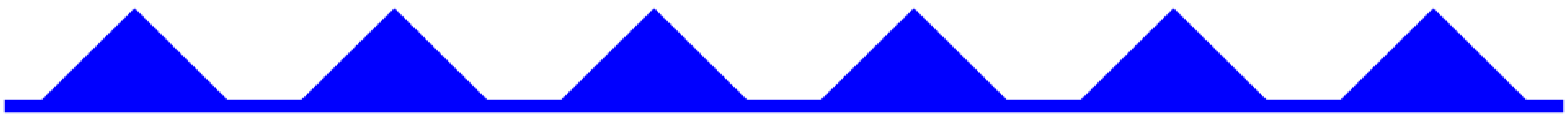
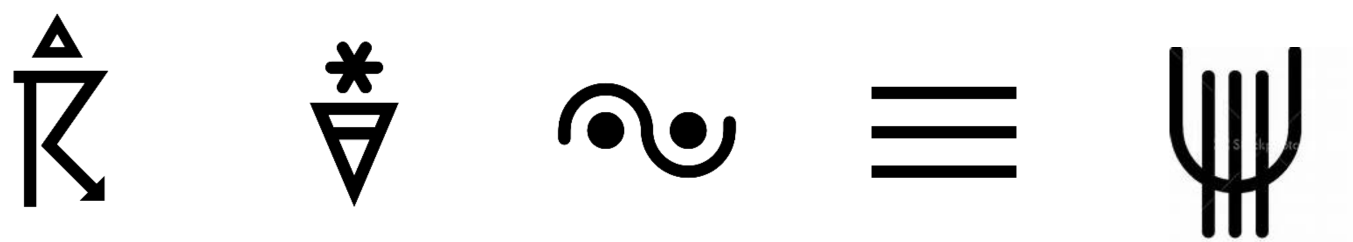
# Latest Nowcasting Technology for Aviation

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

- **Isaac, G.A., P. Joe, J. Mailhot, M. Bailey, S. Bélair, F.S. Boudala, M. Brugman, E. Campos, R.L.Carpenter Jr., R.W.Crawford, S.G. Cober, B. Denis, C. Doyle, H.D. Reeves, I.Gultepe, T. Haiden, I. Heckman, L.X. Huang, J.A. Milbrandt, R. Mo, R.M. Rasmussen, T. Smith, R.E. Stewart, D. Wang and L.J. Wilson, 2014: Science of Nowcasting Olympic Weather for Vancouver 2010 (SNOW-10): A World Weather Research Programme project. Pure Appl. Geophys. 171, 1–24, (DOI: 10.1007/s00024-012-0579-0).**
- **Bailey, M.E., G.A. Isaac, I. Gultepe, I. Heckman and J. Reid, 2014: Adaptive Blending of Model and Observations for Automated Short Range Forecasting: Examples from the Vancouver 2010 Olympic and Paralympic Winter Games. Pure Appl. Geophys. 171, 257–276, (DOI 10.1007/s00024-012-0553-x).**
- **Huang, Laura X, George A. Isaac, and Grant Sheng, 2014: A New Integrated Weighted Model in SNOW-V10: Verification of Continuous Variables. Pure Appl. Geophys. 171, 277–287, (DOI 10.1007/s00024-012-0548-7).**
- **Huang, Laura X, George A. Isaac, and Grant Sheng, 2014: A New Integrated Weighted Model in SNOW-V10: Verification of Categorical Variables. Pure Appl. Geophys. 171, 289–302, (DOI 10.1007/s00024-012-0549-6).**
- **Huang, L.X., G. A. Isaac, and G. Sheng, 2012: Integrating NWP Forecasts and Observation Data to Improve Nowcasting Accuracy. Weather and Forecasting, 27, 938-953.**
- **Isaac, G. A., M, Bailey, F. S. Boudala, W. R. Burrows, S. G. Cober, R. W. Crawford, N. Donaldson, I. Gultepe, B. Hansen, I. Heckman, L. X Huang, A. Ling, J. Mailhot, J. A. Milbrandt, J. Reid, and M. Fournier, 2014: The Canadian airport nowcasting system (CAN-Now).** ***Meteorol. Appl.*** **21, 30–49, (DOI: 10.1002/met.1342).**

# SNOW-V10

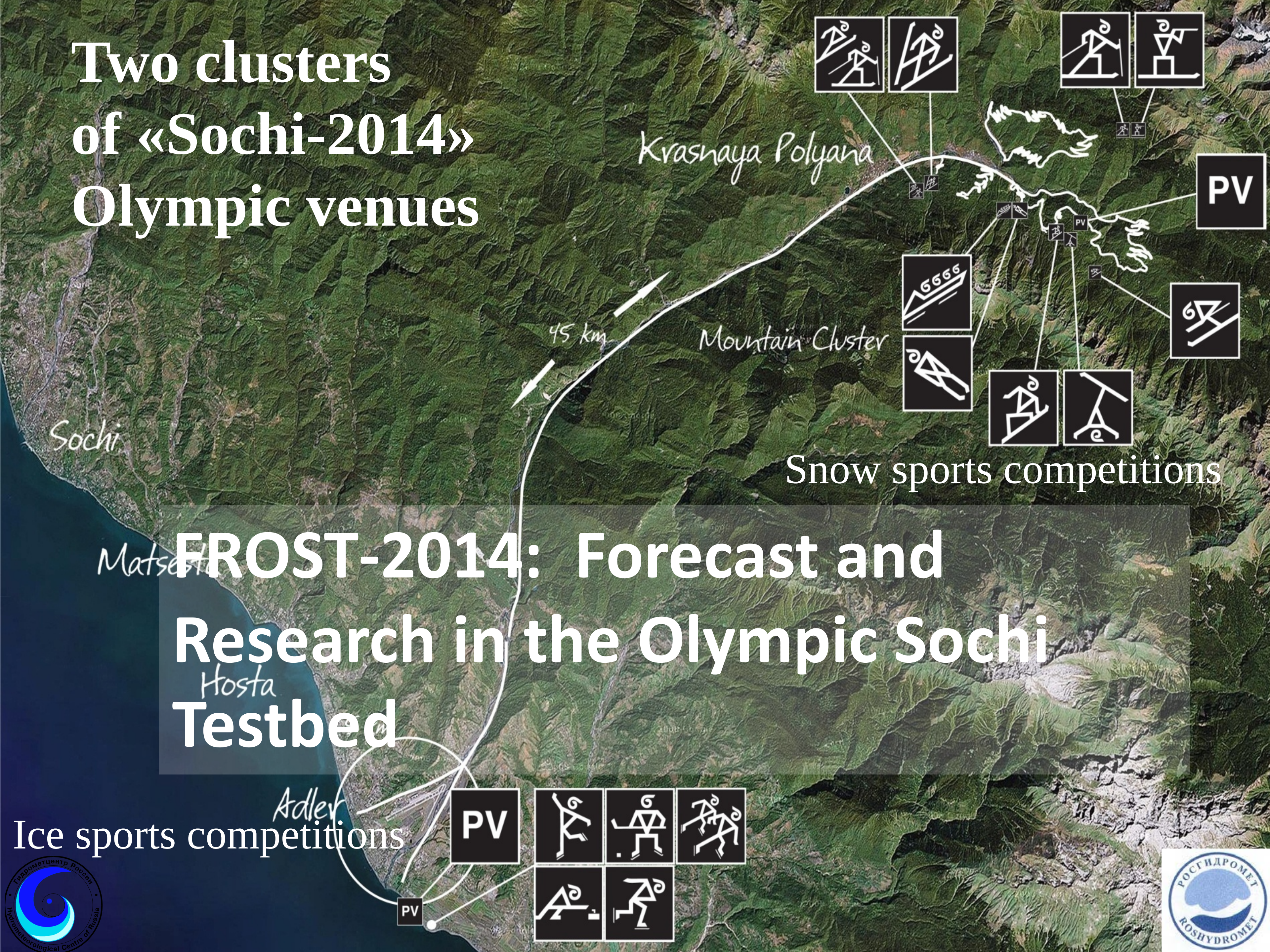
## Science of Nowcasting Olympic Weather for Vancouver 2010
## A World Weather Research Programme approved project

