

Climate change impacts on mean wind speeds in South Africa

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Abstract

Climate change could potentially affect a number of variables that impact the dispersal of and human exposure to air pollutants, as well as climate dependent sectors such as wind energy. This study attempted to quantify the projected changes in seasonal daily mean wind speeds for South Africa around the mid-21st century (2051-2075) under two different atmospheric heat pathways. Seasonal daily mean wind speed increases rarely reach 6% and decreases occur to a maximum of 3% and are variable between different seasons and areas within the country. In all seasons except December-January-February, wind speeds are projected to increase in the Highveld region, suggesting that air pollution dispersing conditions could increase. Wind direction at the 850hPa-level show minor changes, except over the Western and Eastern Cape provinces.

Keywords

climate change, wind speed, air pollution, mitigation, climate models

Introduction

Changes in climate could affect local and regional air pollution concentrations by impacting atmospheric chemical reactions, transport and rates of dispersion of *inter alia* acidic materials (Bernard et al., 2001). The South African government aims to cut greenhouse gas (GHG) emissions by 42% by 2025 by implementing a range of climate change mitigation strategies, including renewable energy of which wind and solar resources are highly dependent on climate. If the country achieves this goal and successfully executes its plan to contribute 30% renewable energy to the country's energy mix by 2025, it would contribute substantially to reducing air pollution. Horton et al. (2014) suggest that large parts of South Africa could expect pollutant-dispersing conditions more often as the 21st century progresses, but their work had been conducted with global climate models (GCMs) on an annual scale.

However, variations in wind climates could occur within finer spatial scales than are represented by GCMs, and finer temporal scales than are represented by assessments at annual intervals. Therefore, the work presented in this study employed an ensemble of eight GCMs that have been dynamically downscaled to regional climate model (RCM) resolution ($0.44^\circ \times 0.44^\circ$).

This study had two objectives. Firstly, to evaluate the representation of past climates by state-of-the-art climate models at a regional scale by verifying them against observational data during a 25-year reference period (1981-2005). Secondly, to

establish whether notable changes exist between seasonal wind speeds at surface level and wind direction at the 850hPa-level during the reference period and a future period (2051-2075) under two atmospheric heat pathways, RCP4.5 and RCP8.5.

Data and Methods

Data

In order to address the research objectives, two CO₂ RCP pathways were considered in eight dynamically downscaled GCM simulations from the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5) to determine the potential influence of global warming on South African winds. The Rossby Centre, a climate modelling research unit at the Swedish Meteorological and Hydrological Institute, has produced a substantial collection of regional climate model simulations for the African region through dynamical downscaling of a subset of eight GCMs from the CMIP5 initiative. These downscaled model simulations were produced by the Rossby Centre's RCA4 RCM.

The initiative formed part of the CORDEX-Africa (COordinated Regional Downscaling EXperiment) project. The forcing GCMs were the CanESM2, CNRM-CM5, EC-EARTH, MIROC5, HadGEM2-ES, MPI-ESM-LR, NorESM1-M, and GFDL-ESM2M coupled GCMs. Winds simulated by models are susceptible to large errors, hence the use of eight models: a multi-model ensemble allows a

more robust assessment (Rasmussen et al., 2012, Pašičko et al., 2012). RCA4 RCM data are available for a historical period from 1951 to 2005, and a projected period from 2006 to 2100.

The implementation of climate change mitigation measures could also affect the manner in which wind climates behave. Fant et al. (2015) emphasise that the probability of small wind speed changes increases considerably under a climate change scenario that incorporates mitigation strategies. Therefore, the model output of this project was considered in terms of two atmospheric heat pathways (RCP4.5 and RCP8.5). In the AR5, GHG emissions pathways considered were expressed in terms of these atmospheric heat based Representative Concentration Pathways (RCPs). IPCC scenarios (SRES) used in previous assessment reports (based on CO₂ concentrations) could be updated in the AR5 to heat based pathways thanks to new information on emerging technology, economies, land use, land cover change and environmental factors of almost a decade (Moss et al., 2010). The new AR5 GHG forcing for future projections used in this study consist of CO₂ RCPs related to 4.5W.m⁻² and 8.5W.m⁻² atmospheric heat increases by 2100 (henceforth RCP4.5 and RCP8.5, respectively), amongst other pathways. The use of the word 'representative' resembles the fact that each RCP signifies one of numerous possible scenarios leading to particular radiative forcing characteristics (Van Vuuren et al., 2011). The word 'pathway' refers to the trajectory taken over a long time to achieve a given radiative forcing point in terms of long-term GHG concentration levels. Such time-evolving concentrations of radiatively active constituent pathways could be incorporated for driving global warming climate model simulations.

In more detail, RCP4.5 (and RCP8.5) represents a radiative forcing of ~4.5W.m⁻² at stabilisation after 2100 (>8.5W.m⁻² in 2100) and a ~650ppm CO₂-equivalent concentration at stabilisation after 2100 (>1370ppm CO₂-equivalent in 2100). RCP4.5 therefore represents a pathway that stabilises without overshoot, and RCP8.5 resembles a rising pathway. RCP4.5 was developed by the Global Change Assessment Model (GCAM) of the Pacific Northwest National Laboratory in the USA, while the RCP8.5 was developed by the Model for Energy Supply Strategy Alternatives and their General Environmental impact (MESSAGE) from the International Institute for Applied Systems Analysis in Austria (Moss et al., 2010). These RCPs are two of four which were used in AR5.

In order to identify model biases, RCA4 RCM output had to be assessed through comparison with observational data such as the ECMWF (European Centre for Medium-range Weather Forecasts) ERA-Interim global reanalysis data, which is a global atmospheric reanalysis available from 1979 to present. Its grid resolution is 0.75° × 0.75°. To examine changes in, for example, mean daily wind speeds, 30-year assessment periods are preferred to comply with the World Meteorological Organisation's definition for 'climate'. Since ERA-Interim reanalysis data is available from 1979 onwards, and the historical period for the RCA4 model output ends in 2005, a 25-

year assessment period (1981-2005) was chosen for this study, which was then compared to a projection period (2051-2075).

ERA-Interim reanalysis data are particularly useful in climate change assessments as it covers numerous climate variables in a coherent structure. Observational data used in the reanalysis originate from inter alia wind profilers, pilot balloons, radiosondes, land stations, aircraft, ships and drifting buoys (Dee et al., 2011).

