1. Introduction

The global air transportation will undergo significant upgrade in the next 15 years and beyond under the ICAO new Global Aviation Navigation Plan (ICAO DOC 9750, 2016). To achieve this, aviation weather services will need to be enhanced following the Aviation System Block Upgrade (ASBU) methodology. One of the key concepts in ASBU is the Trajectory Based Operation (TBO) which would integrate seamlessly high-resolution, rapidly-updated observation, nowcast and forecast along the entire flight trajectory, from take-off, ascending, en-route, descending and to landing phases, into the air traffic management (ATM) system (Fig.1). With increasingly congested airspace, especially within the terminal control area of high capacity airports, the MET information provision, supported by nowcasting and mesoscale modelling, would need to be upgraded to support the tactical and pre-tactical stage of the aircraft trajectory. In this connection, WMO Commission of Atmospheric Science (CAS) and Commission of Aeronautical Meteorology (CAeM), with the endorsement of the 17th WMO Congress, jointly take forward an Aviation Research Demonstration Project (AvRDP) in 2015-2018 with a view to demonstrating the capability of nowcasting and mesoscale modelling techniques and providing a ‘fast-track’ transfer of the research results into operational applications. Under the ASBU roadmap, aviation MET services will be required to provide enhanced services to be phased in during the next 15+ years, namely Block 1 by 2019-2024 (B1-AMET), Block 2 by 2025-2030 (B2-AMET) and Block 3 by 2031 onward (B3-AMET). AvRDP is aimed at providing an assessment of the above-mentioned MET capability and demonstrate its benefits to the aviation community, in particular the terminal area, in support of the ASBU initiative. The outcomes of TBO would not just enhance flight efficiency, but also safety and environment-friendly by reducing fuel waste.
2. Objectives of AvRDP

The objectives of AvRDP are:

(i) to conduct research in nowcasting and mesoscale modelling at a number of international airports located in Northern and Southern Hemisphere with a view to supporting the development of ASBU, especially the Meteorological Services to ATM (MSTA) near airport terminal area;

(ii) to collaborate with the respective Air Traffic Management (ATM) to translate the Meteorological (MET) (nowcast and mesoscale modelling) information into ATM Impact products to demonstrate the benefits of the MET information to the aviation community;

(iii) to help in capacity building via the knowledge transfer to other WMO Members who need to enhance their aviation MET services so as to meet the ASBU initiative.

Initially, the following six airports from different climatological regimes in Northern and Southern Hemisphere impacted by different weather participate in AvRDP: CDG (Paris), HKG (Hong Kong, China), JNB (Johannesburg), SHA (Shanghai), YYY (Toronto) and YFB (Iqaluit). Figure 2 outlines the respective climatological regimes and their respective high impact weather of concern.

The Project is implemented in two phases:

(i) Phase I – MET capability research, focusing on enhanced MET research and development; and

(ii) Phase II – MET-ATM impact translation and validation, focusing on translating MET information into ATM impact parameters. Depending on their readiness, some airports may enter Phase II earlier.

3. Research Components

The researches in Phase I and II are conducted using data collected during the IOPs, post-analysis, simulator and etc. The AvRDP contains the following Components:

(A) Nowcasting\(^1\) Component - This component focuses on the various nowcasting techniques, existing or novel, including but not limited to the following types:

(i) Radar-based nowcasting system or satellite-based nowcasting system, including human-machine interfaced and expert system-based system;

(ii) Convection-resolving mesoscale or microscale NWP model;

(iii) Blending of observations with high resolution NWP model;

(iv) Blending of radar/satellite-based nowcasting products with NWP system; and

(v) Ensemble/probabilistic nowcasting product.

(B) Verification Component - This component is essential to assess the performance skill of the nowcasting techniques adopted at the AvRDP Airports. The evaluation also focuses on

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\(^1\) Nowcasting here means observation-based, high resolution NWP-based or blended 0-6 hours very-short term forecast.
what would be the most suitable verification method for deterministic and probabilistic aviation nowcasting products. Apart from the conventional verification matrix for MET products, metrics will also be evaluated for measuring ATM impact parameters.

(C) Impact and validation Component - This component studies the ways to translate the nowcast products into ATM-impact parameters. Examples include translation of the convection coverage/intensity to airport/runway/airspace capacity or aircraft delay. Representatives from local ATM or airline could be involved to provide expert advice on this component to evaluate directly the benefits of the integrated MET-ATM information to the end users (ICAO/WMO 2014b).

(D) Capacity Building Component - The AvRDP also will include a couple of training workshops that include lectures, demonstration and hands-on training activities geared toward capacity building and ultimately technology transfer. The aim is to equip WMO Members with skills to enhance their aviation weather services so as to meet the ASBU requirements.

4. Preliminary Outcomes

The Project was kicked-started in mid 2016, with different airports carrying out different researches through different Intense Observation Period (IOPs). During the IOPs in Phase I, each airport collected aviation related meteorological data, including observations, nowcasting and mesoscale modelling data (Fig. 3) focusing on the impacting weather as described in Fig.2. For example, JNB implemented nowcasting systems based on radar and satellite data to predict in short-term the movement of convection. CDG tested the capability of a high resolution model for the prediction of fog and low visibility. SHA developed a high resolution model for the prediction of convection. YYZ evaluated the performance of observation adjusted models for nowcasting ATM required elements at the airport. HKG collected blended radar-based nowcast data with rapidly-updated mesoscale model for the prediction of convection within the terminal area, etc. Part of the data have been uploaded onto the AvRDP data server for information exchange and sharing.