Prévision Immédiate du Temps aux Olympiques de Vancouver 2010

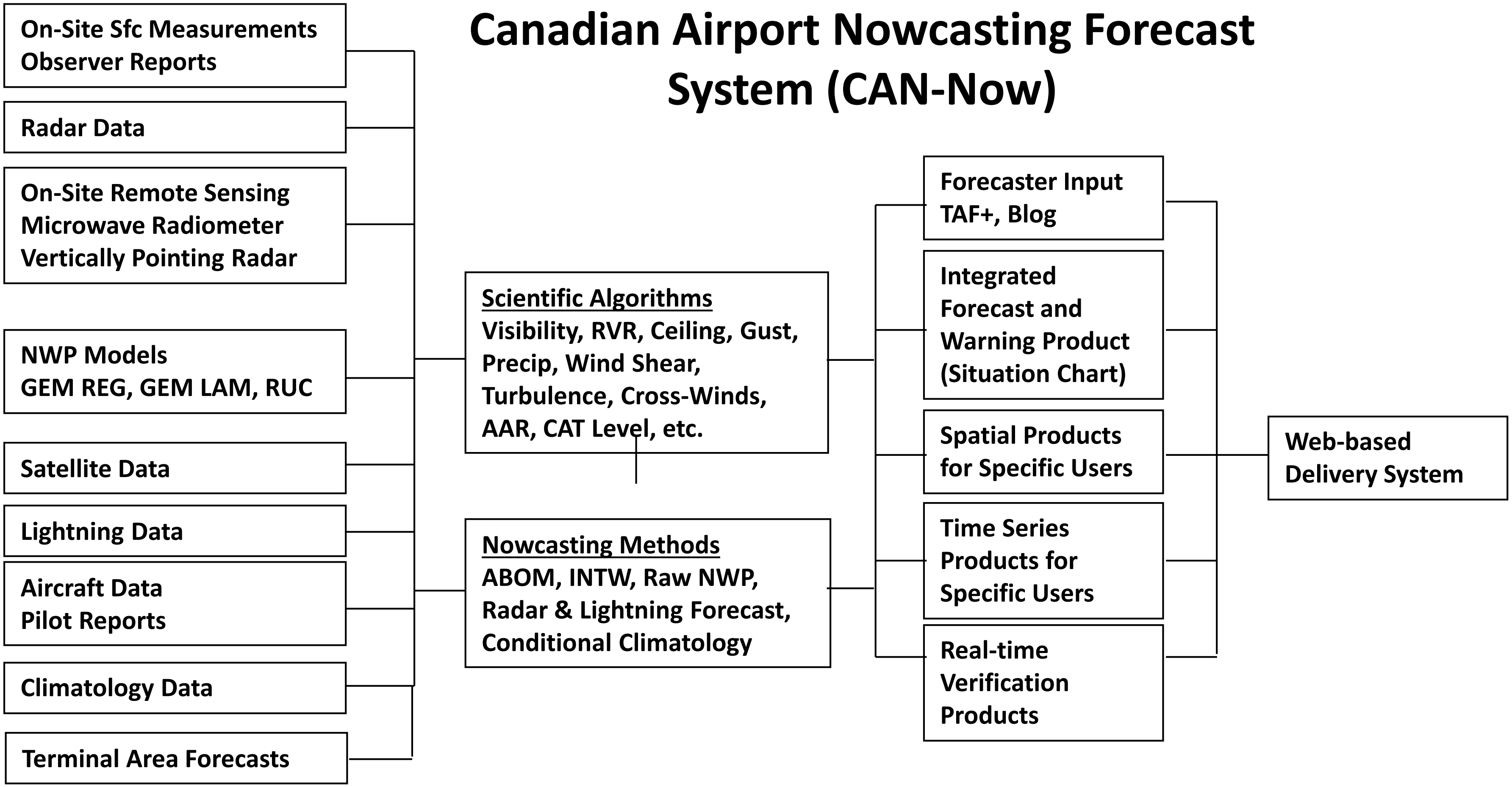
Science of Nowcasting Olympic Weather for Vancouver 2010

- **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.**

**Isaac, G.A., P. Joe, J. Mailhot, M. Bailey, S. Bélair, F.S. Boudala, M. Brugman, E. Campos, R.L.Carpenter Jr., R.W.Crawford, S.G. Cober, B. Denis, C. Doyle, H.D. Reeves, I.Gultepe, T. Haiden, I. Heckman, L.X. Huang, J.A. Milbrandt, R. Mo, R.M. Rasmussen, T. Smith, R.E. Stewart, D. Wang and L.J. Wilson, 2014: Science of Nowcasting Olympic Weather for Vancouver 2010 (SNOW-10): A World Weather Research Programme project. Pure Appl. Geophys. 171, 1–24, (DOI: 10.1007/s00024-012-0579-0).**


Two clusters
of «Sochi-2014»
Olympic venues
Krasnaya Polyana
PV
45 km
Mountain Cluster
Sochi
Snow sports competitions
Matsesta
FROST-2014: Forecast and
Research in the Olympic Sochi
Testbed
Hosta
Adler
Ice sports competitions
PV
PV
РОСГИДРОМЕТ
ROSHYDROMET

# Canadian Airport Nowcasting Forecast System (CAN-Now)




Isaac, G. A., M, Bailey, F. S. Boudala, W. R. Burrows, S. G. Cober, R. W. Crawford, N. Donaldson, I. Gultepe, B. Hansen, I. Heckman, L. X Huang, A. Ling, J. Mailhot, J. A. Milbrandt, J. Reid, and M. Fournier, 2014: The Canadian airport nowcasting system (CAN-Now). Meteorol. Appl. 21, 30–49, (DOI: 10.1002/met.1342).

# Canadian Airport Nowcasting



# Situation Chart for CYYZ

TAF Plus    SIMCOE  WATERLOO  LINNG  MANS    Rwy: ☑ 05/23 ☑ 06/24RL ☑ 15/33RL

| Thresholds | CYYZ METEOROLOGICAL NOWCAST : VALID AT 2011-02-02 10:00 UTC [INTW, GEM_REG_MOLTS, GEM_LAM_MOLTS, RUC, OBS, M300] | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10:00 | 10:10 | 10:20 | 10:30 | 10:40 | 10:50 | 11:00 | 11:10 | 11:20 | 11:30 | 11:40 | 11:50 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 |
| | OBS | +10m | +20m | +30m | +40m | +50m | +1h | +1:10h | +1:20h | +1:30h | +1:40h | +1:50h | +2h | +3h | +4h | +5h | +6h |
| 05/23 WINDS | 050 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 040 17G23 | 030 17G24 | 040 16G24 | 040 14G22 | 040 12G23 |
| 06/24RL WINDS | 050 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 040 17G23 | 030 17G24 | 040 16G24 | 040 14G22 | 040 12G23 |
| 15/33RL WINDS | 050 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 030 17G23 | 040 17G23 | 030 17G24 | 040 16G24 | 040 14G22 | 040 12G23 |
| VISIBILITY | 3/4SM | 1 5/8SM | 1 5/8SM | 1 5/8SM | 1 5/8SM | 1 5/8SM | 1 5/8SM | 1 3/4SM | 1 3/4SM | 1 3/4SM | 1 7/8SM | 1 7/8SM | 1 7/8SM | 2 1/4SM | 2 3/4SM | 3SM | P6SM |
| CEILING | 007 | 009 | 009 | 009 | 009 | 009 | 009 | 008 | 008 | 008 | 007 | 007 | 007 | 009 | 012 | 009 | 009 |
| SHEAR/TURB | | | | | | | | | | | | | | | | | |
| PRECIP | T | T | T | T | 0004 | 0008 | 0007 | 0007 | 0007 | 0006 | 0006 | 0008 | 0020 | 0004 | 0002 | T | 0003 |
| TSTM & LTNG | | | | | | | | | | | | | | | | | |
| ICING | | | | | | 068 | 050 | 043 | 043 | 036 | 036 | 030 | 030 | 043 | 036 | 030 | 036 |