Methods

ERA-Interim reanalysis data

Model performance was evaluated by calculating differences between the RCA4 output and ERA-Interim reanalysis data. For this purpose, daily (00:00UCT, 06:00UCT, 12:00UCT and 18:00UCT) historical near-surface (10m above ground level (agl)) *u*- and *v*-components have been obtained for the 25-year period 1981 to 2005, across the domain 18° to 42°S and 14° to 37°E, from the ERA-Interim reanalysis databank. For comparing RCA4 RCM output (0.44° × 0.44° resolution) to ERA-Interim reanalysis data (0.75° × 0.75° resolution), ERA-Interim reanalysis fields were interpolated (bilinear) to fit the RCA4 fields. The ERA-Interim simulation domain size was also modified to correspond with the RCA4 domain. The boundaries of this domain are 19.5° to 40.5°S and 15° to 35.25°E.

Wind speed (*ws*) was calculated from *u*- and *v*-components as follows:

$$ws = \sqrt{u^2 + v^2} \quad (1)$$

Wind speeds at 00:00UCT, 06:00UCT, 12:00UCT and 18:00UCT were averaged to obtain daily means, which were compatible with RCA4 RCM data: RCA4 data is provided as daily averages taken eight times a day, i.e. three-hourly (Christensen et al., 2014). The first 28 days of each month were then selected for further calculation. Residual days could not be used in the analysis, due to the fact that some model fields consist of 30-day months only, while others included leap years. A uniform month-day number was important for calculating cross-model ensemble averages. Seasonal wind speeds were then obtained after categorising daily data into four groups: December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON). From this, seasonal daily mean wind speeds for each season were calculated.

Model data

Data from eight the GCMs that were dynamically downscaled using the RCA4 RCM were obtained. A domain extending from 22° to 35°S and 16.2° and 33°E was defined for the study. Daily historical near-surface wind speeds (10m agl) were extracted for each model for the 25 years extending from 1981 to 2005. For each of these eight model files, data were grouped into seasons (DJF, MAM, JJA and SON). Days 1 to 28 were then extracted, as explained previously, for each month per season and per model.

Thereafter, ensemble means of the daily data were calculated from the eight RCA4 RCM simulations across the four seasons, from where daily mean wind speeds for each of the seasons were calculated.

To project potential diversions from dominant wind directions, the *u*- and *v*-components at the 850hPa-level were extracted for each model for the 25 years extending from 1981 to 2005 as well. The data were grouped seasonally, extracted from days 1 to 28, and ensemble means were calculated according to the same procedure followed for the near-surface wind speed data. The *u*- and *v*-component data were then used as vectors in the Grid Analysis and Display System (GrADS) to calculate and display wind directions for the historical period of 1981 to 2005.

Statistical evaluation of model performance

In order to verify RCA4 RCM performance, the Root Mean Square Error (RMSE) of seasonal daily mean wind speeds were calculated using the ERA-Interim and the RCA4 RCM data. RMSE was calculated as follows (CTEC, 2015):

$$RMSE = \sqrt{\sum_{i=1}^n \frac{(x_{obs,i} - x_{model,i})^2}{n}} \tag{2}$$

where $x_{obs,i}$ represents the observed ERA-Interim values; $x_{model,i}$ represents the model values at a particular point *i*; and *n* represents the number of values.

Model evaluation against observational data

RCA4 RCM output was evaluated against observational data from six South African Weather Service (SAWS) stations distributed across the country. Data from Malmesbury, Vredendal, Greytown, Upington, Nelspruit, and Mokopane were obtained from SAWS for varying periods starting in 1981 to 2005. Wind speeds were estimated visually from pressure plate anemometers until 1992 (excluding Upington), when wind speeds began to be measured with Automatic Weather Stations (AWS), and are therefore more accurate. The data were provided as it was measured at 08:00, 14:00 and 20:00. These three times daily observations were averaged to obtain single daily averages, which were then employed in calculating seasonal average wind speeds. Model values for comparison were selected from those grid boxes in model data within which the particular weather station’s coordinates lie. These coordinates are shown in Table 1, as well as the period for which data were available. Note that two stations’ data were considered for the Upington area, as the periods of availability of both differ.

Table 1: SAWS weather station particulars

Station name	Coordinates	Period of data availability
Malmesbury	33.4720 S 18.7180 E	1986/02-2005/12
Vredendal	31.6730 S 18.4960 E	1981/01-2005/12
Greytown	29.0830 S 30.6030 E	1993/03-2005/12
Upington (1)	WK 28.4000 S 21.2670 E	1981/01-1992/04
Upington (2)	WO 28.4110 S 21.2640 E	1991/07-2005/12
Nelspruit	25.5030 S 30.9110 E	1993/07-2005/12
Mokopane	24.2050 S 29.0110 E	1995/09-2005/12

Changes in wind climate

Daily means of seasonal near-surface wind speed, in the projected period were calculated from RCA4 RCM output under conditions of the RCP4.5 and RCP8.5 pathways. Data for 850hPa-level *u*- and *v*-components were obtained for these pathways as well. The data were extracted and grouped in the same manner as in the historical period, but in this case for a 25-year period extending from 2051 to 2075.

Anomalies between RCA4 RCM output in the reference period and RCA4 RCM output in the two projections were calculated and expressed as percentage differences. Wind direction changes at the 850hPa-level were also calculated for the two RCPs by subtracting historical *u/v* components from projected *u/v* components, and then by using these anomalies to plot deviations from the dominant wind direction in the reference period.

Results

Mean seasonal wind speed

For the DJF-season, the winds in the north-western quarter of the country are captured well, showing wind speeds in the region of 4m.s⁻¹ to 5m.s⁻¹ in both ERA-Interim (Figure 1) and RCA4 RCM ensemble (Figure 2) runs. However, wind speeds are somewhat overestimated over the eastern escarpment by the RCA4 RCM. The ERA-Interim simulation shows that near-surface winds occur at around 1.5m.s⁻¹ to 3.5m.s⁻¹, whereas the RCA4 RCM simulations project winds in this area to vary from 3m.s⁻¹ to 5m.s⁻¹. Furthermore winds are projected at around 3m.s⁻¹ to 5m.s⁻¹ in the ERA-Interim run, but the RCA4 RCM projection ranges from 4.5m.s⁻¹ to 6m.s⁻¹ in the south-east of the country by the model data. In summary, the RCA4 RCM projects near-surface wind speeds at around 1.5m.s⁻¹ higher than observed data shows it to be, except in the north-western quarter of the country.

