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FINAL REPORT OF O.R. TAMBO INTERNATIONAL AIRPORT
JOHANNESBURG SOUTH AFRICA

(Submitted by Morne Gijben)

Summary

During the AvRDP project, O.R. Tambo International Airport in Johannesburg, South Africa focused on thunderstorms over the airport. The main focus of the study focussed on demonstrating the usefulness of radar-based nowcast for the airport, where a easy to interpret thunderstorm table was developed. Model-based products were also investigated. Adverse Weather Condition data received from the Airport management Centre was used to create nowcasts of the number of flights delayed, probability of rate reductions, as well as probability of stoppages at the airport. This nowcasts were translated into risk matrices and a table with the impact parameters were developed.

I. Introduction

(1) Airport information

South Africa's O.R. Tambo International in Johannesburg, is one of the participating airports in the AvRDP. The airport is situated at 26° 08′ 21″ S and 28° 14′ 46″ E and is situated approximately 20km east-north-east of the city of Johannesburg and 40km south of Pretoria. The airport lies at an altitude of 1694m above MSL and consists of two runways. The airport can handle 30 arrivals or 30 departures per hour, with a combined arrival/departure maximum of 53 flights.

(2) Impacting weather

O.R. Tambo International Airport is mostly affected by thunderstorms in the summer, with a rainfall maximum in December and January (600-800mm per year). Hail occurs roughly 5 days per year in the spring/early summer time (October to December). Lightning also frequently occurs over the airport, with an average of 70 days per year. During the AvRDP project thunderstorms were investigated. The airport is however also affected by fog as well as low cloud and visibility early in the morning but was not focussed on during the project.

(3) ATM/Airline/Pilot/Aviation Community Needs

Operations at O.R. Tambo International Airport is frequently affected by thunderstorms. These thunderstorms results in flight delays, rate reductions, stoppages, delays and sometimes cancellations of flights. All of this has negative impacts on operations at the airport which results in serious operational challenges, financial losses and safety concerns. The aviation community at O.R Tambo is therefore in need of early warning systems at the airport to assist with the planning of their operations, and any amount of lead time is highly appreciated in order to minimize down time at the airport. Weather information is often difficult to interpret due to minimal weather related experience, as well as cluttered maps and forecasts. As such there is a need for easy to interpret products that can assist operations with the impact the weather will have at the airport.

(4) Study approach / techniques

During the kick-off of the AvRDP, communications with ATM proved to be difficult. Luckily O.R. Tambo International Airport has an Airport Management Centre which acts as the middleman between ATM and airlines. This centre was very positive about the AvRDP and assisted SAWS with information, data on adverse weather conditions and guidance on the products.

During Phase 1 of the project, radar was considered to be the most important tool for nowcasting at the airport since it provides the most accurate and complete information needed on thunderstorms. An immediate short coming in radar was realised, where the aviation industry often does not understand the meaning of dBZ values as well as the cluttered storm forecasts up to 2 hours ahead in time. As such an easy to interpret colour-coded risk table, based on the direction of movements of storms were developed that provides the risk for up to two hours ahead, based on colour (green, yellow, orange and red). This product was operationally supplied to the AMC and received very positive feedback since the beginning of 2018. For the table, TITAN tracking for the 0-2 hour period was used. Community-SWIRLS from the Hong Kong Observatory was also implemented at SAWS which extrapolates radar data up to 9 hours ahead in time. Since Com-SWIRLS do not take growth and decay into account, it was used to take over from TITAN for the 2-9 hours nowcast.

For phase 2, adverse weather condition data obtained from the Airport Management Centre at O.R. Tambo international Airport was used for the impact-based forecasts. A linear regression anlysis was performed on the delays dataset, where an equation for the daily prediction, and equations for the hourly predictions was developed whereby the number of flight delays are predicted using radar reflectivities. For the rate reduction and stoppages predictions only yes or no information was available, and as a result a rare-event binary logistical regression technique with replications was used to run 1000 regression models and where the output was combined using a kind of bootstrap technique. The result was a value between 0 and 1 which is translated to probabilities. For each of the predictions in phase 2 of the project different risk matrices were setup that considered the likelihood of a storm reaching the airport vs the impact it will have on operations.

