APPLICATION OF OPTICAL-FLOW TECHNIQUE TO SIGNIFICANT CONVECTION NOWCAST FOR TERMINAL AREAS IN HONG KONG

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Rio de Janeiro, Brazil
Background
Aviation Havoc

- What causes the chaos in a seemingly “normal” thunerstorm day?

monsoon trough, quasi-stationary

09:18:15
5 JUL 2012 HKT
The Hong Kong Int’l Airport

northern runway

250

southern runway

070
Six different approach/departure flight paths

- **Approach 070**
  - Northern runway
- **Approach 070**
  - Southern runway
- **Approach 250**
  - Northern runway
- **Approach 250**
  - Southern runway

mis-approach areas

- **Depart 070**
- **Depart 250**
Wx. Impact to Aviation Quantified
Products
Sig. Conv. Nowcast Product

Key Convection Sensitive Areas

arrival / departure corridors

Abbreviated warning messages deduced from reflectivity forecast

FRQ SQL TS TO W
FCST SCT TS TO N

Prepared at 0624UTC 01 Jun 2010
Warning Criteria

Significant convection over a corridor is defined as either:

“yellow” for moderate impact:
  at least 50% area with echo intensity $\geq 33$ dBZ
  AND at least 4% area with echo intensity $\geq 41$ dBZ

“red” for severe impact:
  at least 10% with echo intensity $\geq 41$ dBZ

In forecast verification, the Performance Diagram refers to a contingency table of “yes/no” significant convection in 1 hour.
## Warning Messages

<table>
<thead>
<tr>
<th>Currently Observed status</th>
<th>Forecast status</th>
<th>Textual message</th>
</tr>
</thead>
<tbody>
<tr>
<td>GREEN</td>
<td>RED</td>
<td>FCST FRQ TS</td>
</tr>
<tr>
<td>YELLOW</td>
<td>RED</td>
<td>SCT TS INTSF</td>
</tr>
<tr>
<td>RED</td>
<td>RED</td>
<td>FRQ TS</td>
</tr>
<tr>
<td>GREEN</td>
<td>YELLOW</td>
<td>FCST SCT TS</td>
</tr>
<tr>
<td>YELLOW</td>
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<td>SCT TS</td>
</tr>
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<td>FRQ TS INTSF</td>
</tr>
<tr>
<td>GREEN</td>
<td>GREEN</td>
<td>FRQ TS WKN</td>
</tr>
<tr>
<td>YELLOW</td>
<td>GREEN</td>
<td>SCT TS WKN</td>
</tr>
<tr>
<td>RED</td>
<td>GREEN</td>
<td>FRQ TS WKN</td>
</tr>
</tbody>
</table>
Stamp Maps

→ f/c reflectivity map every 6 minutes

Latest run

Previous runs
### Option to Stagger Stamp Maps

<table>
<thead>
<tr>
<th>Year-Start</th>
<th>Year-End</th>
<th>Stamp-Start</th>
<th>Stamp-End</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021-01-01</td>
<td>2022-01-01</td>
<td>2021-01-05</td>
<td>2022-01-05</td>
</tr>
<tr>
<td>2022-01-01</td>
<td>2023-01-01</td>
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</tr>
</tbody>
</table>

**Same valid time**
User Interface

Forecast for the Arrival and Departure Corridors

<table>
<thead>
<tr>
<th>Manual</th>
<th>Expired</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>To East</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To North</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To West</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Valid for 0.5 hour

Auto

<table>
<thead>
<tr>
<th>ATNS - 201108310948</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>09:45</td>
</tr>
<tr>
<td>SCT TS TO E WKN MOV SE 8 KT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MOVA - 201108310948</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>09:45</td>
</tr>
<tr>
<td>FRQ TS TO W MOV SE 8 KT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TREC - 201108310948</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>09:45</td>
</tr>
<tr>
<td>FRQ TS TO W MOV SE 9 KT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MGOF - 201108310948</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>09:45</td>
</tr>
<tr>
<td>FRQ TS TO W MOV S 8 KT</td>
</tr>
</tbody>
</table>

4 choices for default tracking method

Automatically generated warning messages, editable by forecasters
Result
Trial Results — Rainstorms in 2012

33dBZ threshold forecast performance of selected cases

41dBZ threshold forecast performance of selected cases

Lead Time (Minute)

Skill Score (POD)

TREC_zrhk
MOVA_zrhk
mugof-lv1-r9-a2000-s1.5-i6-dbz33_zrhk
mugof-lv2-r9-a2000-s2.5-i6-dbz33_zrhk
mugof-lv1-r9-a2000-s2.5-i6-dbz33_zrhk
mugof-lv2-r9-a2000-s2.5-i12-dbz33_zrhk

Amber and Red rainstorm cases in 2012 (up to 5 July)

“orange” for sig. conv. f/c
Performance Diagram (Jun-Oct 2011)

Performance Diagram 1hr corridor forecast

POD

1 - FARatio

Freq. bias=0

CSI=0.5

CSI=0.4

CSI=0.45

trec

atms
Techniques
What Does “Optical Flow” Mean?