In the MAM-season, the lower wind speeds occurring from central South Africa to the Highveld are well captured by the RCA4 RCM, with only a 1m.s⁻¹ difference between ERA-Interim (Figure 3) and RCA4 RCM (Figure 4) output, the latter projecting the higher mean wind speed. An overestimation of wind speeds by the RCA4 RCM is observed along a west-east strip stretching from the Cape Town region to Lesotho. According to the ERA-Interim simulation, wind speeds range from 2.5m.s⁻¹ to 4m.s⁻¹, and the RCA4 RCM projects wind speeds to range from 3.5m.s⁻¹ to 5.5m.s⁻¹. Wind speed projection ranges therefore are estimated by the RCA4 RCM by no more than 1.5m.s⁻¹ higher than ERA-Interim data in this season.

Near-surface wind speeds in the JJA-season are projected at no less than 2.5m.s⁻¹ in the north-eastern quarter of the country in the RCA4 RCM ensemble run (Figure 6) – 0.5m.s⁻¹ higher than the ERA-Interim run (Figure 5). The west-east strip RCA4 RCM ensemble overestimation observed from Cape Town to Lesotho in the MAM-season (Figure 4) is also present in the JJA-season:

the ERA-Interim run shows that these winds range from $3\text{m}\cdot\text{s}^{-1}$ to $5\text{m}\cdot\text{s}^{-1}$, while the RCA4 RCM ensemble run shows it could range from $3.5\text{m}\cdot\text{s}^{-1}$ to $6\text{m}\cdot\text{s}^{-1}$.

Finally, in the SON-season lower wind speeds in the south-eastern tip of the country are once more not well captured by the RCA4 RCM, nor is it represented along the eastern escarpment stretch (Figure 8). The simulation from the ERA-Interim data (Figure 7) suggests that winds range from $2\text{m}\cdot\text{s}^{-1}$ to $5\text{m}\cdot\text{s}^{-1}$, but they range from $3.5\text{m}\cdot\text{s}^{-1}$ to $6\text{m}\cdot\text{s}^{-1}$ in RCA4 RCM ensemble run. On the other hand, winds over the central part of the country are well captured, as they occur at about $3.5\text{m}\cdot\text{s}^{-1}$ to $4.5\text{m}\cdot\text{s}^{-1}$ in both ERA-Interim and model ensemble runs.

The RMSE of seasonal mean daily near-surface wind speeds ($\text{m}\cdot\text{s}^{-1}$) are shown in Figures 9 to 12. The high RMSE values on the south-eastern tip of the country demonstrate overestimations identified in previous paragraphs in all seasons. In general, it is confirmed that the RCA4 RCM performs best over central South Africa. The MAM-season has the largest area with the lowest RMSE, mostly between $0.8\text{m}\cdot\text{s}^{-1}$ and $1.6\text{m}\cdot\text{s}^{-1}$ (Figure 10). The highest RMSE-values of $2.8\text{m}\cdot\text{s}^{-1}$ occur in the JJA-season in the Cape Town region and Lesotho (Figure 11).

Model evaluation against observational data

Mean daily wind speeds as simulated from RCA4 RCM data, plotted together with mean daily wind speeds calculated from ground station data recorded at six SAWS weather stations are shown in Figure 13. Four separate values were plotted per location according to seasons. Wind speeds from RCA4 RCM ensemble data at all of the points plotted were higher than the observational data from the SAWS weather stations. It must be borne in mind that wind speeds vary markedly on scales smaller than the grid resolution of model data of $0.44^\circ \times 0.44^\circ$ (0.44° latitude translates roughly to between 45 and 40km; 0.44° longitude to 49km). Minor topographical variations, land cover and temperature variations can intensify or slow winds (Jarvis and Stuart, 2001). The model performs best at the Upington region and Mokopane regions (locations 13-16 and 21-24, respectively in Figure 13). The overestimation of winds demonstrated by the high RMSE-values in previous figures in the Western Cape region (Figures 9 to 12) are supported by the large differences in Malmesbury and Vredendal observations versus model output in Figure 13 (locations 1-4 and 5-8, respectively).

RCA4 RCM projected mean seasonal wind speed and direction changes

For the DJF-season, it is shown in Figure 14 that wind speeds are expected to increase by up to 4% along the southern parts of the Western and Eastern Cape Provinces under RCP4.5 (Figure 14). For the RCP8.5 pathway, increases in wind speeds could reach 6% in this area (Figure 15). Decreases in wind speeds of up to 1.5% might be expected in the Highveld under the RCP4.5 pathway (Figure 14) and 2.5% under the RCP8.5 pathway (Figure 15).

In the MAM-season under the RCP4.5 pathway, wind speeds are projected to increase by up to 3.5% in the north-eastern quarter of the country, and could also increase by up to 3% in the Cape Town region (Figure 16). Projected increases in wind speeds are more apparent in the RCP8.5 pathway in these regions, where it could increase by up to 5% in the Limpopo province and 4.5% in the Cape Town region (Figure 17). The central part of the country could expect a slight increase in wind speeds of about 1% to 3% under the RCP8.5 pathway as well (Figure 17). Decreased wind speeds are projected under the RCP4.5 pathway in the Northern Cape and the Eastern Cape Provinces, but of only 1% (Figure 16). In the RCP8.5 pathway it is projected that the western half of the Northern Cape Province could expect decreased wind speeds of up to 2% and the Eastern Cape Province could expect wind speeds to increase by 2% along the coast, and decrease by 1% closer to the escarpment edge over the east of South Africa (Figure 17).

In the RCP4.5 pathway in the JJA-season, wind speeds are projected to increase for the majority of the country (Figure 18). Specifically the eastern half of the country could expect wind speeds to increase by up to 4.5%, but central South Africa and the Cape Town region could expect wind speeds to increase by up to 3%. Decreased wind speeds of up to 1% are projected in this same pathway over the coastal Eastern Cape Province and the West Coast. Under the RCP8.5 pathway, wind speeds are projected to increase by up to 6% in the far east of South Africa, and in the region of 1% to 3% in the interior (Figure 19). Wind speeds are projected to decrease along the West Coast by up to 2%, and could decrease by 1.5% in the Eastern Cape Province.