The thunderstorm table developed during phase 1 was then adapted to look at the impact-based forecasts, and provides colour-coded easy to interpret information on the delays, stoppages, and rate reductions at the airport for the next 0-2 hours.

(5) Timeline

O.R. Tambo International Airport participated in the AvRDP project since 2015 where phase 1 was entered. Unfortunately the focal point for O.R. Tambo International Airport, Dr. Estelle de Coning left SAWS in 2016. Mr. Erik Becker took over from Dr. de Coning in 2016, but also left SAWS in 2018. Since October 2018, Mr. Morne Gijben took over as the focal point. SAWS only entered phase 2 of the project in November 2018.

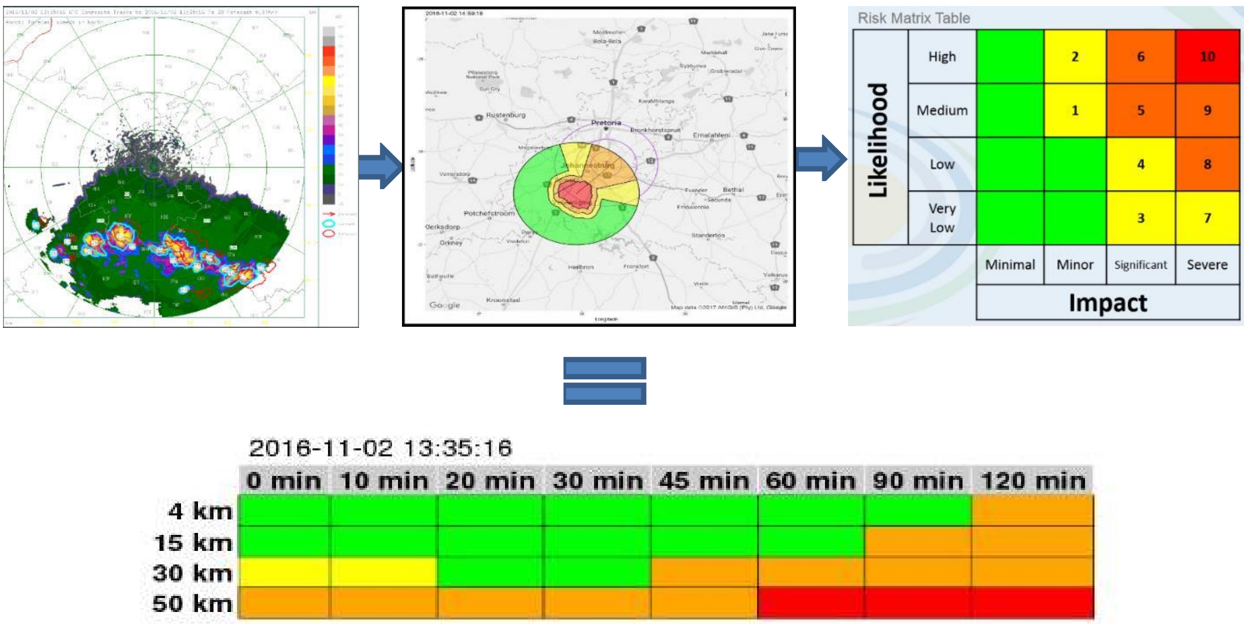
II. Outcomes

(1) Phase I achievements (MET Capability)

During Phase 1 of AvRDP all of the meteorological tools available at the airport was investigated. This includes radar-based, lightning-based and numerical weather prediction model data.