| Thresholds | CYYZ OPERATIONS NOWCAST : VALID AT 2011-02-02 10:00 UTC [INTW, GEM_REG_MOLTS, GEM_LAM_MOLTS, RUC, OBS, M300] | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10:00 | 10:10 | 10:20 | 10:30 | 10:40 | 10:50 | 11:00 | 11:10 | 11:20 | 11:30 | 11:40 | 11:50 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 |
| | OBS | +10m | +20m | +30m | +40m | +50m | +1h | +1:10h | +1:20h | +1:30h | +1:40h | +1:50h | +2h | +3h | +4h | +5h | +6h |
| WX-ONLY AAR | | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 | 62 |
| CAT LEVEL | I | I | I | I | I | I | I | I | I | I | I | I | I | I | I | I | I |
| 05/23 COND | | | | | | | | | | | | | | | | | |
| 06/24RL COND | | | | | | | | | | | | | | | | | |
| 15/33RL COND | | | | | | | | | | | | | | | | | |

# Introduction cont.

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

| | Apron and taxiway | Takeoff | Initial climb | Climb | Cruise | Descent | Initial approach | Final approach | Landing |
|---|---|---|---|---|---|---|---|---|---|
| Accidents | 12% | 19 % | | 36 % | | | | 33 % | |
| Fatalities | 0% | 29 % | | 49 % | | | | 22 % | |
| Time in phase* | >1% | 2 % | | 94 % | | | | 4 % | |

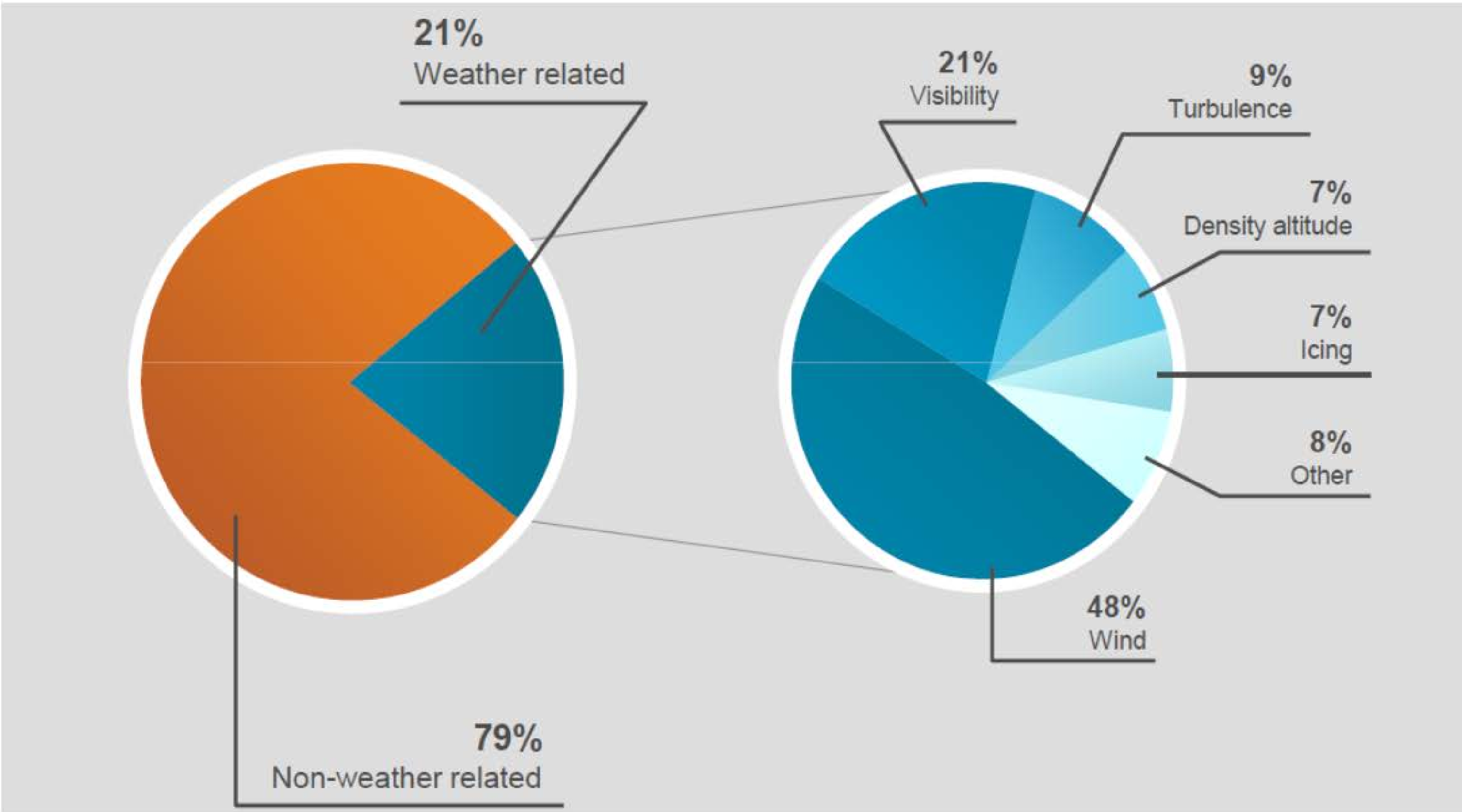
During **6%** of flight time occurs:

