Latest Nowcasting Technology for Aviation

by

George A. Isaac
Weather Impacts Consulting Incorporated

WMO WWRP 4th International Symposium on Nowcasting and Very-short-range Forecast 2016, 25-29 July 2016, Hong Kong
Recent Nowcasting Papers


SNOW-V10
Science of Nowcasting Olympic Weather for Vancouver 2010
A World Weather Research Programme approved project

- To improve our understanding and ability to forecast/nowcast low cloud, and visibility.
- To improve our understanding and ability to forecast precipitation amount and type.
- To improve forecasts of wind speed, gusts and direction.
- To develop better forecast production systems.
- Assess and evaluate value to end users.
- To increase the capacity of WMO member states.

Two clusters of «Sochi-2014» Olympic venues

FROST-2014: Forecast and Research in the Olympic Sochi Testbed

Ice sports competitions

Snow sports competitions
### Situation Chart for CYYZ

**CYZZ METEOROLOGICAL NOWCAST:** VALID AT 2021-02-02 10:00 UTC [INTW, GEM_REG_MOLTS, GEM_LAM_MOLTS, RUC, OBS, M300]

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**CYZZ OPERATIONS NOWCAST:** VALID AT 2021-02-02 10:00 UTC [INTW, GEM_REG_MOLTS, GEM_LAM_MOLTS, RUC, OBS, M300]

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Introduction cont.

• According to Boeing most accidents occur during landing and take off

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<th>Phase</th>
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<th>Fatalities</th>
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<tr>
<td>Apron and taxiway</td>
<td>12%</td>
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<tr>
<td>Takeoff</td>
<td>19%</td>
<td>29%</td>
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<td>Initial climb</td>
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<td>Climb</td>
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<td>Final approach</td>
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<tr>
<td>Landing</td>
<td>33%</td>
<td>22%</td>
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During 6% of flight time occurs:
• 52% of accidents
• 51% of fatalities

* Estimate for 1.5 hour flight

Source: Boeing
Weather Related Accidents

Source: NASDAC / FAA
DND Requests for Information
(From Marie-France Turcotte as presented at CMOS Annual Congress 2016)

Frequency of requests

- Ground visibility: 20%
- Ceiling: 17%
- Wind speed: 17%
- Precipitation: 11%
- Thunderstorms: 9%
- Turbulence: 9%
- Icing: 9%
- Temperature & co: 11%
- Other: 11%
Variables for Airport System

- Snow and rain events
- Freezing precipitation and ice pellets
- Frost
- Blowing snow
- Icing aloft
- High winds/gusts
- Wind shifts/shear
- Turbulence
- Lightning
- Low ceilings
- Low visibility and fog
- Convective cells
Model Resolution

From Kiktev et al., 2016: FROST-2014: the Sochi Winter Olympics International Project. Submitted to BAMS
Model Resolution 2

From Kiktev et al., 2016: FROST-2014: the Sochi Winter Olympics International Project. Submitted to BAMS
Adaptive Blending of Observations and Model (ABOM)

\[ \hat{V}_{k+p} = o_k + s_p (\hat{o}_{k+p} - o_k) + r_p (m_{k+p} - m_k) \]

- Coefficients \( s \) and \( r \) are proportional to the performance over recent history, relative to obs persistence (\( w \)) and to
- Local tuning parameters (not yet optimized at all SNOWV10 sites)
- Updated using new obs data every 15 minutes

Fog event missed during FROST-2014 (February 17, 2014) by both model scheme used during SNOW-V10 and diagnostic method of Boudala et al. (2012) using Nowcast RH. Model failed to produce cloud at low levels. The model visibility scheme is described in Gultepe and Milbrandt (2010).

\[ V_k = \frac{-\ln(\varepsilon)}{\beta} \]
\[ \beta = \frac{3LWC}{\rho_wD_{eff}} \]
\[ LWC = \rho_wN \frac{\pi}{6} D_{eff}^3 \]

Remembering that extinction coefficient (\( \beta \)) is inversely related to visibility, when the liquid water content (LWC) increases, the visibility decreases and when effective diameter (\( D_{eff} \)) increases, for the same LWC, the visibility increases. Similarly, when droplet concentration (\( N \)) increases, for the same LWC, the \( D_{eff} \) decreases and the visibility decreases. So visibility in an all liquid fog strongly depends on \( N \), \( D_{eff} \) and LWC. NWP techniques should be able to predict at least two of these three parameters.