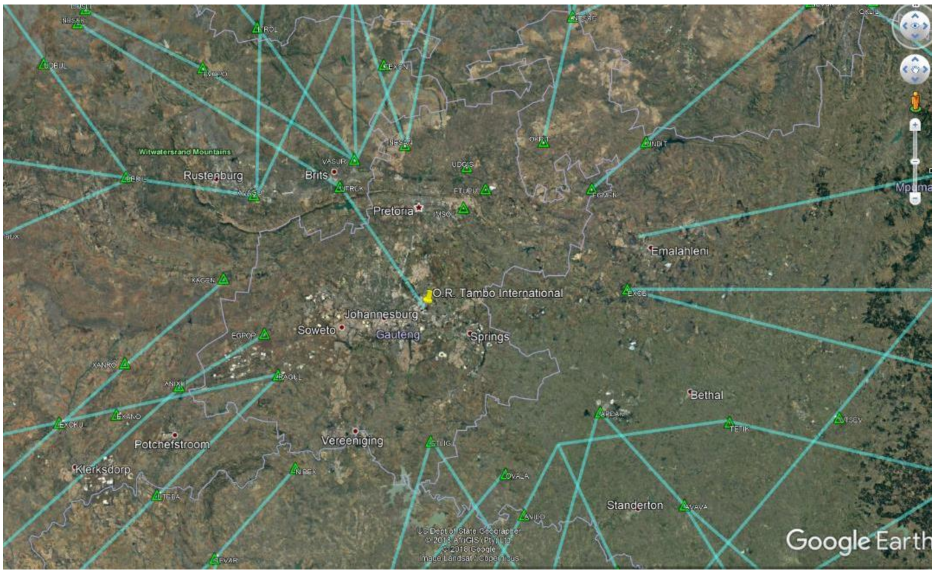
Thunderstorm table

The most important tool available at O.R. Tambo is the Irene Doppler S-band weather radar which is the most important tool for nowcasting purposes. Since radar images (current and forecast tracks) are often difficult to interpret and cluttered, a new color-coded thunderstorm table was developed for O.R. Tambo International Airport. The direction and speed of thunderstorms determines if and when thunderstorms will impact the airport. It is therefore important to track the movement of thunderstorms in relation to the airport. Based on the likelihood of a thunderstorm reaching the airport and the expected impact it will have on operations, a risk matrix was compiled with different colour-coded levels of risk. This was done for 0-2 hours using TITAN tracking algorithms and for different distances from the airport (4, 15, 30 and 50 km).



Extending thunderstorm table to waypoints on approach/departure

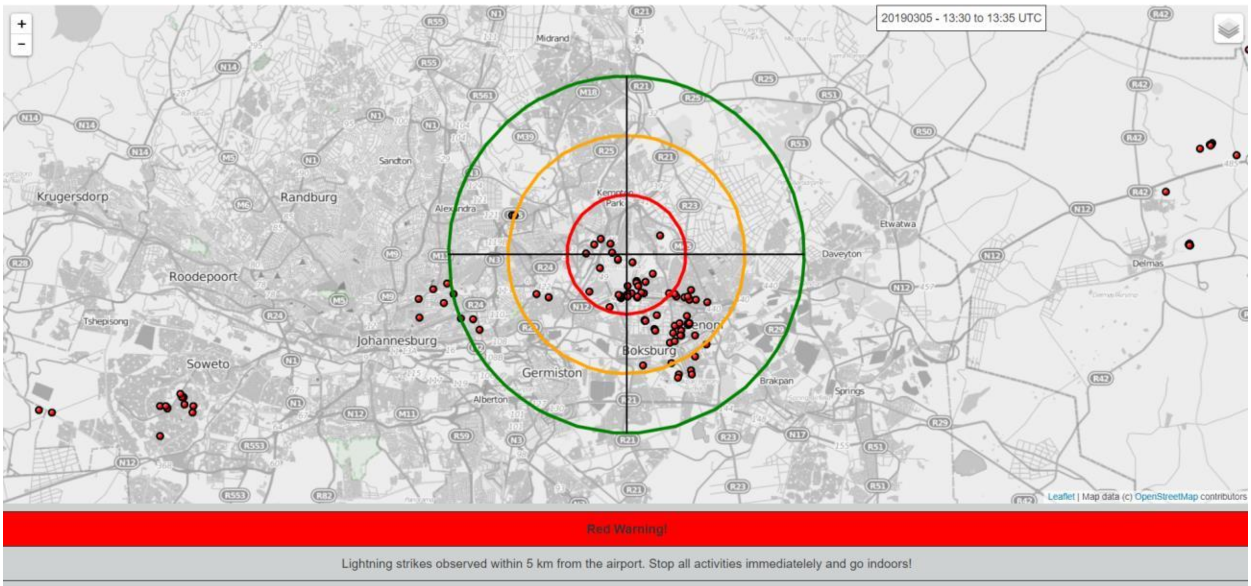
A study was performed where a small thunderstorm table for the next 30 minutes were developed for the waypoints on the approach and departure paths into O.R. Tambo International Airport. The aim of this product will be to route pilots to use the most appropriate flight path when adverse weather conditions are present. This product is nearing completion (display still needs to be finalised) and will be tested in the coming summer season. The information will either be plotted on an image at the waypoints or in table as given in the example below