In the SON-season, wind speeds are projected to increase by 5% in the Limpopo Province, and lesser increases are projected along the South African coast starting at KwaZulu-Natal all the way to Cape Town under the RCP4.5 pathway (Figure 20). The region around and included the Northern Cape Province could expect wind speeds to increase by 0% up to 1.5%. Under the RCP8.5 pathway, the Limpopo Province could expect wind speeds to increase by up to 6% (Figure 21). The rest of the country could expect milder wind speed increase ranging from 0.5% in parts of the Northern Cape Province, to 4% in the Cape Town region and central South Africa. Thus wind speeds are not projected to decrease under either of the pathways for the SON-season.

In the DJF-season, the north-easterlies over the Gauteng region (Figure 2) are projected to deviate towards the east in the RCP4.5 (Figure 14) and the RCP8.5 (Figure 15) pathway. Over the western half of the country, the southerlies (Figure 2) are projected to deviate in an east to south-eastern direction in the interior of the country under both pathways (Figures 14 and 15). The southerlies close to the coast in the Western Cape (Figure 2) are projected to deviate to the west in both pathways as well (Figures 14 and 15). The south-easterlies simulated in the far eastern corner of the country are projected to deviate to the east in the RCP4.5 pathway (Figure 14) and are projected to deviate in an easterly to north-easterly direction in the RCP8.5 pathway (Figure 15).

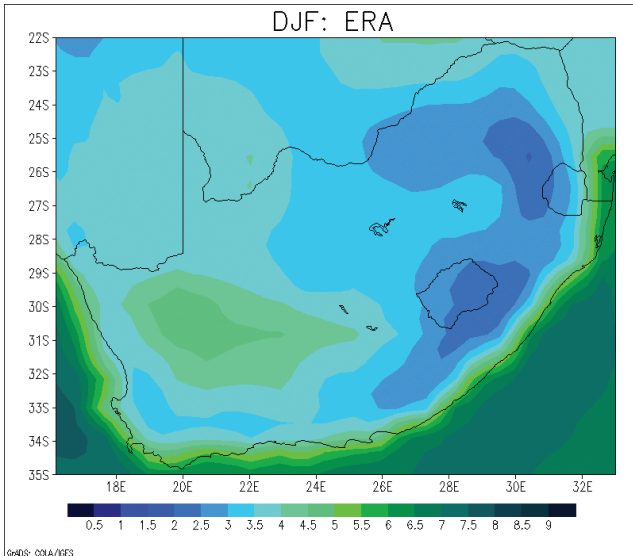


Figure 1: DJF mean seasonal wind speed ($m.s^{-1}$) from ERA-Interim data (1981-2005)

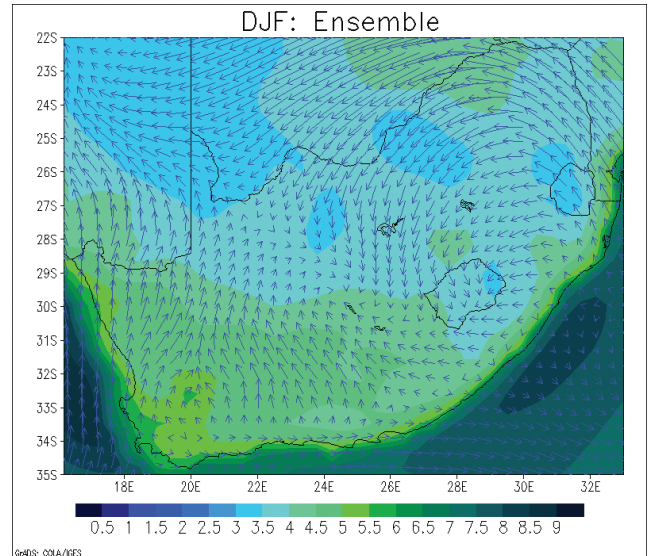


Figure 2: DJF mean seasonal wind speed ($m.s^{-1}$) from RCA4 RCM ensemble data (1981-2005).

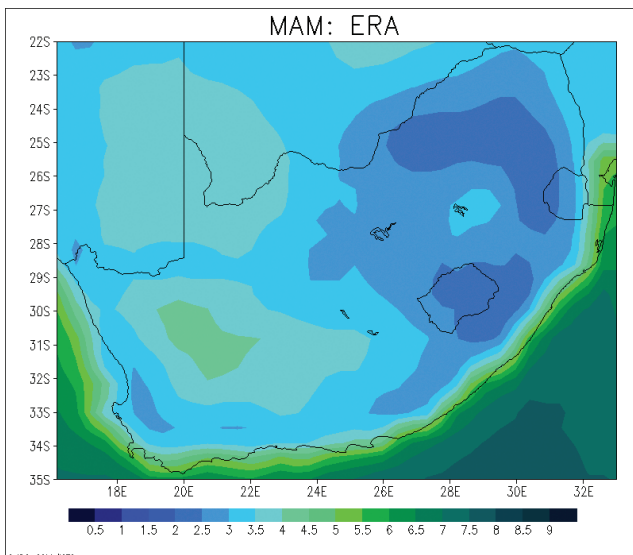


Figure 3: MAM mean seasonal wind speed ($m.s^{-1}$) from ERA-Interim data (1981-2005).

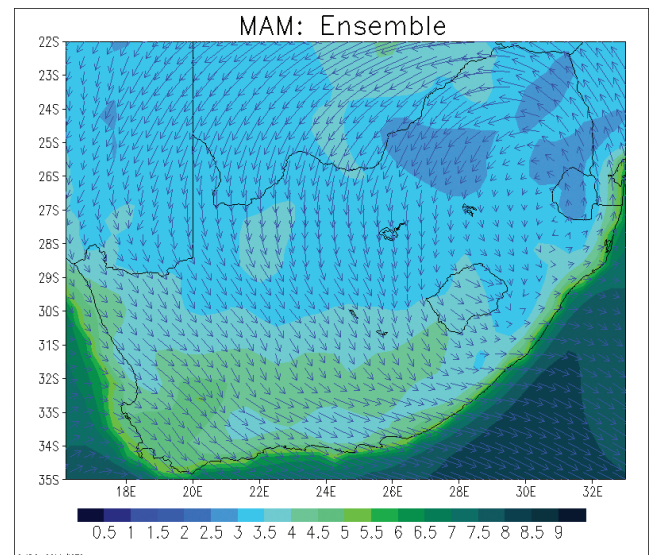


Figure 4: MAM mean seasonal wind speed ($m.s^{-1}$) from RCA4 RCM ensemble data (1981-2005).