- **52%** of accidents
- **51 %** of fatalities

* Estimate for 1,5 hour flight

Source: Boeing

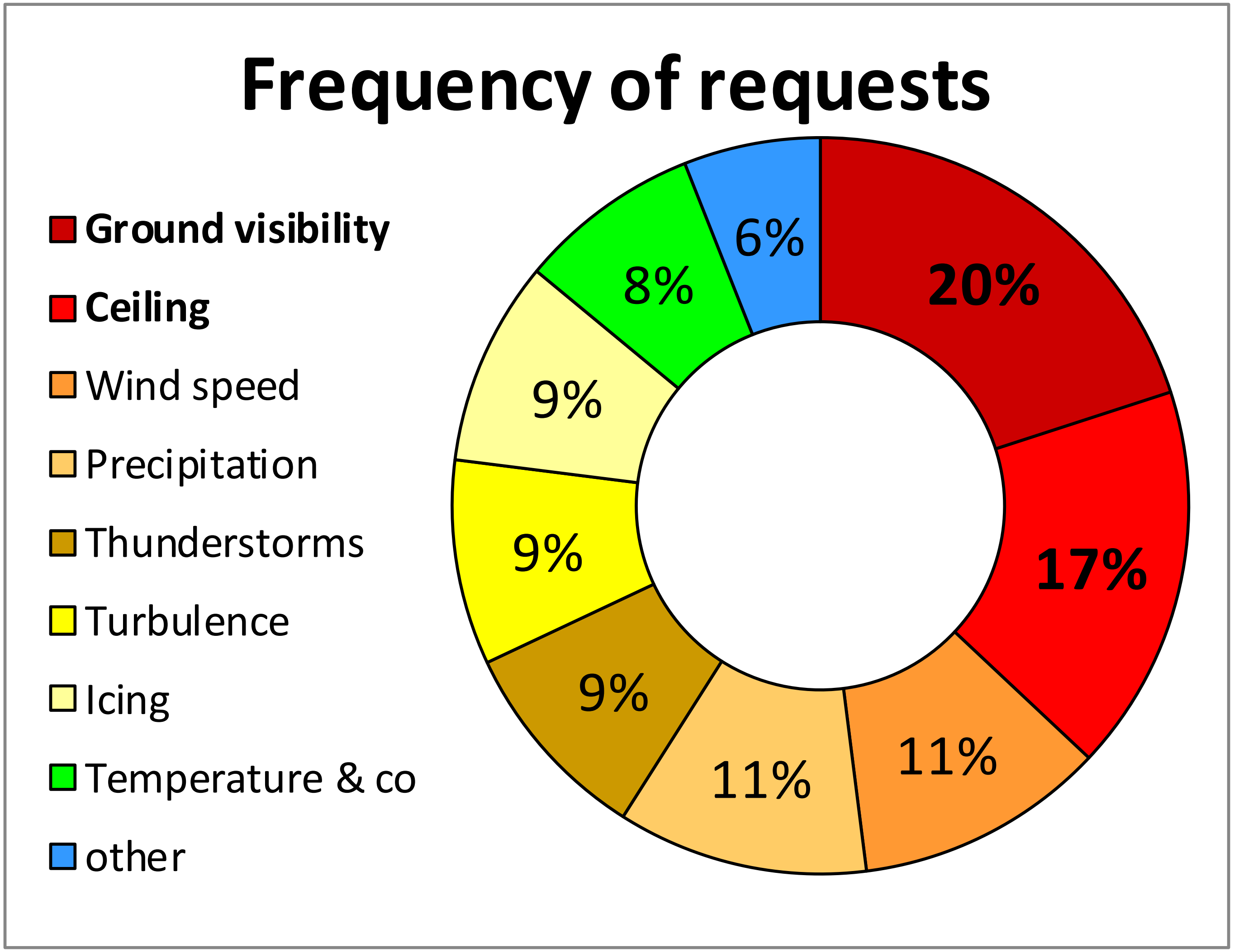
# Weather Related Accidents




Source: NASDAC / FAA

# DND Requests for Information

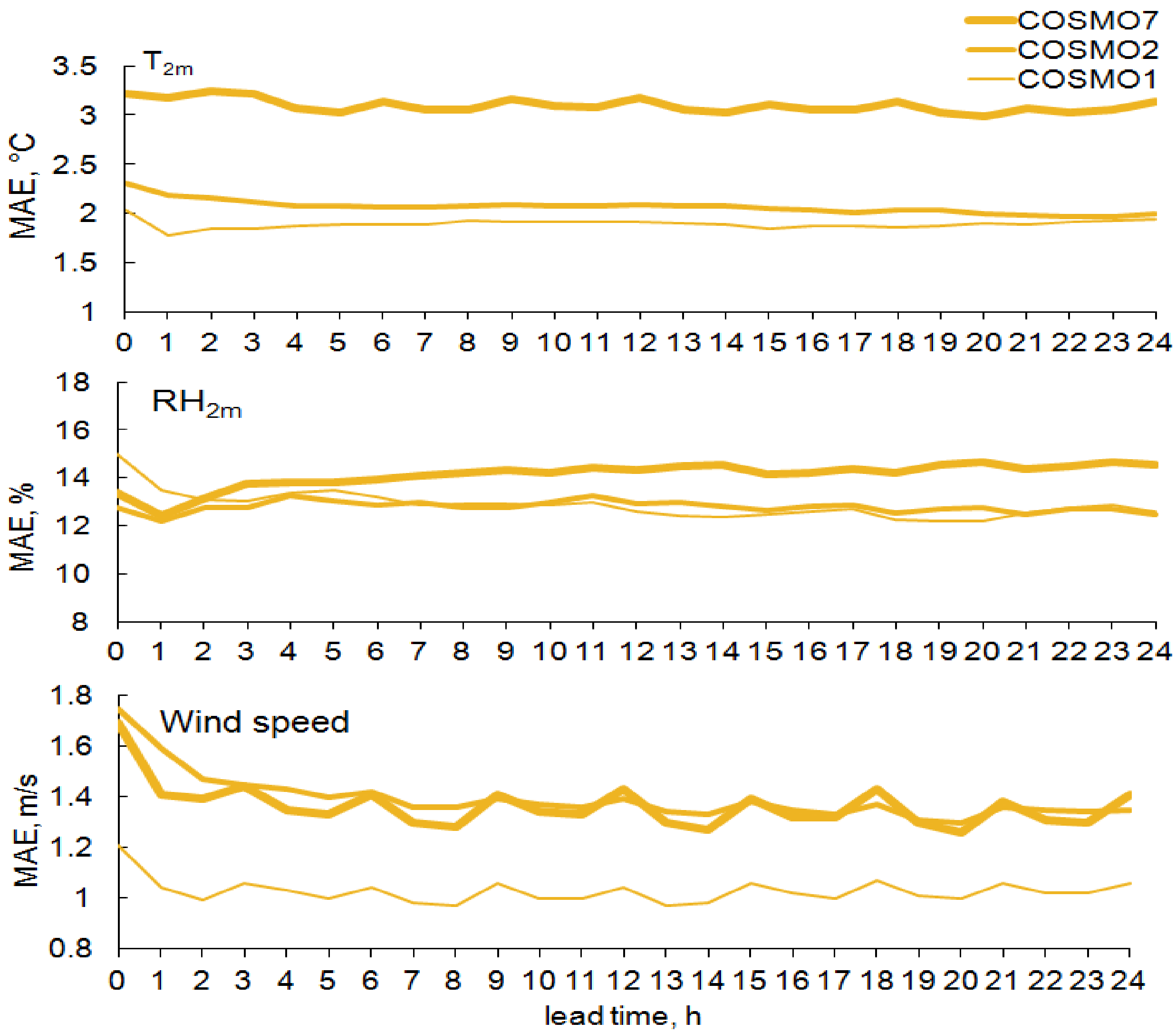
(From Marie-France Turcotte as presented at CMOS Annual Congress 2016)



# Variables for Airport System

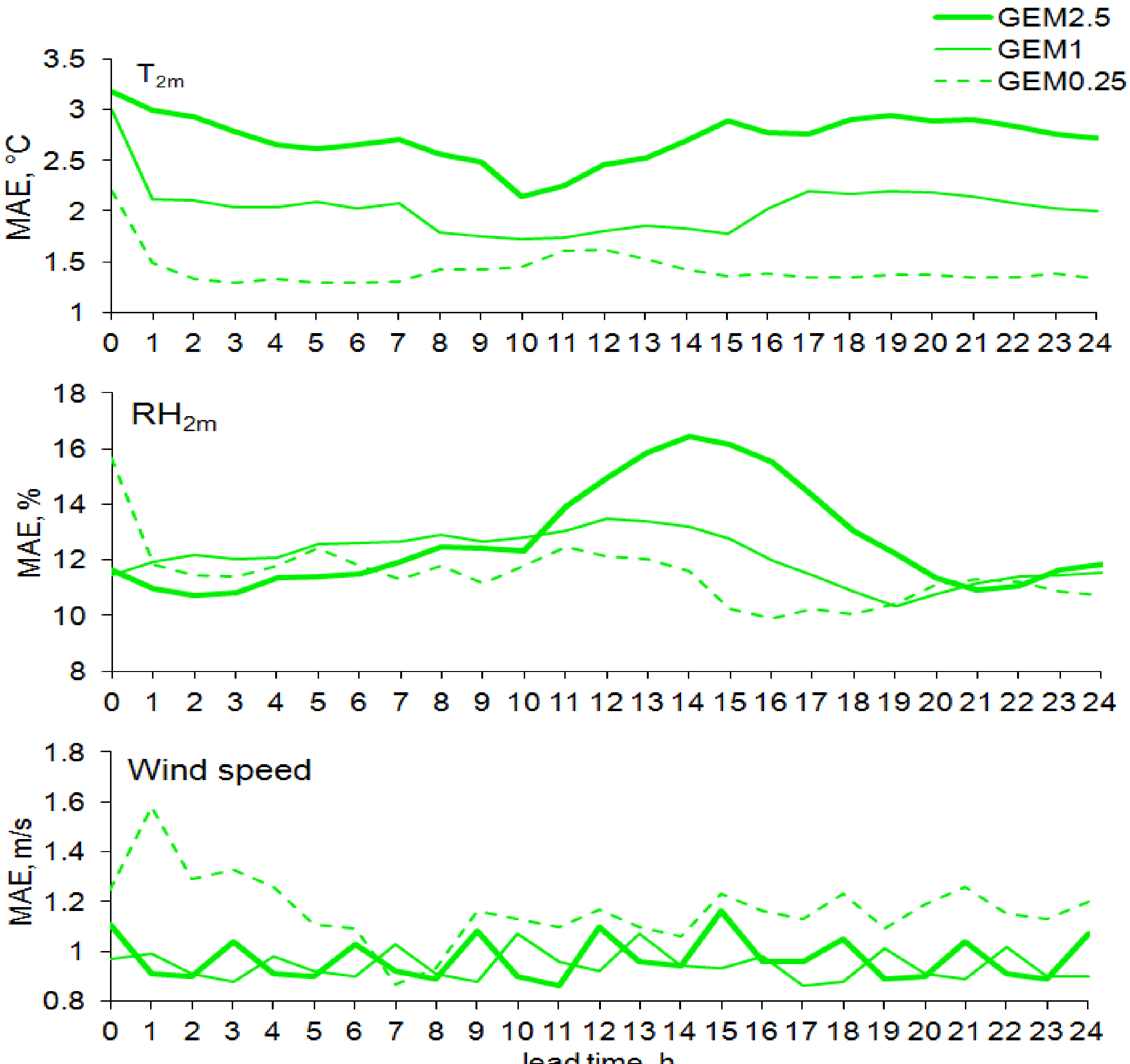
- **Snow and rain events**
- **Freezing precipitation and ice pellets**
- **Frost**
- **Blowing snow**
- **Icing aloft**
- **High winds/gusts**
- **Wind shifts/shear**
- **Turbulence**
- **Lightning**
- **Low ceilings**
- **Low visibility and fog**
- **Convective cells**