Taking HKG as an example, the project aimed at demonstrating the benefit of blending radar-based nowcasting system with high resolution, rapidly updated NWP using innovative blending technique (Fig.4, Li et al. 2005 and Wong et al. 2009). The idea is as follows: SWIRLS, a radar-based nowcasting system, provides skilful thunderstorm nowcast in the next one to two hours, especially in the situations where the advection of convection is dominant. However, when the thunderstorm motion is erratic or when radar echoes develop or dissipate rapidly, advection methods are less reliable. More sophisticated forecasting techniques such as high resolution NWP models would be necessary, especially in the forecast range beyond 3 hours. However, NWP models usually suffer from the intrinsic “spin-up” problem, hence hindering reliability of numerical prognoses in the first couple of hours. So to achieve an optimal performance in the 1 to 6 hour forecast range, SWIRLS and NWP is blended via a number of spatial, temporal adjustment to generate an optimal solution for the terminal area of the airport.

![Fig.3 sample IOP collected data inventory](image)

![Fig.4 Schematic diagram showing the components of the blended nowcasting and non-hydrostatic model to forecast 0 to 6 hrs ahead](image)
In operation, a Significant Convection Monitoring and Forecasting suite has been running semi-automatically (human forecaster could intervene the system by selecting various algorithms according to different weather scenario) to provide nowcast, blended SWIRLS-NWP, as well up to 12 hours ahead outlook of convection forecast to local MET forecaster and ATM personnel to coordinate and issue Capacity Notification daily and whenever necessary to airports in the regional network for flow control purpose. Favourable comments are received from ATM on the inclusion of the enhanced nowcasting/short-term forecast information (ICAO 2013).

5. Translation of MET information into ATM-Impacting parameters

The 2nd Phase of the Project focuses on the research on translating the MET information into ATM-impact parameters, such as airport capacity, air space capacity, air traffic delay, etc.

Taking HKG as an example, during IOP3 in its Phase II, apart from the meteorological information mentioned above, air-traffic data, as well as aircraft positions determined by ADS-B were collected to study:

(i) the impact of significant convection blockage over some ATM holding/way points to airport acceptant rate;
(ii) the behaviour of the pilot avoidance when encountering significant convection using pilot simulator (ICAO/WMO 2014c, Hauf et al. 2016).

Research (i) above can be useful in quantifying the impact to airport capacity. Using all convective weather developed within the terminal area of HKFIR in 2016, we studied the reduction in the number of aircraft arrival per hour as a function of the percentage of intense radar echo over the approach airspace. The study reached a regression relationship shown in Fig. 6. Based on the regression and the seamless forecast in para. 4 above, one can predict how much the airport acceptance rate would drop in the next few hours. This is one of the highly desirable features for local ATM. Of course, the reduction of airport could also be affected by many non-weather factors but the current regression could provide the maximum acceptance rate of HKG should there be significant convection occurs within the approach airspace.

Research (ii) above can be useful in quantifying the aircraft delay as well as proposing optimal sequencing. Aircraft approaching or departing an airport are required to follow certain pre-set Standard Terminal Arrival Route (STAR), separation, minimum flying distance from the realm of a significant convective cell and other local ATM rules. By inputting these rules together with the actual and nowcast movement of the convective cell based on SWIRLS and the
planned trajectory of an aircraft into a pilot simulator, one can predict how the trajectory should be adjusted with time to avoid hitting the convection so as to propose an optimal safe deviated trajectory. Figure 7 shows a simulation results of an aircraft encountering of an intense echo ahead and how it could adjust its trajectory with time so as to achieve an optimal trajectory. The simulation would be useful for ATM to optimize the sequencing, reduce unnecessary holding, shorten the delay and reduce the waste of fuel to protect environment.

Works are underway to simulate large number of flights so as to calculate the overall shortened time delay to assess the overall benefits to ATM and airlines. The next step is to include the real-time ADS-B flight position data and their respective flight plan as well as the CB storm nowcast movements to provide advice in the optimal predicted flight path under multiple flight scenarios to further demonstrate the benefits of this tool.

6. Conclusions

The AvRDP is to provide enhanced nowcasting support for the MSTA as part of TBO. The primary emphasis of the proposal is to demonstrate the MET capability of providing quality 0-6 h convective, winter weather and other weather nowcast for the Terminal Control Area. The AvRDP represents a unique opportunity to demonstrate the utility of modern nowcasting systems in high impact weather situations. Several IOPs have been conducting at different airports representing varied climatological regimes and associated range of weather impact to aviation.

It is obvious that close collaboration between the MET and ATM community would be required. Support from ATM community, airlines and pilots, in particular in the form of advices in the evaluation methodology and the provision of necessary ATM and flight data for evaluation and validation, would be the key for the success of the AvRDP. The experience precipitated from AvRDP would then serve as the basis for defining the ATM-tailored MET service for the terminal area to meet future ATM requirements and shared with other States through technology transfer.

To better support the integration of MSTA with information for Trajectory Based Operation information, the WMO Executive Council at its sixty-eighth session (EC-68, 2016) agreed with general principles for extended research activities coordinated by WMO, building on the progress of the current AvRDP and taking into consideration the envisaged performance improvements in the ASBU blocks with focus on transfer of the results into operational practice.

For details about the background and progress of AvRDP, readers can access the website: https://avrdp.hko.gov.hk or contact the author of this paper.

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