- “Velocity pattern of the apparent motion of moving objects in a visual scene when projected onto a two-dimensional plane”
  - after Aubert et al. 1999

- Originators (in computer vision):
  - Lucas & Kanade 1981 (local approach)
  - Horn & Schunck 1981 (global approach)
  - Bruhn et al. 2003 (combined local-global approach)
    - adapted for use in ROVER of SWIRLS

- In meteorological community:
  - Germann & Zawadzki 2002 (VET)
    - from the wind retrieval technique of Laroche & Zawadzki 1994; 1995
  - Bowler et al. 2006 (Gandolf / STEPS)
  - Wong et al. 2009 (MOVA)
Optical Flow Constraint

- brightness/intensity constancy assumption:
  \[
  \frac{\partial I}{\partial t} + u \frac{\partial I}{\partial x} + v \frac{\partial I}{\partial y} = 0
  \]

- equivalent to the Lagrangian persistence requirement in VET

- can be solved by many ways:
  - e.g. globally by variational method
    - HS, VET or MOVA, with different constraints on \((u, v)\) field
  - e.g. locally by assuming \((u, v)\) constant in a neighbourhood
    - LK, amongst to solving a 2x2 matrix
Variational Formulations

\[ J = J_o + \alpha \cdot J_v \]

\[ J_o = \iint \left[ \frac{\partial I}{\partial t} + u \frac{\partial I}{\partial x} + v \frac{\partial I}{\partial y} \right]^2 \, dx \, dy \]

\[ J_v = \begin{cases} J_{HS} \\ J_{WW} \end{cases} \]

where

\[ J_{WW} = \iint \left[ \left( \frac{\partial^2 u}{\partial x^2} \right)^2 + \left( \frac{\partial^2 u}{\partial y^2} \right)^2 + 2 \left( \frac{\partial^2 u}{\partial x \partial y} \right)^2 + \left( \frac{\partial^2 v}{\partial x^2} \right)^2 + \left( \frac{\partial^2 v}{\partial y^2} \right)^2 + 2 \left( \frac{\partial^2 v}{\partial x \partial y} \right)^2 \right] \, dx \, dy \quad \text{(WW80)} \]

in MOVA & VET

\[ J_{HS} = \iint \left[ |\nabla u|^2 + |\nabla v|^2 \right] \, dx \, dy \quad \text{(HS81)} \]

in original HS formulation
Formulation by Bruhn et al 2003

- **LK-HS combined – fast**
  
  \[ I_x(q) \cdot u + I_y(q) \cdot v = -I_t(q) \quad \text{where} \quad q \in \Omega \]

  \[
  \begin{pmatrix}
  u \\
  v
  \end{pmatrix} = \left( \begin{pmatrix}
  K_\rho * (I_x I_x) \\
  K_\rho * (I_y I_y)
  \end{pmatrix} \right)^{-1} \begin{pmatrix}
  -K_\rho * (I_x I_t) \\
  -K_\rho * (I_y I_t)
  \end{pmatrix}
  \]

  \[
  J_{HS} = \iint \left[ |\nabla u|^2 + |\nabla v|^2 \right] \, dx \, dy \quad \text{(HS81)}
  \]

- **full multi-grid – accurate**
Illustration
$M = 1$

Single vector over whole domain

- largest scale resolvable
\[ M = 5 \]

5x5 vectors
$M = 10$

10x10 vectors

Repeat for

M=20,40 and 80
\( M = 80 \)

80x80 vectors

(final result)
Adaptation
Controlling the “Brightness” of Sig. Conv.

\[ G(Z) = \tan^{-1}\left( \frac{Z - Z_c}{\zeta} \right) \]
Effect of Brightness on Tracking

Non-Linear

Linear
Extrapolation Results (3 horus)

Linear

Non-Linear

Actual
Future Work

- To reduce the jumpiness of the warning messages
  - by adopting time-lagged ensemble approach
- To disseminate the significant convection forecasts to pilots
  - via the ATIS (automatic terminal information system)
- To further optimize the optical-flow tracker
  - using a newly developed “Automatic Parameter Tuning Tool”
    - based on a metahueristic approach using the Cuckoo Search engine
- To enhance the advection scheme
  - by incorporating large scale motion
~ End ~

Questions?