Session 2 – Integration, use cases, fitness for purpose and service delivery

2.2 – Terminal Area and Impact-based forecast

Translating Meteorological Observations into Air Traffic Impacts in Singapore FIR

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1. Introduction

A fundamental responsibility of air traffic flow management (ATFM) is to optimize airspace utility and efficiency while maintaining high operational safety standards. This is accomplished by implementing strategic plans and executing tactical decisions that prevent the occurrence or mitigate the impact of air traffic congestion. Congestion arises when imbalances occur between air traffic demand and capacity, either because of high traffic volume relative to nominal capacity or because of degraded capacity. The most frequent and significant factor that degrades airport and airspace capacity, leading to congestion, is weather hazardous to aviation.

The MITRE Corporation (MITRE) and the Civil Aviation Authority of Singapore (CAAS) are researching models to measure and predict air traffic demand and capacity in support of ATFM decision-making for the Singapore Flight Information Region (FIR). A core challenge and focus of these efforts is translating Singapore’s significant aviation weather phenomena (particularly convection) into air traffic impacts and subsequent reductions to airspace resource capacity (e.g., traffic flow rate, airspace sector capacity). This challenge is exacerbated by the dynamic nature (and associated forecast challenges) of oceanic and monsoonal convection that frequently impinge on the Singapore air traffic operation. These weather impacts can be severe, given Singapore’s significant traffic demand. Passenger traffic demand in the Asia-Pacific region continues to rise at more than 5% per year [1], so the need to recognize and predict weather-induced capacity impact and congestion in support of proactive impact management is becoming a high priority.

Described here are initial efforts and preliminary findings on the needs, opportunities, approach, and challenges for translating meteorological observations and forecasts of convective weather into air traffic impacts in Singapore’s FIR. Implications and broader opportunities for ATFM – Weather Integration (AWI) efforts in the Asia-Pacific region are also discussed.

2. Singapore Air Traffic Operations and Primary Weather Constraints

Air traffic operations in Singapore FIR are dominated by flights to and from Singapore’s Changi airport (Figure 1). Changi is one of the busiest airports in the world [2], serving over 360,000 commercial flights and 58 million passengers in 2016 [3]. The Singapore FIR and major airspace flows are designed to manage and balance the volume of Changi arrival and departure airport, as well as to accommodate other en route traffic and military flights transitioning Singapore FIR (Figure 2).
Singapore air traffic control (ATC) and traffic management operations and responsibilities are distributed among eight en route sectors, in coordination with Changi terminal operations and airport runway management. Congestion typically arises as the air traffic operation reacts to disruptions from weather, military flight activity, or occasional surges in Changi departure or arrival volume. Singapore air traffic is regulated through strategic airport slot allocation, while tactical flow management is done primarily with arrival management (AMAN) controller tools / procedures and airborne holding. As Singapore air traffic demand increases, the frequency and severity of congestion events is expected to overwhelm current tactical practices.

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Instead, more proactive, strategic approaches to ATFM will be needed. Moreover, proactive traffic management must be weather-aware, as weather-induced airspace capacity reduction is more disruptive under high traffic loads, if the reduction is not recognized and planned for in a timely manner.

Weather phenomena adverse to aviation, particularly convective events, occur frequently the Singapore FIR. Terminal impacts such as wind shifts (possibly requiring runway reconfigurations), lightning (requiring ramp safety protocols), and haze from trans-boundary smoke [4] (reducing visibility) all can lead to reduced Changi airport capacity, and to congestion and delay that must be managed. Most significant, however, are the frequent, varied, and widespread convective weather events common in the region which can disrupt Singapore air traffic operations in many ways.

Located near the Inter Tropical Convergence Zone (ITCZ), and under the influence multiple, distinct atmospheric monsoon regimes (Figure 3, from [5]), Singapore’s convective weather can be complex and difficult to forecast. Figure 4 illustrates distinctly organized convective weather days affecting Singapore FIR in 2015.

![Figure 3. Overview of Singapore monsoon regimes and associated annual rainfall distribution, which is largely convectively-driven (from [5]).](image)
3. Weather Impact Translation and Integration

Most effective management of weather-induced airspace capacity reduction and congestion requires ATFM – weather integration (AWI). Ultimately, when seeking to minimize disruption and delay, air traffic controller and managers (who are not meteorologists) care primarily about the effect of weather on their operation, and not the weather itself. Weather impact translation and integration with air traffic both simplifies and focuses disparate weather information to fundamentally inform traffic management decision-makers how that weather may affect the operation and require intervention.

AWI is defined as “the inclusion of weather information into the logic of an air traffic management decision process or decision aid such that aviation weather constraints are directly taken into account when the decision is considered” [6]. An AWI framework, developed in support of the United States of America (U.S.A) National Airspace System (NAS), consists of five levels (Level 0-4) progressing through more advanced staged of weather translation and integration for ATFM (Figure 5).

Adopting the AWI framework for Singapore FIR applications requires the following initial efforts:

- Identify and collect pertinent weather and air traffic data to quantitatively evaluate conditions, responses, and outcomes associated with weather-induced irregular operations
- Develop methods and models for translating weather data into operational impact through statistical analyses of weather, air traffic, and airspace resource data

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• Assess available weather forecast data that may support translated weather impact predictions and subsequent airspace capacity degradation forecasts
• Create new forecast products tailored to predicting weather events that have high impact on aviation operations.