	0 min	5 min	10 min	15 min	30 min
RAGUL					
XAGEN					
NESAN					
EXOBI					
ETLIG					

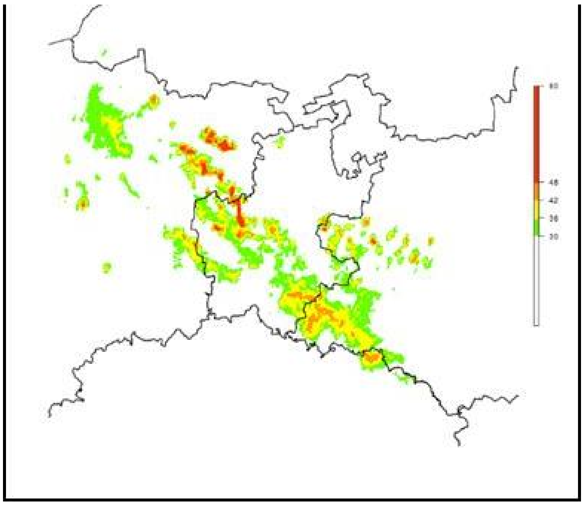
Lightning Monitoring and Warning System

Lightning poses a risk to O.R. Tambo International Airport which receives lightning on 70 days of the year, and also results in stoppages at the airports on these days due to ground workers evacuating the tarmac due to the safety risks. As a result a lightning warning system was developed for the airport. Three different range rings are drawn on an interactive google map with the airport at the centre. The distances that have been chosen for this product are 3, 5 and 15 km. Lightning strikes as plotted by red crosses on the interactive maps. If no lightning is observed within 15 km of the airport all the range rings around the airport remain thin black lines. If lightning occurs 5-15km from the airport the 15km range ring turns from a thin black line to a thick green circle. Lightning that occurs between 3 and 5 km from the airport turns the 5 km range ring into a thick orange colour and finally if lightning is observed within 3 km from the airport the 3 km range rings turns to a thick red colour. The different levels of risk, green, orange and red will also result in different actions to take by airport managers. If the risk is green, staff should be alerted of lightning activity in the vicinity and to take caution. If the risk is orange, ground staff should cease activities, evacuate and start going indoors. With a red warning all should be indoors until the risk is over.



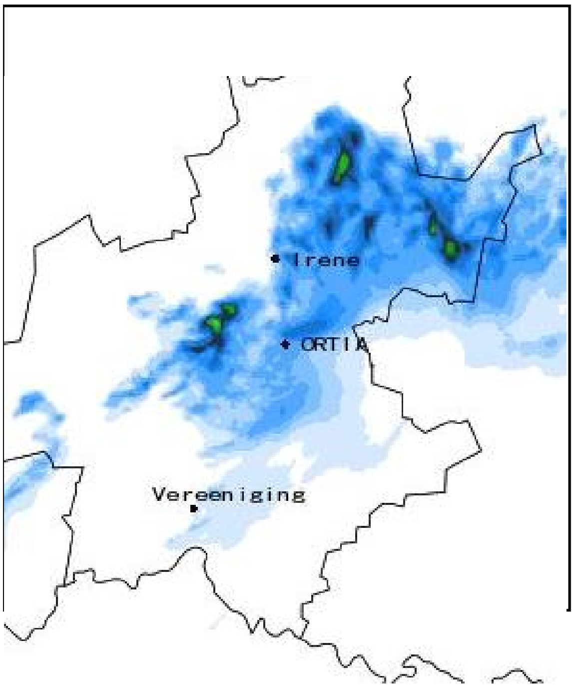
Community-SWIRLS

Community-SWIRLS from the Hong Kong Observatory was installed over O.R. Tambo International Airport. This software package takes the radar information and extrapolates the data 9 hours ahead in time based on the direction of movement from past storms. A downside to the software is that growth and decay from thunderstorms are not taken into account. As such for O.R. Tambo International Airport it was opted to use TITAN for 0-2 hour nowcasts and Com-SWIRLS for 2-9 hour nowcasts.



