Satellite Detection and Nowcasting High-altitude Ice Crystals

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High-altitude Ice Crystals Formation

K. Kerkmann, UNDERSTANDING CONVECTIVE CLOUDS THROUGH THE EYES OF (MSG) Cloud Particle Size
High-altitude Ice Crystals Hazzard

Engine Trouble
A theory that ice can accumulate inside a jet engine and cause temporary shutdown has gradually been embraced by the industry.

Here’s what happens:

- Researchers believe that tiny ice crystals bounce off freezing surfaces near the front and enter into the engine’s core.
- Here the ice melts, creating a film of water that captures additional particles. This process reduces the temperature until it is cold enough for more ice to build up.
- Eventually, the ice can break off and quench combustion. It also can potentially cause other malfunctions or even engine failure.

Note: Diagrams are schematic
Source: Boeing

A. Pastor, Wall Street Journal: Airline Regulators Grapple With Engine-Shutdown Peril
https://www.wsj.com/articles/SB120753403340593953
## Himawari-8 Satellite

Himawari-8 is a Japanese weather satellite that provides high-resolution imaging. It is similar to ABI for GOES-R, with improved spatial and spectral resolution.

### Table of Bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength [μm]</th>
<th>Quantization [bit]</th>
<th>Spatial Resolution (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.46</td>
<td>11</td>
<td>1km</td>
</tr>
<tr>
<td>2</td>
<td>0.51</td>
<td>11</td>
<td>1km</td>
</tr>
<tr>
<td>3</td>
<td>0.64</td>
<td>11</td>
<td>0.5km</td>
</tr>
<tr>
<td>4</td>
<td>0.86</td>
<td>11</td>
<td>1km</td>
</tr>
<tr>
<td>5</td>
<td>1.6</td>
<td>11</td>
<td>2km</td>
</tr>
<tr>
<td>6</td>
<td>2.3</td>
<td>11</td>
<td>2Km</td>
</tr>
<tr>
<td>7</td>
<td>3.9</td>
<td>14</td>
<td>2Km</td>
</tr>
<tr>
<td>8</td>
<td>6.2</td>
<td>11</td>
<td>2Km</td>
</tr>
<tr>
<td>9</td>
<td>7.0</td>
<td>11</td>
<td>2Km</td>
</tr>
<tr>
<td>10</td>
<td>7.3</td>
<td>12</td>
<td>2Km</td>
</tr>
<tr>
<td>11</td>
<td>8.6</td>
<td>12</td>
<td>2Km</td>
</tr>
<tr>
<td>12</td>
<td>9.6</td>
<td>12</td>
<td>2Km</td>
</tr>
<tr>
<td>13</td>
<td>10.4</td>
<td>12</td>
<td>2Km</td>
</tr>
<tr>
<td>14</td>
<td>11.2</td>
<td>12</td>
<td>2Km</td>
</tr>
<tr>
<td>15</td>
<td>12.3</td>
<td>12</td>
<td>2Km</td>
</tr>
<tr>
<td>16</td>
<td>13.3</td>
<td>11</td>
<td>2Km</td>
</tr>
</tbody>
</table>

