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The Impact of Thunderstorms on Take-off Data in South Africa

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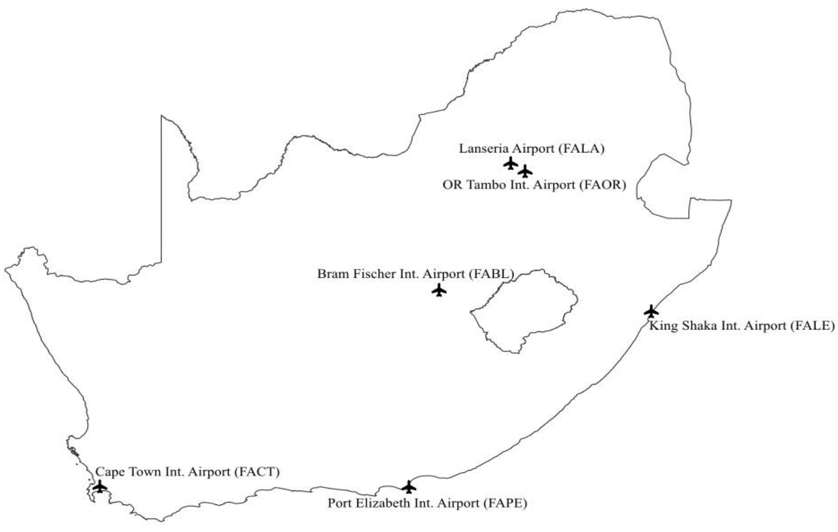
Aviation and meteorology are two disciplines that are tightly entwined. This is because aviation takes place in the atmosphere, which is the realm of meteorology. The prevailing conditions at the aerodrome at the time of departure are paramount to the aircraft's ability to take off. The pressure and temperature determine the payload the aircraft can carry, given the runway length. The wind speed and direction determine the runway in use and the crosswind component the aircraft has to contend with (Airservices Australia, 2022; Civil Aviation Authority of New Zealand, 2020). Aviation as a sector is very dependent on forecast verification as it is the only way to determine the quality of the products (Nurmi et al., 2013).

Therefore, the accuracy of the forecasted take-off data (TOD) is very important for flight planning as it determines the passenger and fuel the aircraft can accommodate given the airport's runway lengths. Moreover, Annex 3 of ICAO (International Civil Aviation Organization, July 2018) states very strict tolerances for TOD, but the format used is given according to local agreement. TOD in South Africa is issued at six aerodromes in South Africa and is shown in Figure 1. The six airports are:

- OR Tambo International Airport (FAOR)
- Cape Town International Airport (FACT)
- Durban King Shaka International Airport (FALE)
- Lanseria Airport (FALA)
- Bram Fischer International Airport (FABL)
- Port Elizabeth International Airport (FAPE)

Figure 1
Map of Aerodromes Take-Off Data



South Africa is located mainly within the mid-latitudes, with only the extreme northern parts extending into the tropics. This in turn divides south Africa into a tropical summer rainfall region in the east and the north and a mid-latitude winter rainfall region over the southwest (Tyson, 2000).

The tropical summer rainfall region is dominated by convective precipitation with cumulonimbus clouds very prevalent. Precipitating cumulonimbus clouds can bring vast changes to the surface weather conditions, changing wind speed and direction, dropping pressure, and reducing temperatures. This can in turn cause TOD to be incorrect and difficult to predict with the timing of these thunderstorms.

FABL's precipitation is mainly from the northwest in the form of airmass thunderstorms in Summer (South African Weather Service, 2012a). FALA and FAOR have a frequency of thunderstorms of about 80 thunderstorms per year which is associated with an eastward moving tropical airmass (South African Weather Service, 2012b, 2012c). FALE rainfall is primarily summer thunderstorms drifting from the interior to the coast (South African Weather Service, 2010).