Sub-kilometre NWP model

A convective-scale 300 meter resolution model using the U.K. Met Office Unified Model was installed. This model is nested in the operational Unified Model over the O.R. Tambo domain. Only a few cases were investigated, but due to computational restrictions the model was not made operational since the operational NWP models makes use of most of the HPC resources.



Operational 1.5 km resolution Unified Model

SAWS is running a 1.5 km resolution version of the Unified Model over the entire South Africa domain, and data from this model was used to provide predictions of rainfall over O.R. Tambo International airport.

Lightning Threat Forecast

A lightning threat forecast for O.R. Tambo was investigated. This forecast product uses model data from the Unified Model to predict the probability of lightning occurrence. The model was developed using lightning observations as well as model parameters over a two year period. This model was implemented over O.R. Tambo International in order to provide probability forecasts of lightning occurrence up to 48 hours ahead.

(2) Phase II achievements (MET-ATM Integration)

During the project, the Airport Management Centre at O.R. Tambo assisted with capturing all the adverse weather events as well as the associated impact on operations in an online Smartsheet spreadsheet which could easily be accessed and which was updated as soon as an event occurred over the airport. Adverse weather conditions and their impact was available from 1 September 2017 up to 25 April 2019. From this dataset 87 events were captured. Although this is not a very large sample, it was still useful to develop impact-based products.

For the development of the impact-based products, radar-based nowcasts were considered to try and predict delays, rate reductions, cancellations and stoppages. The predictions of these impacts worked better for some and less so for others mostly due to lack of data.

Delays

In order to develop a product to do short-term predictions of delays from radar data, a linear regression analysis was performed to try and predict the number of delays based on the radar reflectivity values. In this regression analysis, the number of delays observed was used as the dependent variable while the radar reflectivity's was used as the independent variable. Based on all of the data the following regression equation was developed:

$$\text{Number of delays} = -5.992865 + (0.266400 \times \text{dBZ})$$

It was also realised that the number of delays are dependent on the time of day, since certain times of the days are much busier than others, and as such an equation for every hour of the day was also developed to see if a regression analysis per hour will perform better. For example, for 16:00 to 17:00 UTC the following equations was developed

$$\text{Number of delays} = -0.805463 + (0.147277 \times \text{dBZ})$$

Based on the number of delays (impact data) together with likelihood of a storm reaching the airport a risk matrix could be compiled.

Likelihood					
	High		4	12	20+
	Medium		2	10	18
	Low		1	8	16
	Very low			6	14
		Minimal	Minor	Significant	Severe
		Impact			

Rate Reductions

Unfortunately in the impact data received, for most cases (apart from 7 cases) the rate reduction figures were not provided. Only yes and no confirmations for rate reductions were available. Since 7 cases are way too low to perform a linear regression, it was decided to perform a binary logistical regression analysis, to predict the probability of a rate reductions based on the radar reflectivity values. A binary logistical regression predicts values between 0 and 1 which provides the probability of occurrence. Based on the data from all the cases the following regression equation was developed:

$$= \frac{-9.113631+0.210179}{1 + \quad -9.113631+0.210179}$$

As with the delays, the rate reduction regression analysis was also performed for every hour, where a different equation for every hour of the day is available.

Based on the likelihood of a storm reaching the airport as well as the likelihood of reduced rates, a risk matrix could be compiled.

Likelihood of storm reaching airport					
	High		20	60	100
	Medium		10	50	90
	Low			40	80
	Very low			30	70
		Minimal	Minor	Significant	Severe
		Likelihood of reduced rates			

Cancellations

Cancellations does not occur frequently. In the impact data set only one flight was cancelled due to a technical issue possibly due to a lightning strike on route from Durban to Johannesburg. As such no analysis was performed since cancellations are rare.

Stoppages

A binary logistical regression analysis was also used to predict the probability of stoppages based on the radar reflectivity values. A binary logistical regression predicts values between 0 and 1 which provides the probability of occurrence. Based on the data from all the cases the following regression equation was developed:

$$= \frac{-11.842685+0.263810}{1 + \quad -11.842685+0.263810}$$

Based on the likelihood of a storm reaching the airport and the likelihood of stoppages a risk matrix could be compiled.