**Remark:**
- 0.51 μm (Band 2) instead of ABI’s 1.38 μm
- RGB band Composited

**Imaging Bands:**
- VIS: 0.46–0.70 μm
- IR1: 8.5–13 μm
- IR2: 10.3–12.3 μm

**Imaging Features:**
- True Color Image
- Water vapor
- SO₂
- O₃
- Atmospheric Windows
- CO₂

**Courtesy of JMA**
<table>
<thead>
<tr>
<th>Band</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 01, 02, 03</td>
<td>Clouds, low cloud and fog, winds, vegetation, snow cover etc.</td>
</tr>
<tr>
<td>Band 04</td>
<td>Daytime vegetation / burn scars, flood / standing water, aerosol detection over water, winds, snow cover</td>
</tr>
<tr>
<td>Band 05</td>
<td>Daytime cloud top phase and particle size, snow cover, flood / standing water</td>
</tr>
<tr>
<td>Band 06</td>
<td>Daytime cloud / land properties, cloud particle size, vegetation, snow cover</td>
</tr>
<tr>
<td>Band 07</td>
<td><strong>Surface and clouds, low clouds and fog at night, fires and hot spots, winds</strong></td>
</tr>
<tr>
<td>Band 08</td>
<td>High level atmospheric water vapour, turbulence, winds, rainfall</td>
</tr>
<tr>
<td>Band 09</td>
<td><strong>Mid level atmospheric water vapour, winds, rainfall</strong></td>
</tr>
<tr>
<td>Band 10</td>
<td>Lower level water vapour, winds, rainfall, sulphur dioxide</td>
</tr>
<tr>
<td>Band 11</td>
<td>Total water for stability, cloud phase, dust, sulphur dioxide, rainfall</td>
</tr>
<tr>
<td>Band 12</td>
<td><strong>Total ozone, turbulence, winds</strong></td>
</tr>
<tr>
<td>Band 13</td>
<td><strong>Surface features, clouds, Tropical Cyclone intensity (Dvorak)</strong></td>
</tr>
<tr>
<td>Band 14</td>
<td>Sea surface temperature, clouds, convective cloud top signatures, rainfall, volcanic ash detection, winds.</td>
</tr>
<tr>
<td>Band 15</td>
<td>Total water, volcanic ash detection, sea surface temperature</td>
</tr>
<tr>
<td>Band 16</td>
<td>Air temperature, cloud heights and amounts, volcanic ash height</td>
</tr>
</tbody>
</table>
Quick Access Recorder (QAR) Data

• Available to HKO at cost (well, largely)
• Supplied by major local commercial airlines
• De-identified for scientific analysis & verification
• “Traditionally” – mainly using winds & GPS lat/lon
• Extending usage from windshear/turb. to ICI
Quick Access Recorder (QAR) Data

Total air temperature (TAT)
Pilots report icing when they notice TAT suddenly increase:

Figure: Probes mounted on the surface of the aircraft.

Figure: TAT plotted against time
Study Data

- between April 2015 and October 2016
- 14 icing cases reported by pilot
- justified with the measured static air temperature (SAT) anomalies

In deep convection area with constant altitude, significant jump in SAT
Study Data

• 19 null cases chosen
• flight path passed through deep convection, but no anomalies in SAT

In deep convection area with constant altitude, constant SAT
Random Forest

Stage 1: Bootstrap sampling
2/3 data as training

Stage 2: Model training
Based on BT values and combinations

Stage 3: Model forecasting

Stage 4: Result aggregating
1/3 data as testing

Satellite channels B01-B16 and reported icing cases (CX flight data)

Pixel output: 0 (no icing) or 1 (icing)
Random Forest Results

Most important channel in decision tree accuracy is ranked at the top. The purest trees (i.e., purest classes after classification) are given at the top.
Split Windows Algorithm

<table>
<thead>
<tr>
<th>Split Windows</th>
<th>Properties</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>B07–B13</td>
<td>ice particles sizes for very cold cloud tops</td>
<td>EUMETSAT Severe Storm RGB</td>
</tr>
<tr>
<td>B09–B13</td>
<td>deep convective activity of clouds</td>
<td>COMS Convective RGB</td>
</tr>
<tr>
<td>B05–B13</td>
<td>cloud phase (ice/water) information</td>
<td>COMS Cloud Product</td>
</tr>
<tr>
<td>B12–B13</td>
<td>deep convective activity of high clouds</td>
<td>Kwon et al.</td>
</tr>
<tr>
<td>B13–B15</td>
<td>cloud type classification (optical thickness)</td>
<td>NOAA 7 split-window</td>
</tr>
<tr>
<td>B13–B16</td>
<td>deep convective activity of high clouds</td>
<td>Kwon et al.</td>
</tr>
</tbody>
</table>

B05–B13 and B13–B15 are not used for graphical presentation because it is redundant with B12–B13, where B12–B13 is more useful in distinguishing icing cases.

B09–B13 and B12–B13 are used for detection of deep convection, the less important B13–B16 is not included in the split windows algorithm.