FAPE falls in the region between the summer and winter rainfall regions and therefore receives rainfall all year long. Thunderstorms are not common in FAPE as the Groot Withoek Mountain Ridge diverts the summertime thunderstorms to the east. On average, only two thunderstorms reach the aerodrome per year (South African Weather Service, 2012d). FACT is in the winter rainfall region and mainly gets frontal precipitation. Thunderstorms are a rare occurrence (South African Weather Service, 2012b).

Thunderstorms are one of the main contributing factors in Aviation incidences and can lead to delays in aerodrome operations (Kulesa, n.d.). Take-off of aircraft is severely affected by thunderstorms which leads to delays. It is therefore important to determine the meteorological conditions expected for take-off.

This study was conducted to assess the impact of thunderstorms on TOD as it is considered to be one of the primary reasons the forecasters in South Africa, are missing the high target of 90% accuracy for TOD as imposed by the South African Weather Service (SAWS) and the South African Civil Aviation Authority (SACAA). The high target was deduced from the Operational Desired Accuracy of Forecast Appendix of Annex 3 (International Civil Aviation Organization, July 2018).

Data and Methodology

Data used for this study is the forecaster-generated TOD for the six aerodromes and the observational data for the six aerodromes. The TOD and Observational data were extracted from SAWS' daily archive of meterorological bulletins. The forecaster-generated TOD are evaluated by the observational data using binary verification techniques. This technique uses a 2x2 matrix as shown in Table 1 (Jolliffe & Stephenson, 2012). Accuracy is calculated using the following formula (equation 1) (Wilks, 2011) using the contingency table (Table 1):

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$$Accuracy = \frac{a+d}{n} \quad (1)$$

Table 1
2x2 Contingency Table (Jolliffe & Stephenson, 2012)

		Event Observed		
		Yes	No	Total
Event Forecasted	Yes	*A*	*b*	*a* + *b*
	No	*C*	*d*	*c* + *d*
	Total	*a* + *c*	*b* + *d*	*n* = *a* + *b* + *c* + *d*

Temperature is evaluated where the temperature tolerance is ±2°C as agreed between SAWS and SACAA. Pressure tolerance is ±1hPa. Wind speed is ±5kt and wind direction is ±40° as per agreement between SAWS and SACAA. Variable winds are considered as correct rejections and assigned to the d value.

Since the evaluations are all either a hit or miss, the value of b will always be zero. This will result in the hit rate (equation 2) being equal to the accuracy because b = 0 (equation 3), with wind direction and speed being the only exceptions (Jolliffe & Stephenson, 2012):

$$Hit\ Rate = \frac{a+b}{n} \quad (2)$$

$$Hit\ Rate = \frac{a+b}{n} = \frac{a+0}{n} = Accuracy \rightarrow d = 0 \quad (3)$$