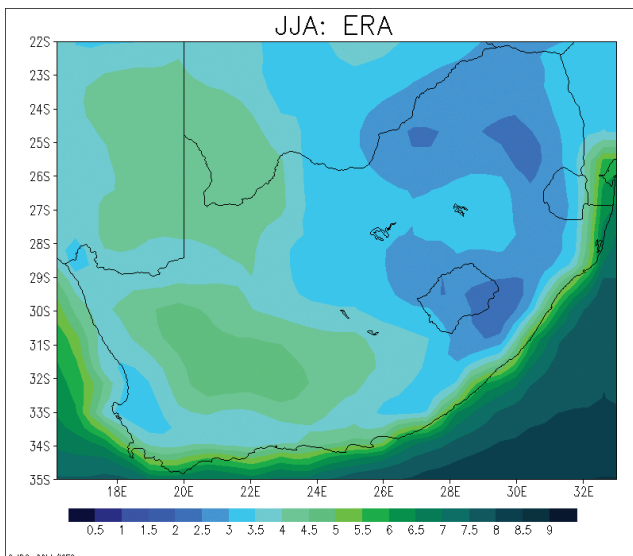


Figure 5: JJA mean seasonal wind speed ($m.s^{-1}$) from ERA-Interim data (1981-2005).

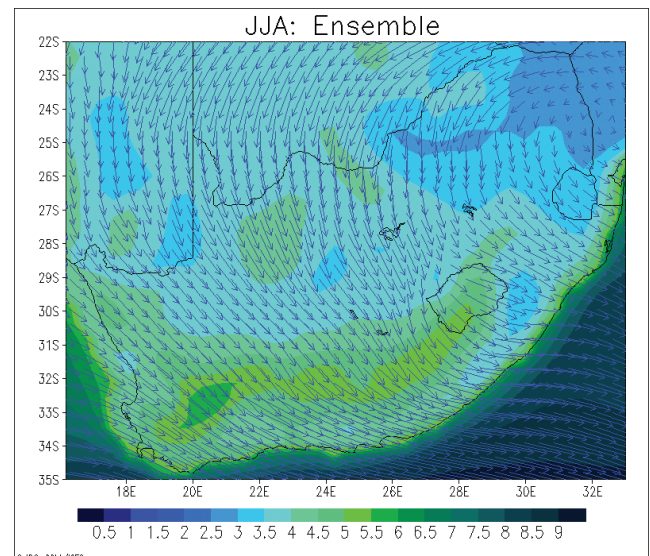


Figure 6: JJA mean seasonal wind speed ($m.s^{-1}$) from RCA4 RCM ensemble data (1981-2005).

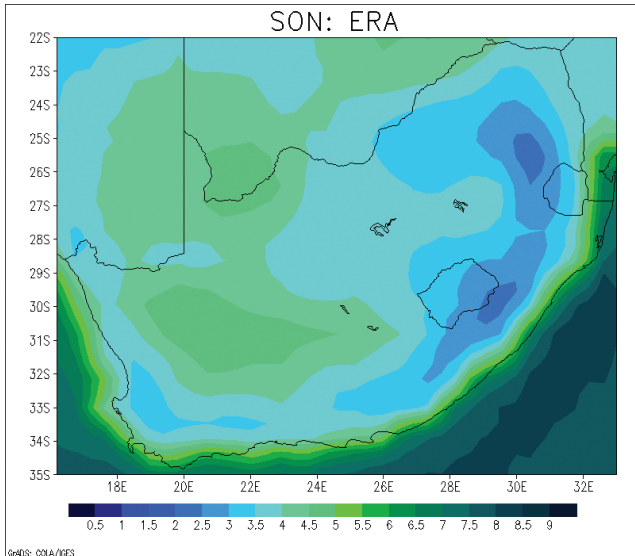


Figure 7: SON mean seasonal wind speed ($m.s^{-1}$) from ERA-Interim data (1981-2005).

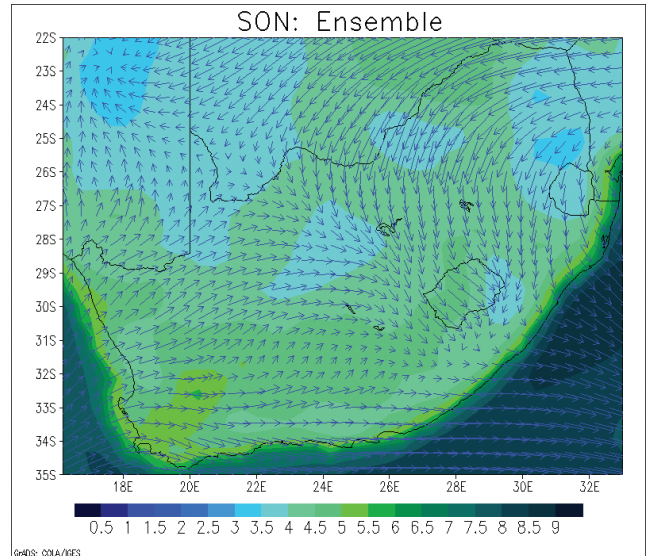


Figure 8: SON mean seasonal wind speed ($m.s^{-1}$) from RCA4 RCM ensemble data (1981-2005).

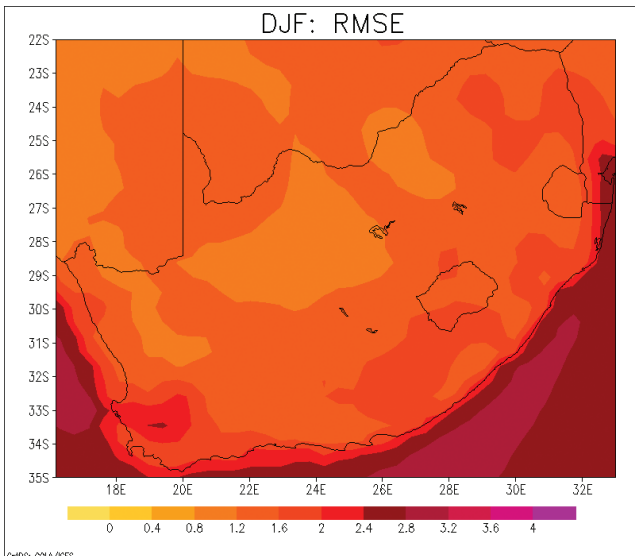


Figure 9: Root Mean Square Error (RMSE) for the DJF wind speeds ($m.s^{-1}$) (1981-2005).