Split Windows Algorithm

VIS Band 03 > 0.4

- **No**
  - **Night-time:** without VIS
    - **Blue:** high cloud tops (regions with ice crystals)
    - $6.5K < \text{Band 12} - \text{Band 13} < 19K$

- **Yes**
  - **Day-time:** with VIS (lower FAR)
    - **Blue:** high cloud tops (regions with ice crystals)
    - $6.5K < \text{Band 12} - \text{Band 13} < 19K$
    - **Yellow:** small ice crystals
    - $\text{Band 07} - \text{Band 13} > 50K$
Sample Case of Successful Detection

Deep convection $-1K \leq IR_{3.6\mu m} - IR_{10.8\mu m} \leq 5K$;
Non-cirrus icy clouds $-3K \leq IR_{10.8\mu m} - IR_{2.12.0\mu m} \leq 1K$.

Figure: Another Provider
Figure: This study
Another Case of Detection

Deep convection \(-1K \leq IR_{3.6.8\mu m} - IR_{10.8\mu m} \leq 5K\);
Non-cirrus icy clouds \(-3K \leq IR_{10.8\mu m} - IR_{212.0\mu m} \leq 1K\).

Figure: Another Provider  Figure: Another Provider  Figure: This study
## Split Windows Algorithm Verification

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>POD</th>
<th>FAR</th>
<th>True skill statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Himawari-8</td>
<td>0.55</td>
<td>0.13</td>
<td>0.42</td>
</tr>
<tr>
<td>CIP (NCAR)</td>
<td>0.76</td>
<td>0.33</td>
<td>0.43</td>
</tr>
<tr>
<td>SIGMA (Meteo-France)</td>
<td>0.59</td>
<td>0.26</td>
<td>0.33</td>
</tr>
<tr>
<td>GDCP (NASA)</td>
<td>0.76</td>
<td>0.67</td>
<td>0.09</td>
</tr>
</tbody>
</table>

*Based on those available pilot reports & QAR data on hand so far*

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M. Chapman, A. Holmes and C. Wolff, Verification of aviation icing algorithms from the second alliance icing research study, 12th Conference on Aviation Range and Aerospace Meteorology
https://ams.confex.com/ams/Annual2006/techprogram/paper_104158.htm
Nowcasting

Deep convection for high clouds
19 > B12 (9.6 µm)–B13 (10.4 µm) > 6.5 in blue;
Small ice particles for very cold cloud tops
B07 (3.9 µm)–B13 (10.4 µm) > 50 in yellow.

Red dot showed the location of an icing event with moderate severity reported by pilot at 0345Z and FL250.

Positions estimated using atmospheric motion vectors (red arrows) derived from Satellite pictures on 3 September 2017 at 0330Z and 0340Z.
Multi-channel Radiance Simulation
Forecasting (+6 hours)

Deep convection for high clouds
19 > B12 (9.6 µm)–B13 (10.4 µm) > 6.5 in blue;
Small ice particles for very cold cloud tops
B07 (3.9 µm)–B13 (10.4 µm) > 50 in yellow.

Model run on 7 October 2016 at 0000Z, forecast hour: +6 hours. Simulated satellite channels have been adjusted using histogram matching method for observed and simulated pictures at 0000Z.
Deep convection for high clouds
19 > B12 (9.6 µm)–B13 (10.4 µm) > 6.5 in blue;
Small ice particles for very cold cloud tops
B07 (3.9 µm)–B13 (10.4 µm) > 50 in yellow.

Model run on 7 October 2016 at 0000Z, forecast hour: +9 hours. Simulated satellite channels have been adjusted using histogram matching method for observed and simulated pictures at 0000Z.
Concluding Remarks

• Satellite + Machine Learning => Detection
• ICI “patches/objects” + Advection => Nowcasts
• NWP + Radiance Simulator => Forecasts

• Detection + Nowcast + Forecast => Seamless Service
• QAR data offer useful alternative obs. source

• Questions remain...
  – How best to verify?
  – How best to blend?
Thank you