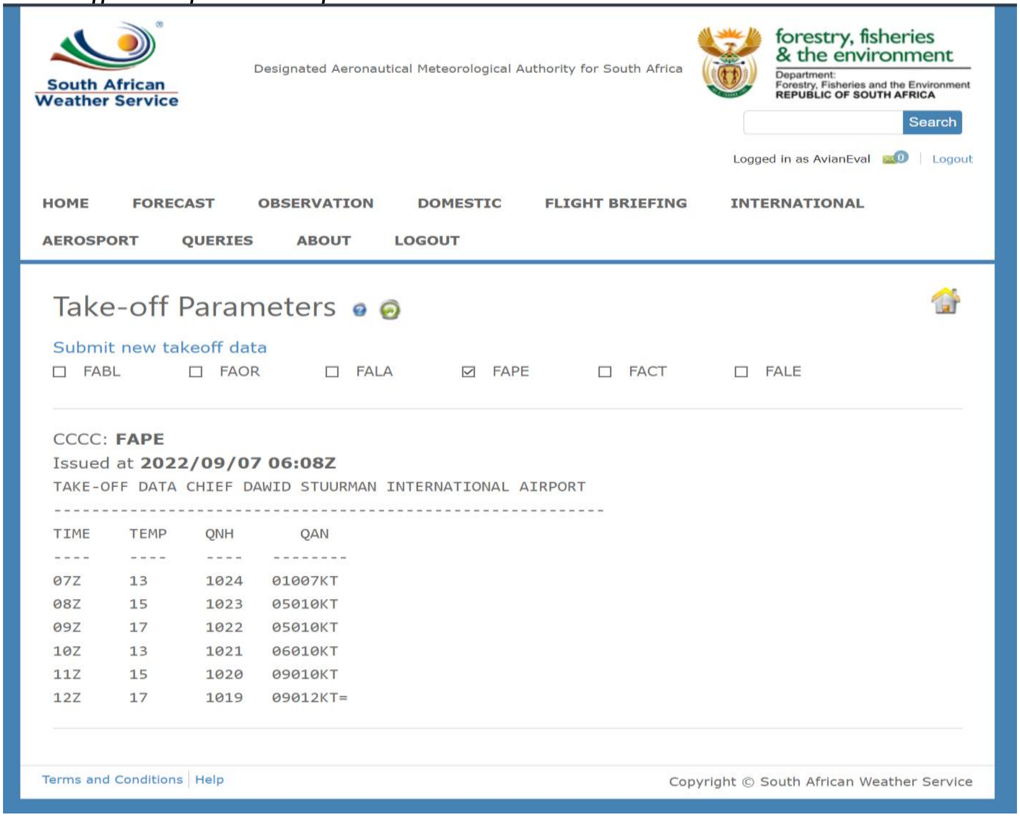
False Alarms will not exist as b is always zero. Thus, the evaluation will always be a hit-or-miss situation. Accuracy is normally not the best verification index to use, but due to the lack of false alarms and mostly a lack of correct rejections other verification indexes are irrelevant as most cannot be calculated due to division by zero (Jolliffe & Stephenson, 2012).

The period of the data considered for this study was January 2019 to March 2022. This is the past three years of data and is a representative data set of recent events.

The data sets were first divided into the six aerodromes' data and then split further between days with thundershowers and days without. Thus ending up with 12 sets of data to be evaluated. The 12 data sets are then evaluated using SAWS' aviation evaluation program. The data analysis was done using the corporate quarters of SAWS, but for this article only the total values will be discussed as the article will become way too long. The full data analysis is available by request.

Figure 2

Take-off Data for FAPE from SAWS Aviation Website



TOD in South Africa are issued as a collection of hourly values for temperature, sea-level pressure (QNH) and wind (direction, speed and gusts). Figure 2 shows a screenshot of the SAWS Aviation Website as an example of issued TOD (South African Weather Service, 2022). The length of TOD changes depending on the need, for example, TOD for FAOR and FACT can be quite long to accommodate long-haul flights from Europe, Asia, the Americas, and Australia. As for the verification of TOD, only the first three hours of the bulletin are evaluated as this is considered the crucial part of the forecast.

Results

Results will be discussed by component for the six stations. The six stations are treated as separate entities as the climate and challenges are different for each of the station even FAOR and FALA which is nearby. Thus, temperature, pressure, wind direction and wind speed will be discussed as separate forecasts as well.