# 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)

$$\hat{V}_{k+p} = o_k + s_p\left(\hat{o}_{k+p} - o_k\right) + r_p\left(m_{k+p} - m_k\right)$$

Forecast at lead time p

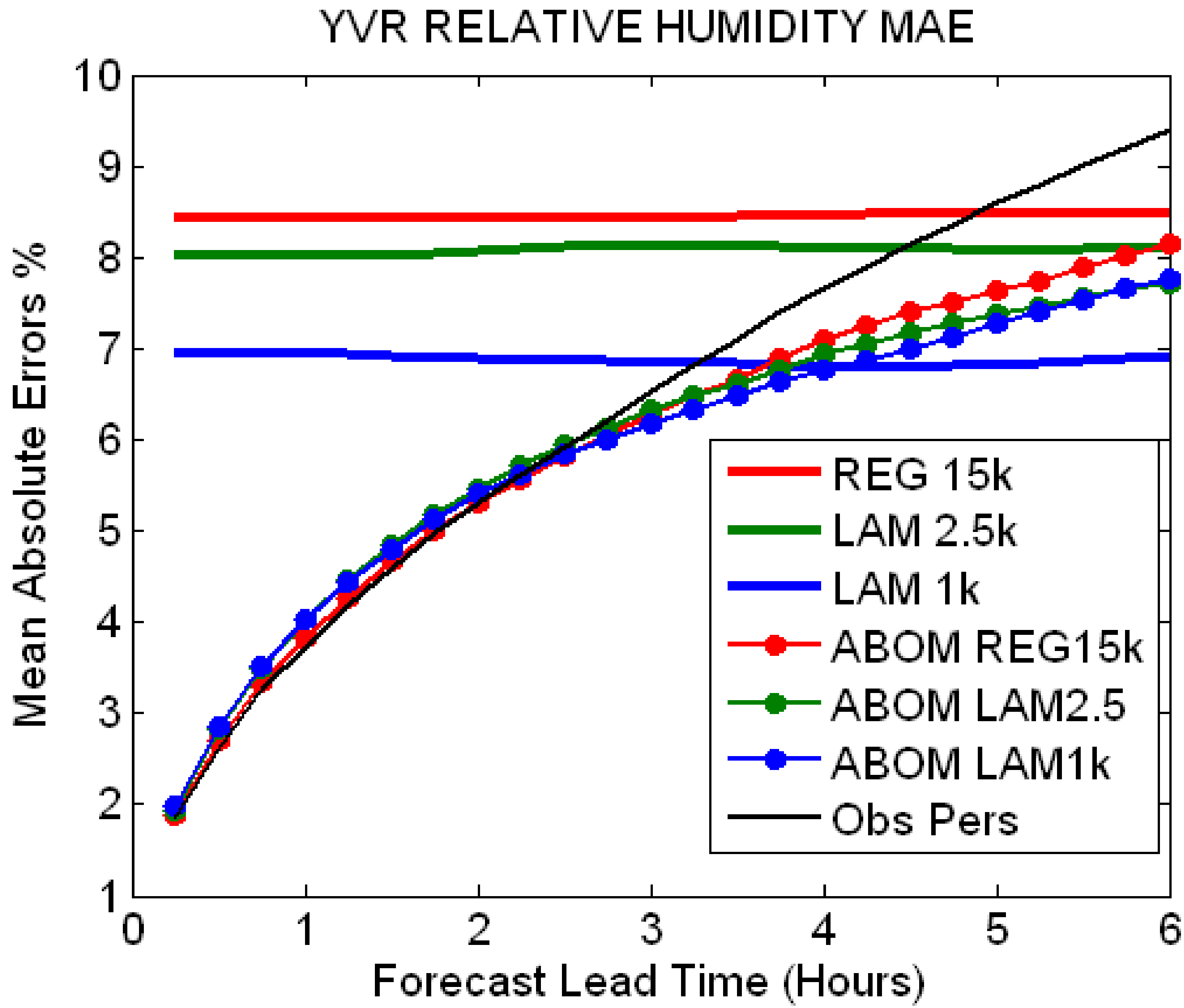
Current Observation

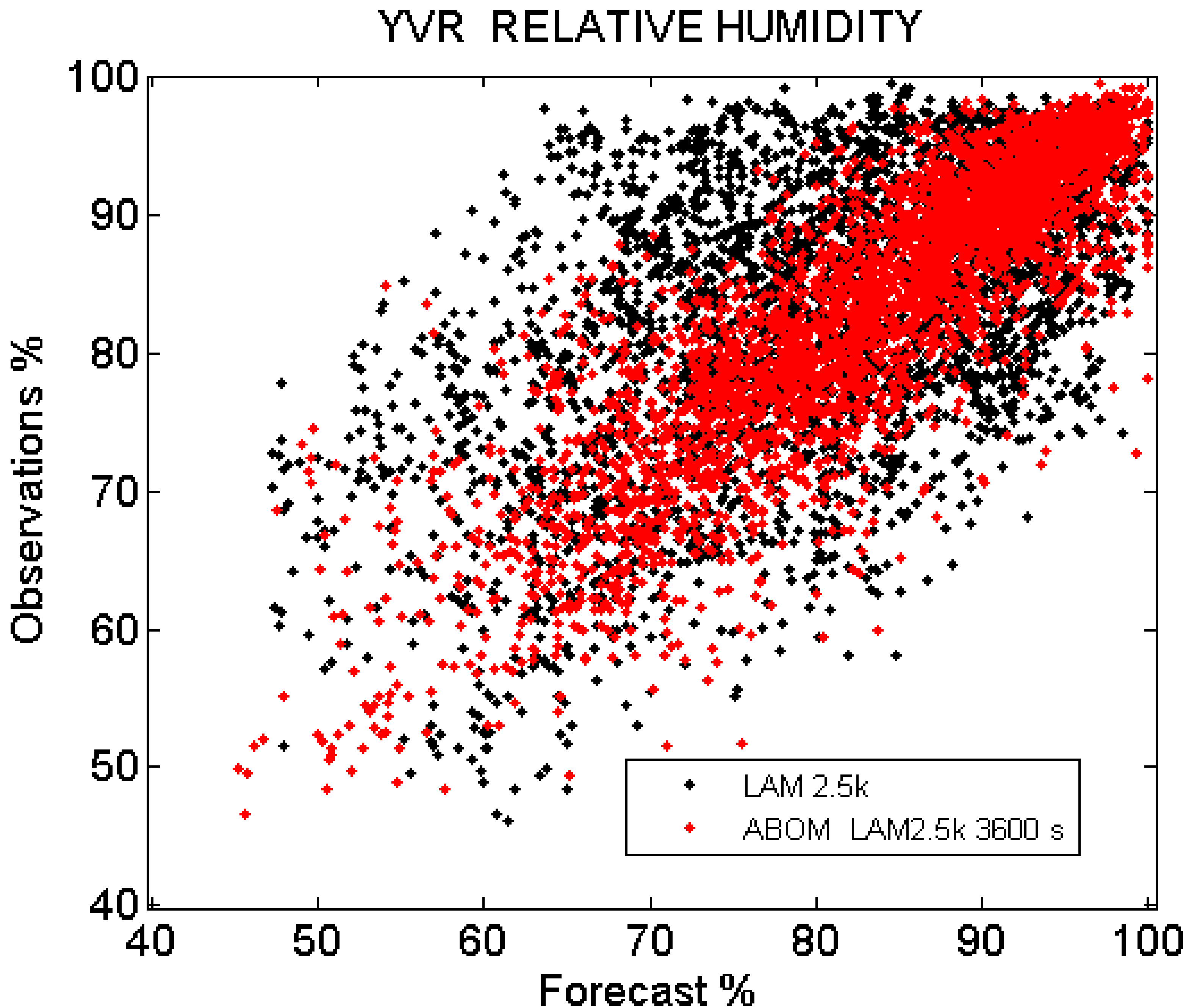
Change predicted by obs trend

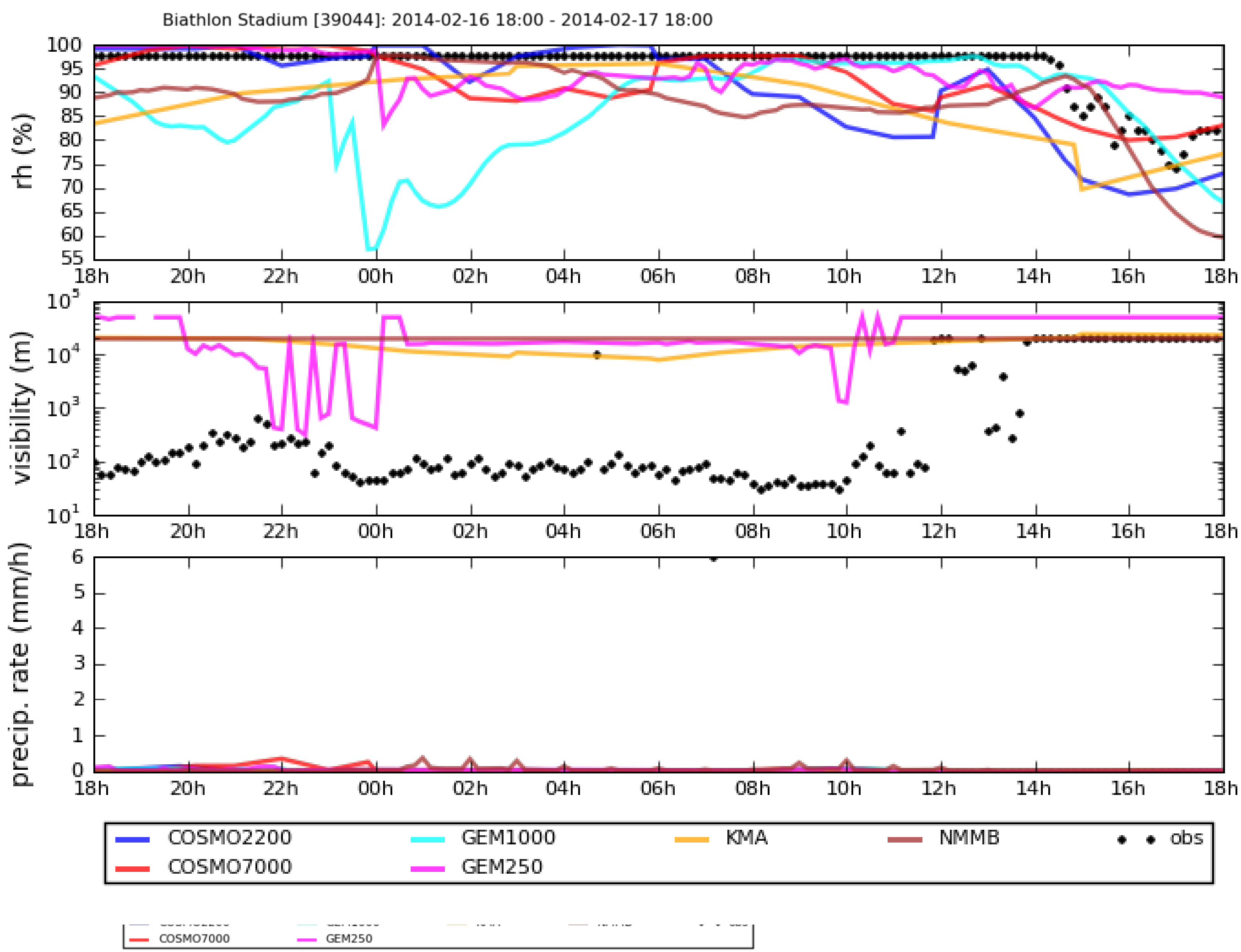
Change predicted by model

- 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

**Bailey, M.E., G.A. Isaac, I. Gultepe, I. Heckman and J. Reid, 2014: Adaptive Blending of Model and Observations for Automated Short Range Forecasting: Examples from the Vancouver 2010 Olympic and Paralympic Winter Games. Pure Appl. Geophys. 171, 257–276, (DOI 10.1007/s00024-012-0553-x).**


YVR RELATIVE HUMIDITY MAE
Mean Absolute Errors %
Forecast Lead Time (Hours)
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
REG 15k
LAM 2.5k
LAM 1k
ABOM REG15k
ABOM LAM2.5
ABOM LAM1k
Obs Pers


YVR RELATIVE HUMIDITY
Observations %
Forecast %
100
90
80
70
60
50
40
40
50
60
70
80
90
100
LAM 2.5k
ABOM LAM2.5k 3600 s


Biathlon Stadium [39044]: 2014-02-16 18:00 - 2014-02-17 18:00
rh (%)
visibility (m)
precip. rate (mm/h)
18h
20h
22h
00h
02h
04h
06h
08h
10h
12h
14h
16h
18h
COSMO2200
COSMO7000
GEM1000
GEM250
KMA
NMMB
obs

$$V_k = \frac{-\ln(\varepsilon)}{\beta} \qquad \beta = \frac{3LWC}{\rho_w D_{eff}} \qquad LWC = \rho_w N \frac{\pi}{6} D_{eff}{}^3$$

**Remembering that extinction coefficient (β) 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, β.*

*Korolev, A.V., G.A. Isaac, I.P Mazin and H. Barker, 2001: Microphysical properties of continental clouds from in-situ measurements. Quart. J. Roy. Meteorol. Soc., 127, 2117-2151.*

