used.**

RESULTS AND DISCUSSION

As mentioned previously, the correlation coefficient, average bias and mean absolute error (MAE) calculations (as well as a few others) were used in this research. In this section, some of the results of the analyses will be shown and discussed. This will be done for the KI, LI and TPW for the 5 stations mentioned. Due to a lack of space, only tables will be displayed to show the results that were obtained. Irene and Bloemfontein stations are both interior situations, situated well above sea-level (Table 1). This sometimes leads to the fact that the KI values cannot be calculated because these stations are situated around the 850 hPa level. This also leads to the LI values being erroneous at times. In addition, during December 2007, Bloemfontein only had radiosonde data in the morning. From January 2008 radiosondes were available in the morning and afternoon. This could have an impact on Bloemfontein's results for DJF.

K-index (KI):

In South Africa a KI value of 30 and higher, which is obtained frequently during the summer, usually indicates that the atmosphere is unstable, which may lead to the development of thunderstorms. Negative KI values are also frequently observed, especially during the Autumn and Winter seasons, but also during the Spring and Summer seasons, particularly over the coastal areas.

Table 2 (left) below shows the correlation coefficient values that were obtained when comparing the GII, RII and AveRII KI values to the KI values obtained from the radiosondes for all 5 stations. The product with the highest score for each season (per station) is underlined for easy comparison. One can clearly see that all three products performed well, with a minimum correlation coefficient of at least 0.5 being obtained. However, it is evident that the GII outperforms the RII and AveRII products for all of the seasons, except SON, where the AveRII product has the highest correlation coefficient values. If one only refers to the GII correlation values, one can see that over Irene, MAM has the highest scores, Bloemfontein has the highest scores during JJA, Durban has the highest scores during SON and both Cape Town and Port Elizabeth have the highest scores during SON. It should be noted that during DJF Bloemfontein has very low correlation values. This might be due to the previously mentioned fact that Bloemfontein receives afternoon thunderstorms regularly during this period, as well as the fact that radiosondes were only launched twice daily at this site from January 2008.

Table 2 (right) below also shows the MAE results between the forecast KI and the observed KI values as well as the average bias between the two (GII/RII/AveRII minus radiosonde values). The MAE value is given, and only the sign of the average bias is given in brackets after the MAE. Additionally, the product that obtained the lowest MAE (the best score) for each season is underlined for easy comparison. MAE values are relatively large for all of the products, with results ranging between 4 and 9. It is evident that the GII product again outperforms the RII and AveRII for all seasons and stations with the GII product obtaining the lowest MAE values. However, the RII and AveRII products perform comparatively well as can be seen. The GII product on average has a positive bias, especially over the 3 coastal stations, and the forecast GII KI values are higher (and thus shows more atmospheric instability) than the observed KI values, whereas the RII and AveRII products shows mixed results in terms of having positive or negative biases.

Correlation Coefficient				
Station	Season	K-index		
		GII	RII	Ave RII
Irene	DJF	0.82	0.651	0.653
	MAM	0.919	0.882	0.891
	JJA	0.804	0.787	0.821
	SON	0.874	0.847	0.837
Bloemfontein	DJF	0.574	0.53	0.528
	MAM	0.852	0.841	0.845
	JJA	0.892	0.857	0.873
	SON	0.826	0.878	0.906
Durban	DJF	0.834	0.79	0.778
	MAM	0.802	0.725	0.691
	JJA	0.885	0.819	0.844
	SON	0.892	0.814	0.844
Port Elizabeth	DJF	0.738	0.675	0.679
	MAM	0.816	0.766	0.778
	JJA	0.88	0.74	0.788
	SON	0.765	0.787	0.813
Cape Town	DJF	0.795	0.75	0.772
	MAM	0.791	0.735	0.739
	JJA	0.82	0.785	0.806
	SON	0.669	0.719	0.773