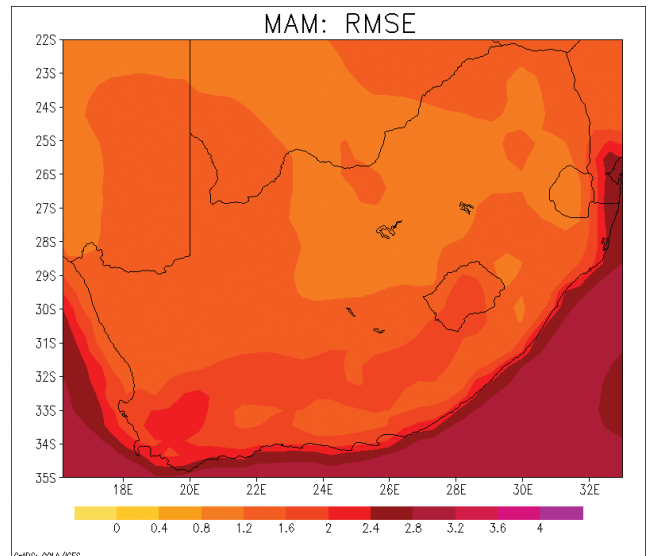


Figure 10: Root Mean Square Error (RMSE) for the MAM wind speeds ($m.s^{-1}$) (1981-2005).

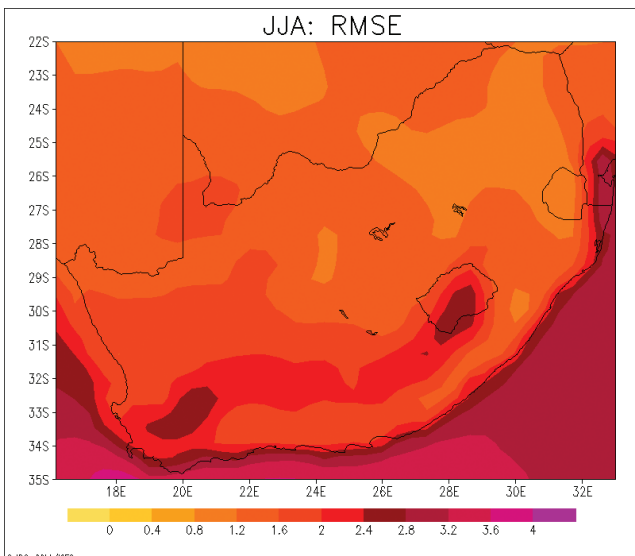


Figure 11: Root Mean Square Error (RMSE) for the JJA wind speeds ($m.s^{-1}$) (1981-2005).

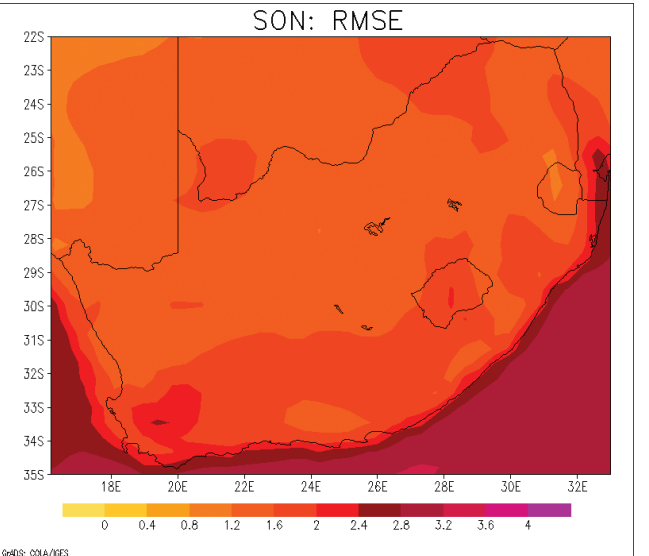


Figure 12: Root Mean Square Error (RMSE) for the SON wind speeds ($m.s^{-1}$) (1981-2005).

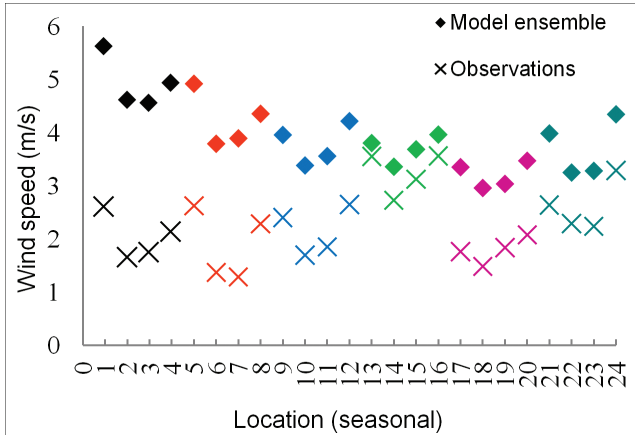


Figure 13: Comparison of wind speeds from SAWS station data with RCA4 RCM ensemble data. Location numbers 1-4 denote Malmesbury DJF, MAM, JJA, SON; location numbers 5-8 denote Vredendal DJF, MAM, JJA, SON etc. - in the same order as in Table 1.

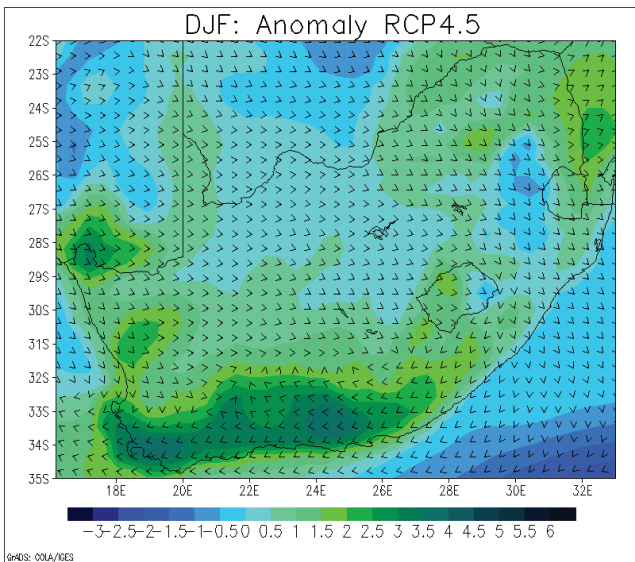


Figure 14: Projected anomaly in mean wind speed (%) and direction for DJF (2051-2075 relative to 1981-2005) under the RCP4.5 pathway.