4. Convective Weather Impact Translation for Singapore Air Traffic Operation

Characteristics of convective weather most pertinent to air traffic impact translation include storm intensity (two- and three-dimensional [2-D, 3-D]), coverage, location, movement, and evolution. These traits are best measured by Doppler weather radars. Singapore’s weather radars operated by Meteorological Services of Singapore (MSS), uses eight elevation angles between 0.3° and 40° to sweep a complete volume for remote sensing of convective weather out to 480 km (260 nm) from Singapore. Utilizing the radar’s multiple elevation angles supports initial assessments of convective intensity and ‘vigor’ (enhanced radar intensity aloft, indicative of stronger convection that pilots are more apt to avoid) needed for impact translation.

Assessments of Singapore radar data suggest that combined use of (a) 1.0° plan position indicator (PPI) and (b) 5 km (16 kft) and 7 km (23 kft) constant altitude plan position indicator (CAPPI) radar observations is best suited to investigate convective weather disruptions in Singapore FIR and primary traffic flows (Figure 6).
Merging this radar data with one minute flight position and trajectory data in Singapore FIR supports analyses of pilot weather avoidance behaviour as different convective weather is encountered under different operational scenarios (e.g., location, time of day, phase of flight, aircraft type). Evaluation of 2-D and 3-D weather avoidance is the initial step in convective weather impact translation (Figure 7).

Given a large enough sample size and varied weather encounters, probabilistic relationships for the likelihood that a pilot will seek to avoid weather given specific characteristics can be determined. This information allows for the generation of a new (translated) weather avoidance field that shows convection not as a meteorological representation but as a field representing the probability that a pilot will avoid the weather. Weather avoidance fields used in conjunction with specific airspace resources can then measure the likelihood of flow and fix blockage, and in turn to quantify resource capacity loss due to weather [9], [10], [11]. In this manner, meteorological radar observations can be directly translated into air traffic route / flow impacts (Figure 8) as well as quantified estimates of reduced sector capacity – which inform traffic managers of when and where weather impact mitigation tactics and strategies may be needed to optimize operational efficiency.

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The primary challenges with initial weather impact translation efforts for Singapore air traffic operations are associated with (1) access to convective weather observations and (2) suitability of weather forecasts for predicting (rather than observing) weather impacts.

Weather radar data is well-suited to most robust methodologies for converting meteorological observations to air traffic impacts. However, ground based weather radar has limited coverage (out only to 130 nmi). Weather satellite data can fill this void but this data too must first be assessed and evaluated in the context of convective weather severity and as a potential hazard to aviation and air traffic interests. Fortunately, this effort has been completed by the U.S. National Center for Atmospheric Research (NCAR), who in collaboration with Basic Commerce and Industries, Inc. (BCI) produce real-time, global, satellite-based convective hazard products pertinent to aviation interests. MITRE, in collaboration with NCAR and BCI, is using archived Convective Diagnostic for Oceanic (CDO) and Cloud Top Height (CTH) hazard products ([12], [13]), merged with Singapore flight trajectory data to assess weather avoidance behaviour and to translate convective weather observations into air traffic impacts for the complete airspace region of interest (Figure 9).

To be most effective to air traffic decision-making, models for translating meteorological observations to aviation impacts must transition to constraint prediction. This is most readily accomplished by utilizing weather forecasts that predict core meteorological characteristics required for impact translation, such as precipitation (convection) intensity, coverage, and location, and then applying similar translation logic to the weather forecast. It is more complex however, as these predictions are inherently uncertain, and thus forecast performance (pre- and post-translation) must be understood. Moreover, impact prediction needs and limitations will vary by forecast lead-time, as the type of decision and the temporal and spatial characteristics of the hazard depend on the anticipated performance of the forecast – which can be significantly different in tactical (0-2 hour) vs. strategic (2-10 hour) time scales for traffic management. Numerical weather models used by MSS to date have largely focused on hydrological support to Singapore, and options and opportunities, relative to ATFM needs, must still be defined.

1 In this region of the world, weather satellite coverage is provided by the Himawari meteorological satellite operated by the Japan Meteorological Agency (JMA): http://www.jma.go.jp/jma/eng/satellite/index.html
5. Air Traffic – Weather Integration (AWI) Opportunities: Asia-Pacific Region

Although the weather impact challenges are country-specific, the approaches, models, and initial data analysis used in Singapore for weather impact translation in support of ATFM are applicable to the wider Asia-Pacific region. In fact, adopting Singapore models and weather impact products and metrics will help ensure synergy when seeking to mitigate adverse weather impacts for the region. This would be particularly helpful to the Singapore operation (given long flight times from many origin airports destined for Changi) in managing cross-FIR-boundary weather constraints and its potential effect on traffic demand predictions and volume management needs. AWI, as a relatively new endeavour in Singapore and the broader region, would better overcome initial challenges via a dedicated AWI program seeking to:

- Define key air traffic decision needs and associated aviation weather challenges
- Establish strong AWI partnerships between civil aviation authorities (e.g., CAAS) and National Meteorological and Hydrological Services (NMHS; e.g., MSS) to identify gaps and jointly develop AWI requirements and services
- Identify weather impact translation and integration needs, challenges, and requirements – with special emphasis on impact prediction for ATFM
- Define and develop a “two way” (air traffic and meteorological operations) AWI training program
- Develop regional, multi-country FIR-NMHS partnerships for AWI in support of ATFM

6. References


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