Mean Absolute Error				
Station	Season	K-index		
		GII	RII	Ave RII
Irene	DJF	6.076 (-)	7.452 (-)	6.621 (-)
	MAM	4.788 (-)	5.724 (-)	5.633 (-)
	JJA	7.072 (+)	8.793 (-)	7.932 (+)
	SON	6.902 (+)	7.558 (+)	7.282 (+)
Bloemfontein	DJF	9.474 (+)	8.730 (+)	8.058 (+)
	MAM	5.324 (+)	5.807 (-)	5.360 (-)
	JJA	5.431 (-)	7.203 (-)	6.694 (-)
	SON	7.476 (-)	6.940 (+)	6.309 (+)
Durban	DJF	8.567 (+)	8.671 (+)	8.313 (-)
	MAM	6.393 (+)	7.404 (-)	7.985 (-)
	JJA	5.603 (+)	7.625 (-)	7.047 (-)
	SON	5.736 (-)	8.340 (-)	7.179 (-)
Port Elizabeth	DJF	10.841 (+)	10.380 (+)	10.008 (+)
	MAM	7.044 (+)	7.547 (+)	7.397 (+)
	JJA	5.978 (+)	9.933 (+)	8.473 (-)
	SON	7.701 (+)	8.369 (-)	7.886 (-)
Cape Town	DJF	7.921 (+)	8.761 (+)	8.695 (+)
	MAM	7.214 (+)	9.336 (-)	9.222 (-)
	JJA	6.393 (-)	9.535 (+)	8.885 (-)
	SON	8.273 (+)	9.991 (-)	8.780 (+)

***Table 2*: Correlation coefficient (left) and mean absolute error with sign of average bias (right) of K-index values for each station and season.**

From the above results it is apparent that the GII product shows the best performance when calculating the KI values over South Africa, with the highest correlation coefficient and the lowest MAE being obtained by this product. Thus, one can deduct that although the RII and AveRII products perform relatively well, it is suggested that the GII product be used when calculating the KI

Lifted Index (LI):

Negative LI values usually indicates that the atmosphere is unstable and may lead to thunderstorm development later that same day – the same is true for South Africa, where a LI of -2 or -3 (and less) usually leads to thunderstorms. It should be noted that during June 2007 the RII's LI parameter was improved for local circumstances. It was observed that before this time, the RII computed LI values which were very negative and values such as -6 and less were a regular occurrence even when there was no thunderstorm activity later in the afternoon. Therefore the RII's LI was improved during June 2007 and this lead to improved results from this month onward.

Table 3 shows the results for the correlation coefficient (left) comparisons and the MAE together with the average bias (right), respectively. As was the case the with the KI tables, the products with the best scores are underlined for each station and season for easy comparison. It is apparent from Table 3, that in terms of the correlation coefficient scores, the GII product performs the best over all the stations, except Cape Town, where the RII product performed the best when comparing the LI values. Here for the interior stations of Irene and Bloemfontein, the SON season had the highest overall correlation coefficients and the DJF season had the lowest overall correlation coefficient scores. The low scores during DJF might be due to the same reasons as stated for the KI values. Durban has the complete opposite results, with the DJF season having the highest average correlation coefficient and SON having the lowest average correlation coefficient scores. Port Elizabeth and Cape Town, where cold fronts (and associated storms) move over during the winter season, both had the highest correlation coefficient scores during JJA and the lowest scores during MAM.