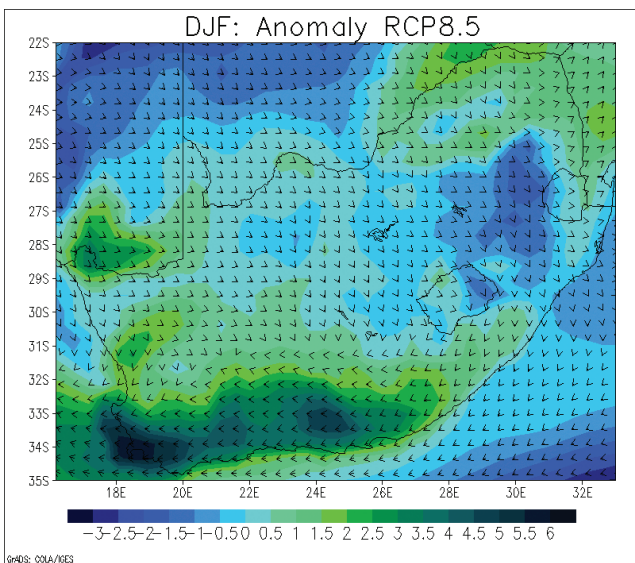


Figure 15: Projected anomaly in mean wind speed (%) and direction for DJF (2051-2075 relative to 1981-2008) under the RCP8.5 pathway.

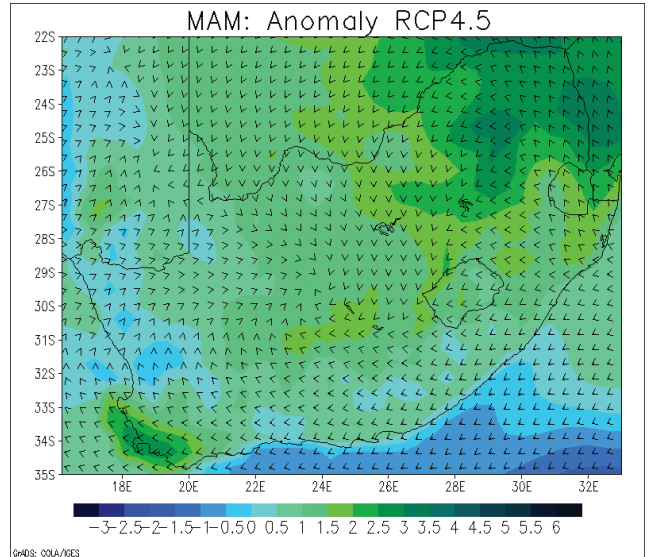


Figure 16: Projected anomaly in mean wind speed (%) and direction for MAM (2051-2075 relative to 1981-2005) under the RCP4.5 pathway.

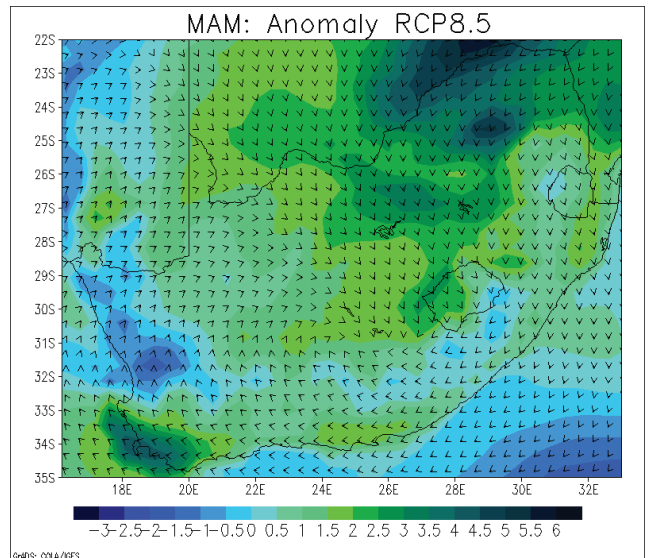


Figure 17: Projected anomaly in mean wind speed (%) and direction for MAM (2051-2075 relative to 1981-2008) under the RCP8.5 pathway.

In the MAM-season, the primarily southern direction in which winds blow over the Eastern Cape and Western Cape Provinces (Figure 4) are projected to deviate in a western direction in the RCP4.5 (Figure 16) and the RCP8.5 (Figure 17) pathways where current wind farm developments are underway. In the RCP4.5 pathway, winds are projected to deviate (Figure 16) minimally from their dominant directions (Figure 4) in central South Africa. However, in the western expanses of the country, the northerlies (Figure 4) are projected to deviate to an eastern direction (Figure 16). Winds in the Limpopo area are projected to remain fairly unchanged in the both the RCP4.5 (Figure 16) and RCP8.5 (Figure 17) pathways. North-westerlies along the Eastern Cape coast (Figure 4) are projected to deviate in the opposite direction i.e. to the southwest in both pathways (Figures 16 and 17).

The north-easterlies in Limpopo (Figure 6) are projected to deviate in a southern direction in both the RCP4.5 (Figure 18) and RCP8.5 (Figure 19) pathways in the JJA-season. The north-

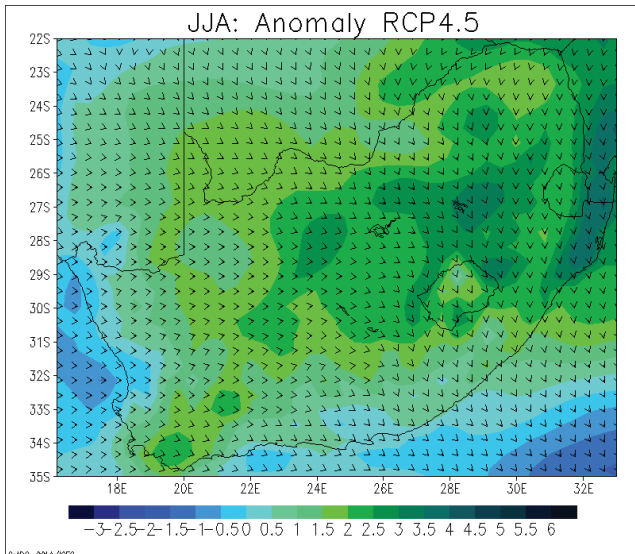


Figure 18: Projected anomaly in mean wind speed and direction (%) for JJA (2051-2075 relative to 1981-2005) under the RCP4.5 pathway.