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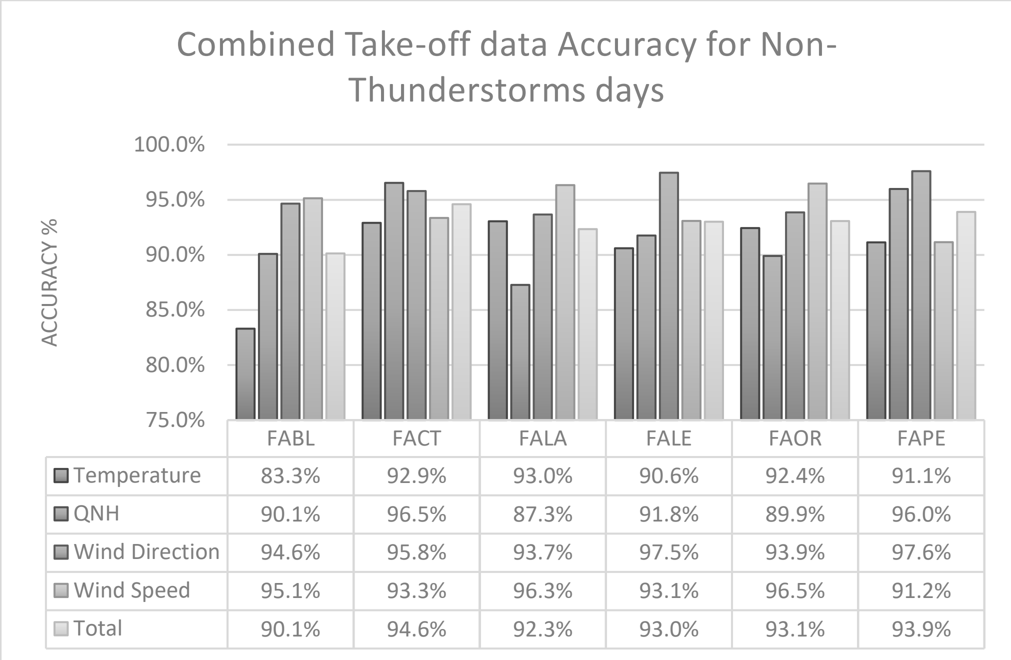
Figure 3

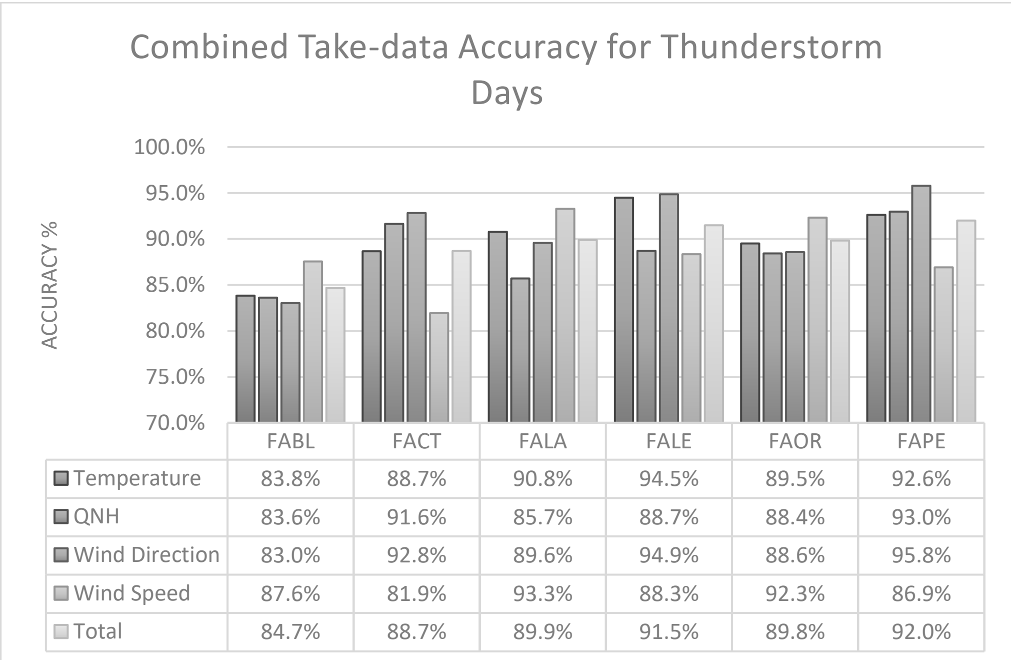
Combined Take-off data Accuracy for Non-Thunderstorm days