Correlation Coefficient				
Station	Season	Lifted Index		
		GII	RII	Ave RII
Irene	DJF	0.731	0.687	0.704
	MAM	0.874	0.667	0.718
	JJA	0.841	0.837	0.847
	SON	0.84	0.858	0.851
Bloemfontein	DJF	0.731	0.561	0.551
	MAM	0.934	0.704	0.715
	JJA	0.953	0.836	0.857
	SON	0.909	0.874	0.894
Durban	DJF	0.871	0.796	0.828
	MAM	0.847	0.725	0.784
	JJA	0.847	0.797	0.811
	SON	0.805	0.743	0.774
Port Elizabeth	DJF	0.818	0.651	0.657
	MAM	0.713	0.701	0.71
	JJA	0.867	0.79	0.749
	SON	0.807	0.782	0.787
Cape Town	DJF	0.836	0.727	0.719
	MAM	0.726	0.744	0.701
	JJA	0.848	0.873	0.874
	SON	0.855	0.874	0.854

Mean Absolute Error				
Station	Season	Lifted index		
		GII	RII	Ave RII
Irene	DJF	3.456 (-)	2.603 (-)	2.009 (-)
	MAM	2.487 (-)	2.805 (-)	2.662 (+)
	JJA	3.431 (-)	2.089 (-)	2.025 (+)
	SON	3.333 (-)	3.333 (-)	2.736 (-)
Bloemfontein	DJF	7.438 (-)	4.907 (-)	4.519 (-)
	MAM	3.423 (-)	3.353 (-)	3.227 (-)
	JJA	2.825 (-)	3.692 (-)	3.125 (-)
	SON	4.070 (-)	3.718 (-)	3.547 (-)
Durban	DJF	1.836 (-)	1.645 (+)	1.800 (+)
	MAM	1.921 (-)	2.417 (+)	2.209 (+)
	JJA	2.066 (-)	2.550 (+)	2.327 (-)
	SON	1.943 (-)	2.377 (+)	2.429 (+)
Port Elizabeth	DJF	2.977 (-)	2.630 (-)	2.672 (+)
	MAM	2.678 (-)	2.645 (+)	2.816 (-)
	JJA	1.837 (-)	2.740 (+)	2.924 (-)
	SON	1.939 (-)	2.223 (+)	2.374 (+)
Cape Town	DJF	3.200 (-)	2.266 (+)	2.331 (+)
	MAM	2.692 (-)	2.313 (+)	2.503 (+)
	JJA	1.784 (-)	2.525 (+)	2.649 (-)
	SON	2.211 (-)	2.500 (+)	2.652 (+)

***Table 3*: Correlation coefficient (left) and mean absolute error with sign of average bias (right) of Lifted index values for each station and season.**

The MAE results are a little more complicated than the correlation coefficient results. Here the AveRII product performed the best over the interior stations (Irene and Bloemfontein) and the GII product performed the best over Durban and Port Elizabeth. For Cape Town, the RII product had the best overall score during DJF and MAM and the GII product performed the best during JJA and SON. However, taken as a whole, the RII product had the best overall score over the 12 month period for Cape Town. For Irene and Bloemfontein, the season with the best score was JJA, when thunderstorms only very rarely occur. The season with the worst MAE for Irene was SON and for Bloemfontein was DJF. Durban's season with the best MAE was DJF and the season with the worst MAE was JJA. Both Port Elizabeth and Cape Town stations had DJF as the season with the worst MAE for LI values. The season with the best MAE for Port Elizabeth was SON and for Cape Town was JJA.

On average, the GII LI product has the best overall score over all the stations, however the AveRII product also has very good results over specifically Irene and Bloemfontein. Therefore, both these products can be used to calculate LI values over Irene and Bloemfontein, but the GII product can be used with a high degree of confidence over all 5 stations.

Total Precipitable Water content (TPW):

The TPW is a measure of the amount of moisture that is available in the vertical atmosphere. This is not an instability index, but a true measure of the moisture availability in the atmosphere, which is important, because the availability of moisture is one of the key ingredients for the development of thunderstorms. If there is no moisture, the few existing clouds will dissipate due to entrainment and other factors. Table 4 shows the results for the correlation coefficient (left) comparisons and the MAE together with the average bias (right), respectively. As previously stated, the products with the best scores are underlined for each station and season for easy comparison.

