Frequent-output sub-kilometric NWP models supporting enhanced runway throughput and performance-based navigation

K.K. Hon* and P.W. Chan
Hong Kong Observatory

*kkhon@hko.gov.hk

6 to 10 November 2017, Météo-France, Toulouse
Thread: WAKE

Performance Improvement Areas

PIA 1
Airport Operations

PIA 2
Globally Interoperable Systems and Data

PIA 3
Optimum Capacity and Flexible Flights

PIA 4
Efficient Flight Paths

Block 0 (2013)
- Optimization of approach procedures using vertical guidance
- Increased runway throughput through wake turbulence separation
- Safety and efficiency of operations

Block 1 (2018)
- Optimized airport accessibility
- Increased runway throughput through dynamic wake turbulence separation
- Enhanced safety and efficiency of operations

Block 2 (2023)
- Advanced wake turbulence separation (time-based)
- Optimized surface routing

Block 3 (2028 onward)
Known RECAT initiatives
- Heathrow
- Charles de Gaulle
- San Francisco Int’l
- (more to follow)

Advanced wake turbulence separation (time-based)

The application of time-based aircraft-to-aircraft wake separation minima and changes to the procedures the ANSP uses to apply the wake separation minima.

KPA-02 – Capacity

Aerodrome

Most complex - establishment of time-based separation criteria between pairs of aircraft extends the existing variable distance re-categorization of existing wake turbulence into a conditions-specific time-based interval. This will optimize the inter-operation wait time to the minimum required for wake disassociation and runway occupancy. Runway throughput is increased as a result.

Increased capacity and arrival rates through time-based separation coupled with weather dependent separation (WDS) concept

These advanced concepts are provided with support from the ANSP (or airport operator) and to the flight deck in the instances of cooperative separation which assumes already available flight deck tools for interval management. Further development of the time-based separation will use weather dependent separation (WDS) which develops the basic weather dependent concepts further and integrated with time-based separation for approach. This concept utilizes both wake decay and transport concepts (such as PRBS and CROPS) into a single coherent concept, backed by advanced tools support and provides
HKO’s **Aviation Model (AVM)**

- Sub-km implementation of WRF-ARW (v3.7.1) for HKIA
- Hourly-updated up to T+9 (or so)
- Inner (200-m) domain recently expanded to whole of HK
- Windshear/turbulence, good ol’ winds & temp. forecasts

---

**Zoom-in of model topography around HKIA**
(Contoured between 0 – 1000 m)
## Configuration of AVM

<table>
<thead>
<tr>
<th>Domain</th>
<th>PRD</th>
<th>xHKA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Resolution</td>
<td>600 m</td>
<td>200 m</td>
</tr>
<tr>
<td>Time Step</td>
<td>~ 10 s (adaptive)</td>
<td>~ 3 s (adaptive)</td>
</tr>
<tr>
<td>Domain Size</td>
<td>581 x 581</td>
<td>581 x 581</td>
</tr>
<tr>
<td>Vertical Levels</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>Soil Layers</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Topography / Landuse</td>
<td>Based on USGS 3-sec / MODIS 30-sec (With local adaptations)</td>
<td></td>
</tr>
<tr>
<td>Radiation (Long/short-wave)</td>
<td>RRTMG or Goddard</td>
<td></td>
</tr>
<tr>
<td>Convection</td>
<td>Explicit</td>
<td></td>
</tr>
<tr>
<td>Land Surface</td>
<td>Noah LSM</td>
<td></td>
</tr>
<tr>
<td>Boundary Layer</td>
<td>MYJ</td>
<td>Modified “LES” mode</td>
</tr>
<tr>
<td>Initial Conditions</td>
<td>WRFDA 3D-VAR with adjusted length-scales, etc.</td>
<td></td>
</tr>
<tr>
<td>Boundary Conditions</td>
<td>HKO RAPIDS-NHM (2 km)</td>
<td></td>
</tr>
</tbody>
</table>
What does 200-\textit{m} res. look like?