Likelihood of storm reaching airport					
	High		20	60	100
	Medium		10	50	90
	Low			40	80
	Very low			30	70
		Minimal	Minor	Significant	Severe
		Likelihood of stoppages			

Based on the information from all of the impacts the following table shows an example of the combination of the products. The table is an expansion of the Thunderstorm Table developed in Phase 1 of the project. It now however incorporates the impact data for time periods from 0-2 hours and contains the colour coding based on the above risk matrices as well as demonstrates the probabilities of rate reductions and stoppages as well as the number of expected delays.

	0 min	10 min	20 min	30 min	45 min	60 min	90 min	120 min
Stoppages	94%	97%	68%	8%	0%	0%	0%	0%
Reduced Rates	96%	98%	64%	3%	1%	0%	0%	0%
Delays	9	10	7	2	1	0	0	0

(3) Verification

During the project no quantitative evaluation was completed. The thunderstorm table was however used in an operational environment during the 2017/18 and 2018/19 summer seasons by the Airport Management Centre at O.R. Tambo International airport. The usefulness of the radar-based thunderstorm table was demonstrated by the positive feedback received. The impact-based products for the airport will be tested during the 2019/20 summer season in collaboration with ATM. Since a limited number of impact data was available and as a result since all of the impact data received was used in the development of the products (data from 2016/17, 2017/18 and 2018/19 summer seasons), the phase 2 products will be evaluated in the next summer season with new cases.

III. Summary

(1) Benefits to local ATM

The outcomes of the AvRDP will assist ATM with easy to interpret weather products for their operations at the airport without the need to analyse difficult images. The outcomes of phase 2 of the project will also assist ATM to provide impact-based forecasts of delays, rate reductions, stoppages and diversions.

(2) Contributions to ASBU

With the air traffic growing at a rapid pace, airports are struggling to handle the increasing number of flights. If adverse weather conditions occur at the airport, the already overcrowded airports struggle to accommodate the air traffic due to the long stoppages, rate reductions, delays and diversions. With the development of the new products during AvRDP, these delays and stoppages can be minimized by providing ATM with the tools needed to plan efficiently during adverse weather events. ATM systems needs to be standardized during the ASBU, and the developments in this project is a step in the right direction in order to follow international trends. The impact-based products for the ATM systems will not only optimize air traffic flows, but also enhance safety, reduce environmental impacts and minimize costs.

(3) Gap identified

The output from this project is only touching the possibilities available to assist the aviation industry. SAWS is currently in the process of converting its general forecasts of what the weather will be to what the weather will do, and as such in the near future all of the forecasts from SAWS will be impact-based. The AvRDP project exposed SAWS to impact-based products for aviation, and has inspired SAWS to continue with its development in the field.

IV. Recommendation

(1) Future Studies

During the AvRDP focus were only given to thunderstorms. O.R. Tambo International Airport also frequently experiences fog/low cloud/low visibility, and new products will also be investigated that address these weather conditions at the airport. Wind shear and turbulence studies also needs to be performed at the airport in the future.

Extending products to outside the aerodrome is also needed to cover the entire trajectory-based operations of pre-flight, departure, en-route cruise, descend, arrival. Products are planned along all of the flight routes in South Africa (even Africa and the Globe).

(2) Plans

Due to the limited impact data collected during the project, all of the data was used in the regression analysis to develop the impact-based products. As such these products will be tested together with ATM in the coming summer season (September 2019 to April 2020). If needed the verification results will determine if some adaptations needs to be made to the products.

A useable and interactive display system for all the products needs to be developed, which will not only provide all the information needed, but must also be easily interpreted by airport officials in their daily operations.

Training needs to be provided to all stakeholders who will use the systems, so that informative decisions are made based on the data.

The Airport Management Centre at O.R. Tambo international Airport provided valuable impact data at the airport for the 2017/18 and 2018/19 summer season. A request will be made if they can get hold of historic adverse weather impact data. This will however require additional work by the custodians of the data, to put all the information together. In the current dataset received, the actual rate reduction and stoppages details were only provided as yes and no for most cases, and it will be requested if the actual numbers can also be obtained for the studies.

The usefulness of the products developed at the airport has been demonstrated, and based on the outcomes there are still a number of solutions that can be developed to assist ATM in their daily operations. SAWS will continue to expand and improve the products at O.R. Tambo International airport as well as extend these products to all of the airports in South Africa.