It can be deducted from Table 4, that in terms of the correlation coefficient results, the GII product performed the best over all the stations, for all the seasons tested. Irene, Bloemfontein, Durban and Port Elizabeth all had the best overall correlation coefficient results during SON and the worst results during DJF. Cape Town on the other hand obtained different results with the SON season having the worst and the DJF season the best correlation coefficient values. Furthermore, all three products had high correlation values, indicating that there is good linear association between the forecast GII, RII and AveRII PW values and the observed TPW values.

Correlation Coefficient				
Station	**Season**	**TPW Value**		
		GII	**RII**	**Ave RII**
Irene	**DJF**	0.802	0.767	0.759
	MAM	0.899	0.923	0.926
	JJA	0.919	0.888	0.89
	SON	0.929	0.909	0.923
Bloemfontein	**DJF**	0.802	0.764	0.774
	MAM	0.911	0.842	0.88
	JJA	0.917	0.907	0.911
	SON	0.931	0.895	0.925
Durban	**DJF**	0.845	0.793	0.836
	MAM	0.919	0.891	0.879
	JJA	0.911	0.875	0.891
	SON	0.925	0.944	0.931
Port Elizabeth	**DJF**	0.855	0.718	0.73
	MAM	0.829	0.81	0.808
	JJA	0.871	0.775	0.82
	SON	0.854	0.867	0.877
Cape Town	**DJF**	0.894	0.876	0.892
	MAM	0.891	0.874	0.884
	JJA	0.886	0.883	0.879
	SON	0.882	0.859	0.848

Mean Absolute Error				
Station	**Season**	**TPW value**		
		GII	**RII**	**Ave RII**
Irene	**DJF**	2.689 (+)	3.269 (+)	3.135 (+)
	MAM	2.087 (-)	1.695 (-)	1.716 (-)
	JJA	1.042 (-)	1.219 (+)	1.209 (+)
	SON	1.851 (+)	2.382 (+)	2.388 (+)
Bloemfontein	**DJF**	3.113 (+)	2.867 (+)	3.113 (+)
	MAM	1.982 (-)	2.445 (-)	2.207 (-)
	JJA	0.974 (-)	1.434 (-)	1.381 (-)
	SON	1.659 (-)	1.974 (+)	2.014 (+)
Durban	**DJF**	4.131 (-)	4.571 (-)	5.078 (-)
	MAM	2.528 (-)	2.963 (-)	3.873 (-)
	JJA	2.116 (-)	2.392 (+)	3.253 (-)
	SON	3.038 (-)	2.736 (-)	3.845 (-)
Port Elizabeth	**DJF**	2.705 (+)	4.070 (+)	3.928 (+)
	MAM	2.967 (-)	2.981 (+)	3.176 (+)
	JJA	1.826 (-)	2.375 (+)	2.145 (-)
	SON	2.131 (-)	2.398 (-)	2.374 (-)
Cape Town	**DJF**	3.150 (-)	2.357 (-)	2.305 (-)
	MAM	3.538 (-)	2.746 (-)	2.595 (-)
	JJA	2.701 (-)	1.697 (+)	1.924 (-)
	SON	2.615 (-)	2.306 (-)	2.174 (-)

***Table 4*: Correlation coefficient (left) and mean absolute error with sign of average bias (right) of the Total Precipitable Water values for each station and season.**

CONCLUSION

After extensive statistical analysis one can conclude from the above that the GII, RII and AveRII products all show good linear association when comparing their index values to observed index values obtained from radiosonde data. All three products also show good accuracy with regard to the observed values. Ultimately, one can deduct from the above that the GII product performs the best when calculating the KI, LI and TPW values. The RII and AveRII products both do well statistically when comparing their forecasts to the observed index values. Therefore, the GII product can be used for best results when forecasting the KI, LI and TPW values over South Africa. However, the AveRII product can also be used to calculate the LI and TPW over Cape Town. Further in-depth studies are needed on the performance of the GII and RII products, and data over a longer time-period should be used for the analysis.

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