	FABL	FACT	FALA	FALE	FAOR	FAPE
Temperature	83.3%	92.9%	93.0%	90.6%	92.4%	91.1%
QNH	90.1%	96.5%	87.3%	91.8%	89.9%	96.0%
Wind Direction	94.6%	95.8%	93.7%	97.5%	93.9%	97.6%
Wind Speed	95.1%	93.3%	96.3%	93.1%	96.5%	91.2%
Total	90.1%	94.6%	92.3%	93.0%	93.1%	93.9%

Figure 4

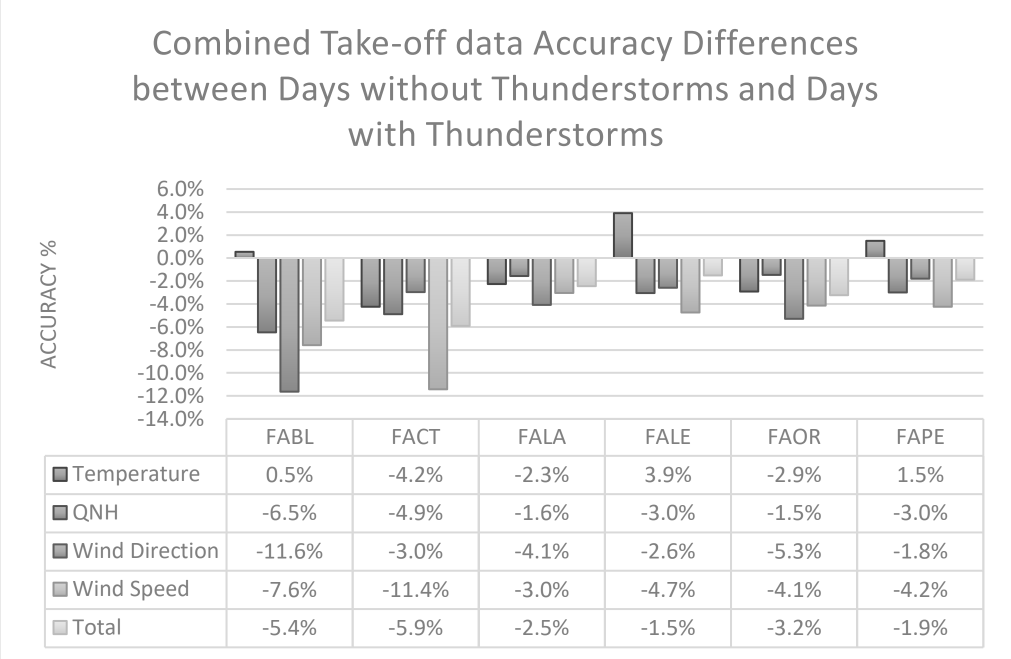
Combined Take-off Data Accuracy for Thunderstorm days



	FABL	FACT	FALA	FALE	FAOR	FAPE
Temperature	83.8%	88.7%	90.8%	94.5%	89.5%	92.6%
QNH	83.6%	91.6%	85.7%	88.7%	88.4%	93.0%
Wind Direction	83.0%	92.8%	89.6%	94.9%	88.6%	95.8%
Wind Speed	87.6%	81.9%	93.3%	88.3%	92.3%	86.9%
Total	84.7%	88.7%	89.9%	91.5%	89.8%	92.0%

Figure 5

Combined Take-Off Data Accuracy Differences Between Days Without Thunderstorms and Days with Thunderstorms



	FABL	FACT	FALA	FALE	FAOR	FAPE
Temperature	0.5%	-4.2%	-2.3%	3.9%	-2.9%	1.5%
QNH	-6.5%	-4.9%	-1.6%	-3.0%	-1.5%	-3.0%
Wind Direction	-11.6%	-3.0%	-4.1%	-2.6%	-5.3%	-1.8%
Wind Speed	-7.6%	-11.4%	-3.0%	-4.7%	-4.1%	-4.2%
Total	-5.4%	-5.9%	-2.5%	-1.5%	-3.2%	-1.9%