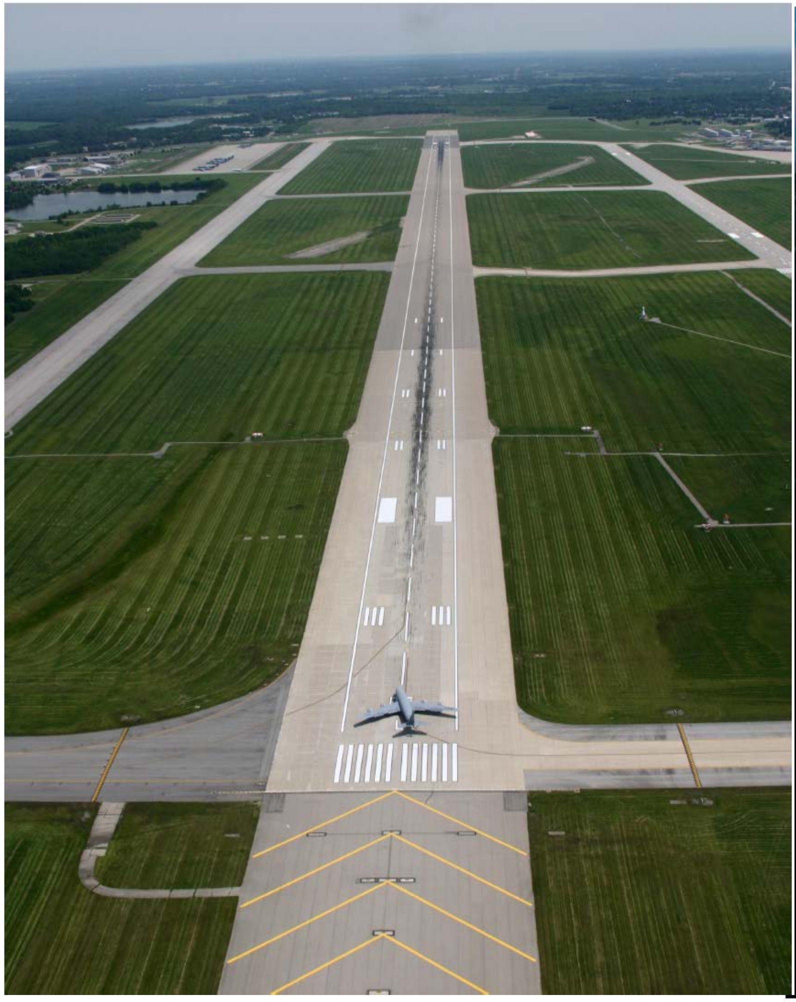
# Relationship between $V_a$ & $V_k$

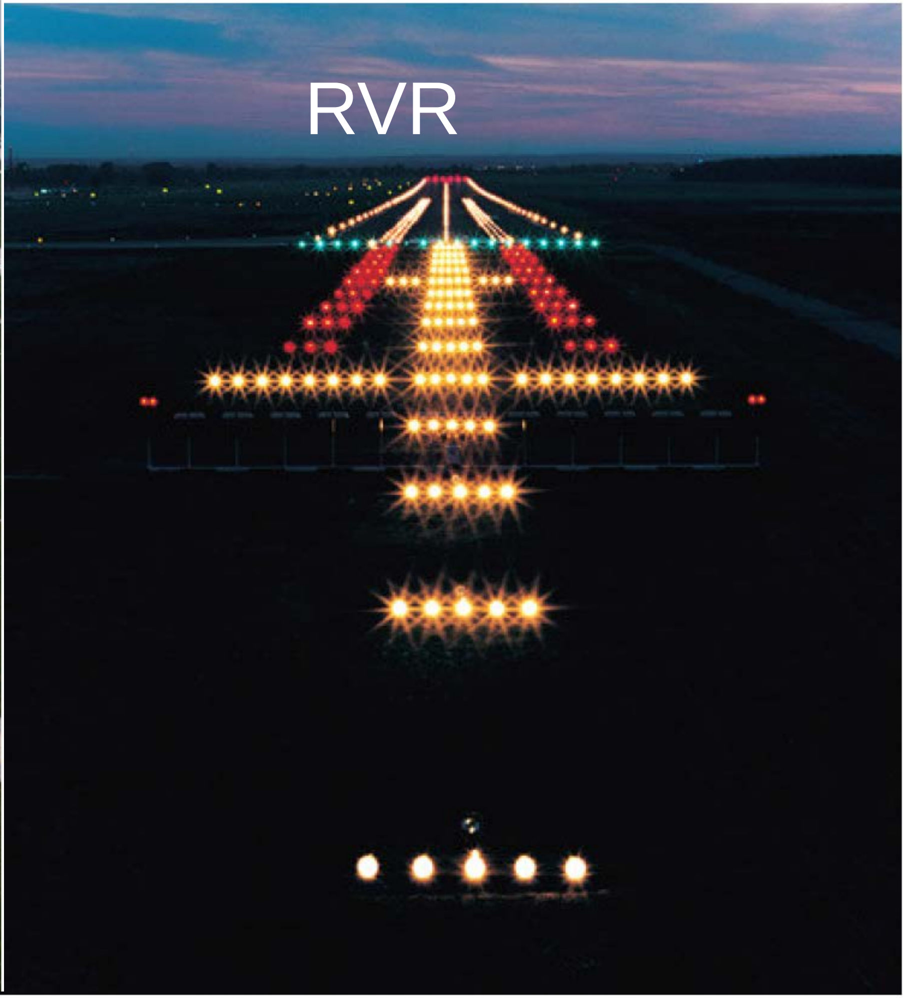
$$V_k = \frac{V_a \ln(\varepsilon)}{\ln\left(\frac{V_a^{\,2} E_T}{I}\right)} \qquad RVR = \max(V_k, V_a)$$

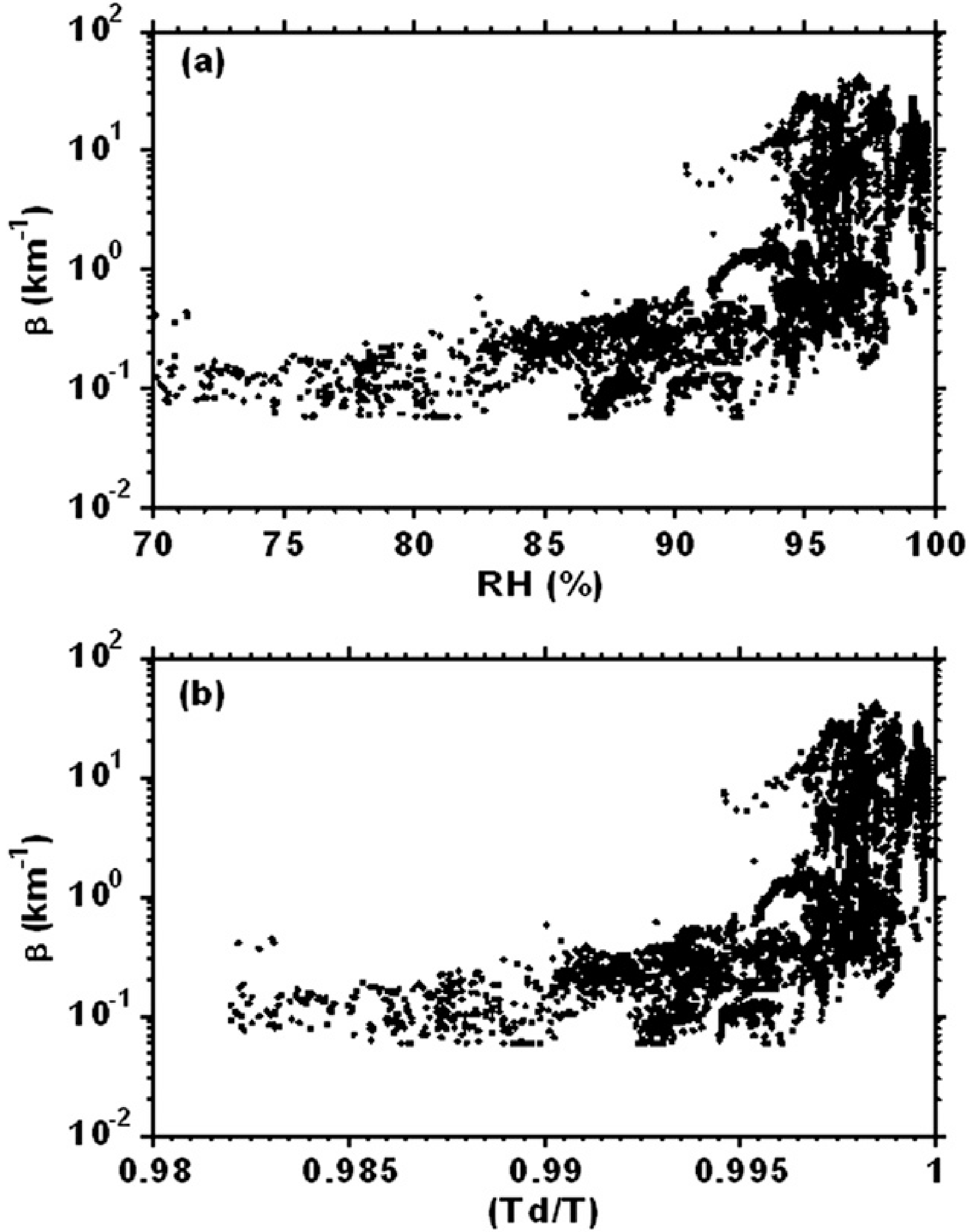
**Non-linear, but can be solved numerically for given I, $E_T$, and ε. We found a way to forecast or predict the Runway Visual Range (RVR) using this equation.**