See Korolev et al. (2001) for the definition of the extinction coefficient, \( \beta \).
Relationship between $V_a$ & $V_k$

\[ V_k = \frac{V_a \ln(\varepsilon)}{\ln \left( \frac{V_a^2 E_T}{I} \right)} \]

\[ RVR = \max(V_k, V_a) \]

Non-linear, but can be solved numerically for given $I$, $E_T$, and $\varepsilon$. We found a way to forecast or predict the Runway Visual Range (RVR) using this equation.

Example of Nighttime/daytime visibility
Suggestion for a fog diagnostic scheme to be used with an NWP model

From Boudala et al., 2012
\[ \beta_f = \begin{cases} \exp(-5.605 + 0.0114 \text{RH}\phi), & r = 0.83 \\ \exp(-14.188 + 0.159 \text{RH}), & r = 0.75 \end{cases} \]  

where \( \phi \) is defined as

\[ \phi = \ln \left( \frac{1}{\ln \left( \min \left( \frac{T_d}{T}, 0.9998 \right) \right)} \right) \]

\[ \beta = \begin{cases} \max(\beta_{rs}, \beta_f) & \text{if } T \geq 0, \text{ RH} > 98\%, \text{ P} < 0.5 \text{ mm h}^{-1} \\ \max(\beta_{rs}, \beta_f) & \text{if } T < 0, \text{ RH} > 98\%, \text{ P} < 0.25 \text{ mm h}^{-1} \\ \beta_{rs}, & \text{otherwise} \end{cases} \]

\( B_s \) and \( \beta_r \) are as defined in Boudala et al. (2012). There are thresholds for wind speed and updraft applied (Tardif and Rasmussen, 2008) as well but these can cause problems.
\[ \ln(\beta_s) = 0.71 - 0.0288T + 0.783 \ln(S + 0.04), \] \tag{7}

where \(\beta_s\) is in kilometers, \(T\) in degrees Celsius, and \(S\) is the snowfall intensity in millimeters per hour.

\[ \beta_r = 0.4R^{0.63} \]

Based on Marshall Palmer (1948) size distribution of raindrops. \(R\) is rainfall rate in mm/h.

\[ \beta = \beta_f + \beta_r + \beta_s \]

From Boudala et al. (2012)
Forecasting Techniques for Visibility

• Conditional Climatology
• Fuzzy Logic
• Rules Based
• Satellite Based
• Numerical Weather Prediction
  • NWP Coupled with 1 or 2D models
Parameterizations used in NWP Models


For all liquid clouds, most use a relationship between RH and visibility or a diagnostic prediction method. The UK Met office predicts LWC and droplet concentration directly, which should be an improvement.
Forecasting by Rule Based Technique


- A long list of rules, based on output from the Regional Deterministic Prediction System (RDPS) has been developed to forecast fog (visibility < ½ mile).

- The system covers radiation fog and stratus, advection fog, fog over marine surfaces, ice edge fog, arctic sea smoke, and anthropogenic ice fog.

- The system is currently being assessed for operational implementation.
Rule Based Fog Forecast for 30 Dec 2010  (From Burrows and Toth, 2011)

14-hour forecast generated from the 0000 UTC 30 December 2010 RDPS run, valid at 1400 UTC 30 December 2010. The brown shaded area is the forecast of stratus with ceiling 500 feet or less, the yellow shaded area is fog with visibility ½ mile or less, and the tan shaded area is either fog with visibility ½ mile or less or stratus with ceiling 500 feet or less.
Dorman, C., and Darko Koračin, 2016: A Comparison of the World’s Foggiest Marine areas that are in the NW Pacific and the NW Atlantic Based on 58 years of Ship Observations. Presented at CMOS Annual Congress, Fredericton.
Jeanne-D’Arc Basin is some 340 kilometers east-southeast of St. John’s in 80 m to 100 m of water. This is the location of the Hibernia, White Rose and Terra Nova fields. Recent discoveries of hydrocarbons in the Flemish Pass, some 500 km east of St. John’s, and in deeper water (e.g. some 1000 m), have led to increased exploration drilling in that area.
### Helicopter Stats (Jan to Sept/14)

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<td>939</td>
<td>Does not include missed approaches or flight turn arounds</td>
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<tr>
<td>Total industry passengers</td>
<td>22279</td>
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<td>Days all flights cancelled</td>
<td>73</td>
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<tr>
<td>Total missed approaches</td>
<td>91</td>
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Len Coughlan, 2014: Industry Perspective, Presentation at HMDC Workshop on Metocean Monitoring and Forecasting for the Newfoundland & Labrador Offshore, 22-24 September, St. John’s, Newfoundland
Taylor (1917) identified the dominant process forming fog over the Grand Banks was due to warm moist air moving over cold waters (Advection Fog).