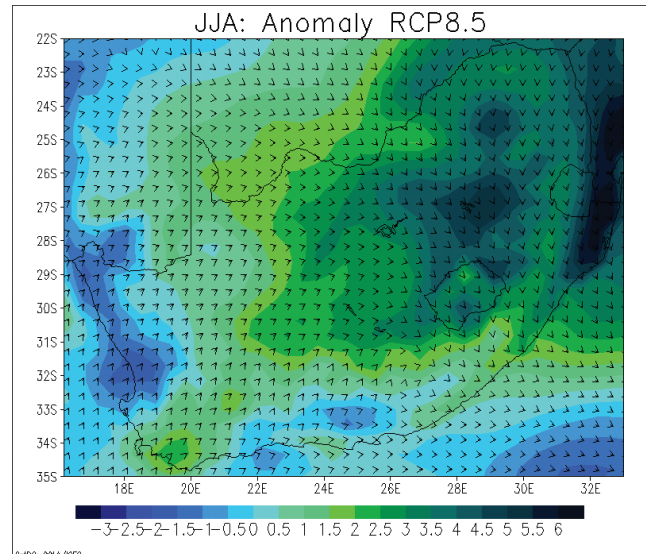


Figure 19: Projected anomaly in mean wind speed and direction (%) for JJA (2051-2075 relative to 1981-2005) under the RCP8.5 pathway.

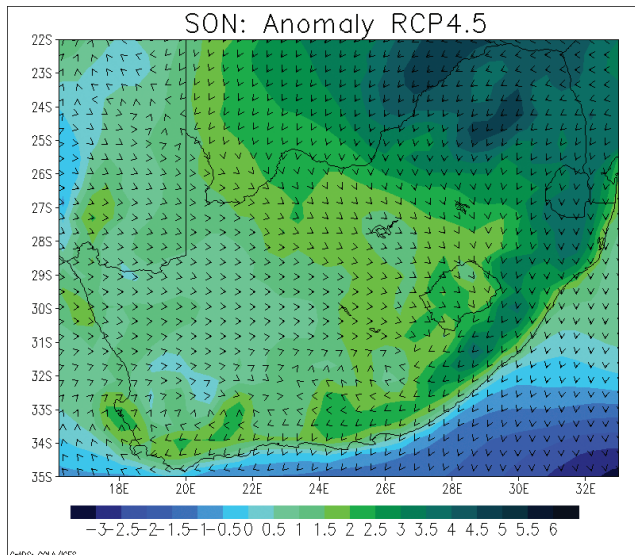


Figure 20: Projected anomaly in mean wind speed (%) and direction for SON (2051-2075 relative to 1981-2005) under the RCP4.5 pathway.

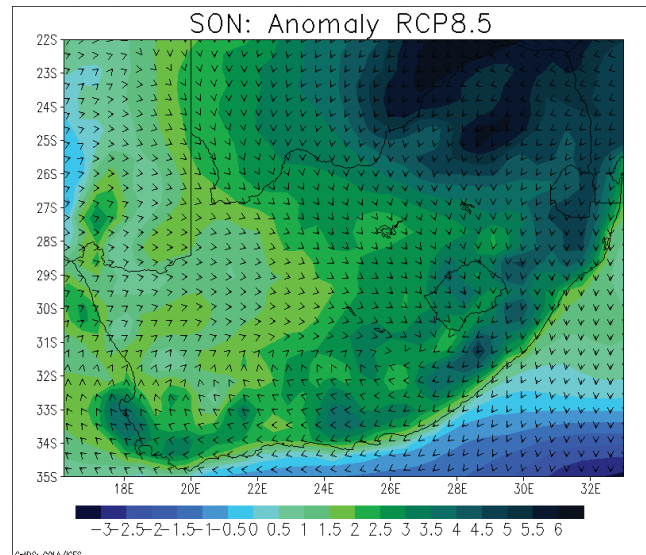


Figure 21: Projected anomaly in mean wind speed (%) and direction for SON (2051-2075 relative to 1981-2008) under the RCP8.5 pathway.

westerlies over the Western Cape and Eastern Cape Provinces (Figure 6) are projected to deviate very little in the RCP4.5 pathway (Figure 18), but are projected to deviate in a northern direction under the RCP8.5 pathway (Figure 19).

While wind directions in the eastern half of the country (Figure 8) are projected to remain relatively unchanged in the SON-season under both the RCP4.5 (Figure 20) and RCP8.5 (Figure 21) pathways, they are projected to deviate to the west along the coasts of the Western Cape and Eastern Cape Provinces under both pathways (Figures 20 and 21). South-westerly winds in the Northern Cape Province (Figure 8) are projected to deviate in an eastern direction in both pathways (Figures 20 and 21).

Conclusions

Numerous studies are beginning to clarify the impacts of climate

change on various physical climatic variables (Fant et al., 2015). Two such variables, wind speed and direction, were assessed in this study to gauge its potential changes in South Africa within the mid-21st century (2051-2075), relative to a historical period (1981-2005). Seasonal daily mean wind speed increases rarely reach 6% and decreases occur to a maximum of 3% and are variable between different seasons and areas within the country. In all seasons except DJF, wind speeds are projected to increase in the Highveld region, suggesting that air pollution dispersing conditions could increase. Dominant wind direction at the 850hPa level is projected to remain unchanged, except over the Western and Eastern Cape provinces in most seasons.

RCPs impact the severity of changes in wind speeds, showing that climate change mitigation measures could curb drastic changes to wind climates in South Africa (Fant et al., 2015). Climate change impact studies such as this one could also

contribute to understanding its potential effects on various other sectors such as wind energy (Herbst & Lalk, 2014). The findings of the study are consistent with those of Jury (2013). In his 20th century analysis, he found no trend in surface zonal winds, but future projections from circulation models suggested intensified easterly flow along the south coast of South Africa.

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