Temperature

Temperature is the most difficult of the forecast variables to forecast FAOR and FACT have been doing TOD for a very long time and have worked systems to accommodate the diurnal changes for the stations. FALE is the newest of the aerodromes so it has a limited climate data set to work with. FAPE and FABL only stated doing TOD in the last ten years so no such systems are in place. FALA is also a recent addition to the list of TOD, but the system the forecasters employ in FAOR seems to be working for FALA as well.

It is also noteworthy that the numerical weather prediction (NWP) models handle coastal conditions a lot better than interior conditions. This is evident in the results for temperatures (Figure 3). FACT, FAPE, and FALE, which are coastal aerodromes all have temperature accuracies of greater than 90% for days without thunderstorms, which is the target set by SAWS for TOD. FABL has the lowest value of 83.3%. FALA and FAOR, with the existing system for diurnal change, are also all above 90%.

When considering days with thunderstorms (Figure 4), FAPE, FALA and FALE are all above 90%. FACT and FAOR just miss the target with 88.7% and 89.5% respectively. FABL is 83.8%, which is better than the days without thundershowers.

When subtracting the days without thundershowers from days with thunderstorms temperature shows an interesting trend, which is different from all the other forecasting variables (Figure 5). FABL’s temperatures with thunderstorms are 0.5% better than without. FALE’s temperatures with thunderstorms are 3.9% better than without. FAPE's temperatures with thunderstorms are 1.5% better than days without. FACT, FALA, and FAOR are the opposite. FACT's temperatures with thunderstorms are 4.2% less than without. FALA's temperatures with thunderstorms are 2.3% less than without. FAOR's temperatures with thunderstorms are 2.9% less than without.

QNH

QNH is a variable that is rounded down instead of the nearest number. This can cause values to be out by more than one hPa even though it is less than 2 hPa different. The forecasters' ability to forecast QNH is better than with temperature, but the NWP models are once again failing the interior station, as the conversion to sea-level pressure can yield greater errors.

Looking at days without thunderstorms (Figure 3), most of the stations manage to reach the 90% target. The exceptions are FALA and FAOR with 87.3% and 89.9%. This is indicative of the coastal regions being easier to forecast as conversion to sea-level leads to smaller errors. FABL manage 90.1% which is within the limit of the expected target.

Days with thunderstorms show a completely different picture (Figure 4). FACT and FAPE, which is the two aerodromes not in the summer rainfall belt both manage QNH accuracy values of greater than 90%. It is noteworthy to note that the data sample for these stations is low as thunderstorms are less common and FAPE experienced drought conditions during this period (Bartlett, 2022; Sgqolana, 2022).

The stations within the summer rainfall belt, where thunderstorms are frequent in the summer have fared poorly. The QNH accuracy for FABL is 83.6%. The QHN accuracy for FALA is 85.7%. The QNH accuracy for FALE is 88.7%. The QNH of FAOR is 88.4%.

This is indicative that thunderstorms do impact the accuracy of QNH. Values for QNH are lower for all stations (figure 5). FABL's days with thunderstorms are 6.5% less than days without. FACT's days with thunderstorms are 4.9% less than days without. FALA's days with thunderstorms are 1.6% less than days without. FALE's days with thunderstorms are 3.0% less than days without. FAOR's days with thunderstorms are 1.5% less than days without. FAPE's days with thunderstorms are 3.0% less than days without.

Wind Direction

For wind direction, the following is taken into account before the verification is done. If either or both observed and forecasted wind directions are variable a wind direction comparison can't be made and the verification is ignored. If both observed and forecasted wind speeds are below 10kt, it is considered a correct rejection as winds below 10kt is considered insignificant for aviation (International Civil Aviation Organization, July 2018). After these tests, the observation and forecasted wind direction is done as a hit-or-miss.