Climatology of Fog at Hibernia Platform: (from Beale et al., 2016: CMOS Presentation. Work funded by Hibernia Management Development Company (HMDC) and managed by Amec Foster Wheeler.)
Koračin et al. (2014) made the following statements: “From the many modeling studies of sea fog, ...it becomes clear that deterministic forecasting of sea fog onset and its duration has generally been unsuccessful. The extreme sensitivity of model output to elements of control [initial conditions, boundary conditions, and forcing (empirical/physical parameterization)], in concert with the chaotic nature of dynamic prediction, is at the heart of prediction inaccuracy. Ensemble prediction is a possibility, but it comes with complications when applied to sea fog. The complications arise because the phenomenon is discontinuous with an impulsive start and an abrupt end. The fundamentals of ensemble prediction applied to discontinuous dynamical systems such as this one are in their infancy. Without doubt, however, this area of investigation is needed and promising.”

A GOES-13 IFR Probability Chart for the May 2014 offshore fog event showing that St John’s and Hibernia report visibility < 1 NM while Long Pond reports ~10 nm. GOES-R IFR probabilities accurately capture the gradient in visibility between St. John’s and Long Pond showing ~70% at St John’s and ~30% at Long Pond while also maintaining high probabilities around the oil field.

Steven Goodman, 2014: Uses of Meteorological Satellite Data for Forecasting. Presentation at HMDC Workshop on Metocean Monitoring and Forecasting for the Newfoundland & Labrador Offshore, 22-24 September, St. John’s, Newfoundland
Background of INTW

- INTW refers to integrated weighted model
- Available models are used to generate INTW

**Major steps of INTW generation**

- Data pre-checking - defining the available NWP models and observations
- Extracting the available data for specific variable and location
- Calculating statistics from NWP model data, e.g. MAE, RMSE
- Deriving weights from model variables based on model performance
- Defining and performing dynamic and variational bias correction
- Generating Integrated Model forecasts (INTW)

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**Time (h) for Model to Beat Persistence**

Winter

<table>
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<tr>
<th>Variable</th>
<th>LAM</th>
<th>REG</th>
<th>RUC</th>
<th>INTW</th>
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<td>GUST</td>
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<td>no</td>
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</table>

Summer

From AMDAR, wind shear cases occur more often in autumn and winter, and during local morning. 70% of wind shear cases are present at 1st 500ft. REG, LAM and RUC are not capable of forecasting low level wind shear directly for Pearson Airport.

Wind Shear Threshold at 500 ft is 25 kts or 12.9 m/s.
From Hassan, D., P.A. Taylor, and G.A. Isaac, 2016: Snowfall Rate Estimation Using C-Band Polarimetric Radars. Accepted to Meteorological Applications

WMO SPICE (Solid Precipitation Intercomparison Experiment) underway
Example of freezing rain on 21/11/2014

From Boudala et al. 2016: ICCP Presentation
Terminal Area Forecasts

• Terminal Area Forecasts are now handled by TAFs which are old technology and don’t convey all the information needed.

• However, ECCC, like other organizations, are working on autoTAF in which TAFs are created directly from model output.

• What follows are some comments from Alister Ling, a Senior Aviation Meteorologist involved in the development.
  • Expect savings only when there is a lot of TAFs with good weather
  • If you have 3 TAFs with good weather, faster to do it manually!
Summary

• It is necessary to get good measurements more frequently than 1 hour (recommend one minute). This especially applies to rapidly changing variables like visibility, winds, precipitation rate and type. It would be useful to obtain model output at higher time resolution.

• Higher spatial resolution models show skill but there needs to be effective information delivery tools.

• The modeling community needs to concentrate more on important meteorological variables. Users need to be consulted.

• There does need to be further advances in instrumentation, even for basic parameters such as RH and precipitation amount. More effective use of remote sensors should be promoted.

• Improved nowcasting tools which integrate models and observations need to be further developed. Some older techniques probably need to be discarded.
Summary 2

• Forecasting techniques need verification and nowcasting methods should be compared with persistence.

• Field projects involving forecasters, scientists, and end users are very useful and they speed up the implementation of new techniques into operations.

• International projects, such as those being organized by WWRP, are quite useful.

• Although automated techniques are being developed, they contain significant errors. There is still a need for the human forecaster to provide oversight and add value.