\textit{Top}: Cloud distribution over Pearl River Estuary during passage of an E’ly wind front as observed on MODIS (true colour)

\textit{Bottom}: Simulated cloud imagery (through RTTOV) based on AVM forecast

(Gridlines at 1-deg lat./lon.)

Hon (2017):
Simulated satellite imagery at sub-\textit{km} resolution by the Hong Kong Observatory

\textit{Weather}, accepted, DOI:10.1002/wea.3100
Prediction of Low-level Windshear

Simulated LIDAR PPI of Doppler velocities @ 3-/6-deg elevation

AVM Windshear Forecast at 4 Hours Ahead
4 Pilot Reports received:

Predicted headwind changes along 8 x arrival/departure glide-paths
(Note only 1 combination can be in use at a time – e.g. 07LA/07RD)

Hit!
Spatio-temporal Variability @ HKIA

- LIDAR range gate ≈ 100 m
- AVM $\Delta x = 200$ m
- Note the astonishing amount of wind variations within just 3 NM!
- What, then, is “headwind”?
Minute by-minute Wind Variations

- It would appear that precise wind variations down to the minute intervals are, at least in principle, predictable.
- But most likely with the aid of statistical post-processing.
- How to integrate such forecast information, *if and when ready*, into e.g. planning at the tactical timescale?
Trajectory-based Verification

- Based on 600-m AVM-PRD
- Some 20,000 data points
- QAR from Apr – Jun 2014
- Exact match of lat/lon/time
- Along flight trajectories

- Note these are “windshear” flights – hence much larger variability at the lowest few hundred metres
Prediction of Turbulence Intensity

LIDAR-derived EDR$^{1/3}$ distribution
- Based on “VSF” method
- Computed on 3-deg PPI surface

AVM-HKA 7-hour forecast
- “Online” calculations under “LES” mode
- Here projected onto LIDAR PPI surface
Hon and Chan (2014):
Terrain-Induced Turbulence Intensity during Tropical Cyclone Passage as Determined from Airborne, Ground-Based, and Remote Sensing Sources. 

The Problem with $EDR^{1/3}$...
Predictability of Turbulence Intensity

Grid-by-grid comparison between LIDAR-derived and AVM-forecast EDR$^{1/3}$ value (Jan – Jul 2014)

Spatial distribution of discrepancies

Histogram (by %) of RMSE at each model grid
First Wake Vortex Measurements at the Hong Kong International Airport

The Observatory has always been keen in applying the latest technology in advancing aviation meteorological service. Over the past few summers, a rented unit of short-range LIDAR (SRL) – a higher-resolution, more agile counterpart to the long-range LIDARs currently used in the alerting of low-level windshear – has been installed on the rooftop of the AsiaWorld-Expo to study the properties of building-induced windshear and turbulence at corridor 25RA. This was achieved by performing rapid near-horizontal planar scans, up to 3 times per minute, over the region spanned by the last 1 to 2 nautical miles before touch-down (Fig. 1a).

“Building effect” scans (PPI every 20 – 30 s)  Prelim. wake vortex scans (RHI every 5 s or so)
Prelim. Wake Observations @ HKIA

Wake Turbulence or Windshear?
Wake Turbulence or Windshear?
Wake Turbulence or Windshear?
Upcoming Measurement Campaign

- 2-year observation campaign
- Expected 4 x dedicated SRL
- To commence around Q1 2017

- Establishing WV database @ HKIA
- Input to building a “safety case”

<table>
<thead>
<tr>
<th></th>
<th>J</th>
<th>H</th>
<th>M</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Existing separation minima @ HKIA
Delineation of Responsibilities

Civil Aviation Department (CAD)
- Air traffic management & regulator

HK Airport Authority (AAHK)
- Airport operator & management

Hong Kong Observatory (HKO)
- Met. service provider
Closing Remarks

• Forecast uncertainties notwithstanding, there exist certain areas where MET capabilities quite possibly exceed existing or anticipated requirements

• Geographically complex aerodromes, given their high spatio-temporal meteorological variability, may well be a “last citadel” in face of overwhelmingly powerful global models expected down the road

• Wake vortex experience in Hong Kong perhaps an interesting “anomaly” where MET people took the first step, then in turn be requested “on-board”
Thank you