Wind direction is the forecasting variable the SAWS forecasters seem to have the least problems with. For days without thunderstorms, all the stations have easily surpassed the target of 90%. The lowest accuracy value is FALA with 93.7% and the highest is 97.6% at FAPE.

Days with thunderstorms were again lower for all stations. Along the coast, the accuracy values were still above 90%. The interior stations, where thunderstorms are most prevalent, have decreased significantly. FABL dropped to 83.0%, FALA dropped to 89.6% and FAOR dropped to 88.6%.

All stations showed a drop in accuracy when thunderstorms are present. FABL shows an 11.6% drop. FACT shows a 3.0% drop. FALA shows a 4.1% drop. FALE shows a 2.6% drop. FAOR shows a drop of 5.3% and FAPE shows a drop of 1.8%. The wind direction in the interior is adversely affected by thunderstorms.

Wind Speed

As with wind direction, wind speed is evaluated as correct rejection when both observed and forecasted winds are below 10kt. The hit-or-miss verification is done on all forecasts where either or both wind speeds are greater or equal to 10kt. Thus, insignificant winds cannot be missed.

Wind speed for days when there are no thundershowers is also generally easy for forecasters to forecast. All stations' accuracies are above the target of 90%. The lowest accuracy is 91.2% for FAPE and the highest accuracy is 96.5% for FAOR.

When thunderstorms do occur, the picture changes significantly. Only FALA and FAOR accuracy are above 90% with 93.3% and 92.3% respectively. FABL’s accuracy drops to 87.6%. FACT’s accuracy drops to 88.7%. FALE’s accuracy drops to 88.3% and FAPE’s accuracy drops to 86.9%. This is indicative to the impact of thunderstorms’ gust fronts.

The drop from days without thunderstorms to days with thunderstorms are all significant. FABL’s accuracy drops by 5.4%. FACT’s accuracy drops by 11.4%. FALA’s accuracy drops by 3.0%. FALE’s accuracy drops by 4.7%. FAOR’s accuracy drops by 3.2% and FAPE’s accuracy drops by 4.9%.

Discussion and Conclusion

When considering the total values, days without thunderstorms all stations are above the target of 90%. For days with thunderstorms, the total accuracy for FALE of 91.5% and FAPE of 92.0% are the only stations above the 90% target. The other stations are all below the target. FABL is the hardest hit by thunderstorms with its total accuracy dropping to 84.7%. FACT, FALA and FAOR narrowing missing the target with accuracy values of 88.7%, 89.9% and 89.8% respectively.

If the difference between thunderstorm days and non-thunderstorm days is considered, FACT and FABL are the most severely affected with drops in the accuracy of 5.9% and 5.4% respectively. FALA’s accuracy drops by 2.5%. FALE’s accuracy drops by 1.5%. FAOR drops by 3.2% and FAPE’s accuracy drops by 1.9%.

FACT rarely gets any thunderstorms thus the high drop in accuracy between days without thunderstorms and days with thunderstorms is not significant. FABL however, is known to have thunderstorms plenty of times

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during the summer season. A drop of 5.4% is significant if one considers that the number of days with thunderstorms is a significant amount of days in the year.

For the three interior stations, the lowest drop in total accuracy was 2.5%, which is not a lot, but if one considers that the accuracy without thundershowers is 92.3%, 2.5% is enough to not make the target. With the high target set small changes can be considered significant as one considers that the target is exceeded by less than 5% for all stations.

It is therefore fair to conclude that thunderstorms have an impact on the forecasting of TOD within South Africa. It is however safe to assume that thunderstorms are not the only meteorological condition that causes the TOD accuracy targets to be missed. Further study needs to be conducted to further fine-tune the forecast to meet the high demands of modern aviation.

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