**Boudala, F.S., G.A. Isaac, R. Crawford, and J. Reid, 2012: Parameterization of runway visual range as a function of visibility: Implications for numerical weather prediction models. J. Amos. Oceanic Tech., 29, 177-191.**

# Example of Nighttime/daytime visibility








**Suggestion for a fog diagnostic scheme to be used with an NWP model**

**From Boudala et al., 2012**

$$\beta_f = \begin{bmatrix} \exp(-5.605 + 0.0114\mathrm{RH}\phi), & r = 0.83 \\ \exp(-14.188 + 0.159\mathrm{RH}), & r = 0.75 \end{bmatrix}, \tag{8a}$$

where $\phi$ is defined as

$$\phi = \ln\left[\mathrm{abs}\left(\frac{1}{\ln\left(\min\left(\frac{T_d}{T}, 0.9998\right)\right)}\right)\right], \tag{8b}$$

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

**$B_s$ 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.**

$$\ln(\beta_s) = 0.71 - 0.0288T + 0.783 \ln(S + 0.04), \qquad (7)$$

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

**Boudala, F.S., G.A. Isaac, R. Crawford, and J. Reid, 2012: Parameterization of runway visual range as a function of visibility: Implications for numerical weather prediction models. J. Amos. Oceanic Tech., 29, 177-191.**

**Gultepe I, Milbrandt JA. 2010: Probabilistic parameterizations of visibility using observations of rain precipitation rate, relative humidity, and visibility. *J. Appl. Meteorol. Climatol.* 49, 36–46.**

**Stoelinga M.T*, *Warner T.T*.*, 1999*:* Nonhydrostatic, mesobeta-scale model simulations of cloud ceiling and visibility for an East Coast winter precipitation event*.* *J. Appl. Meteorol.* 38*:* 385–404*.***

**Wilkinson, J. M., A. N. F. Porson, F. J. Bornemann, M. Weeks, P. R. Field and A. P. Lock, 2013: Improved microhysical parameterization of drizzle and fog for operational forecasting using the Met Office Unified Model. Q. J. R. Meteorol. Soc., 139, 488-500.**

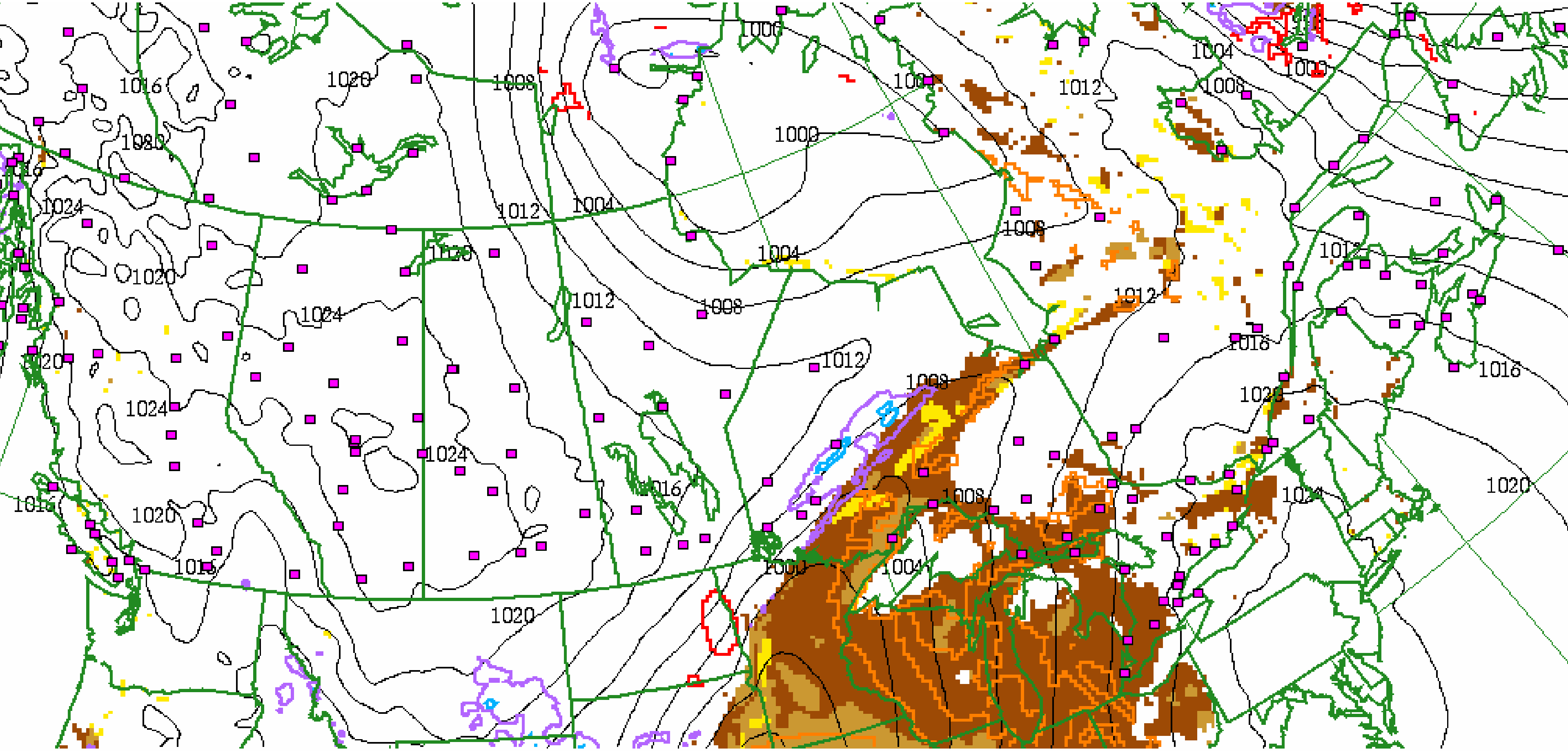
**For all liquid clouds, most use a relationship between RH and visibility or a diagnostic prediction method. The UK Met office predicts LWC and droplet concentration directly, which should be an improvement.**

# Forecasting by Rule Based Technique

**Burrows, W.R., and G. Toth, 2011: Automated fog and stratus forecasts from the Canadian RDPS Operational NWP Model. 24th Conference on Weather analysis and Forecasting, 23-27 January 2011, Seattle Washington, USA.**

- *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.*

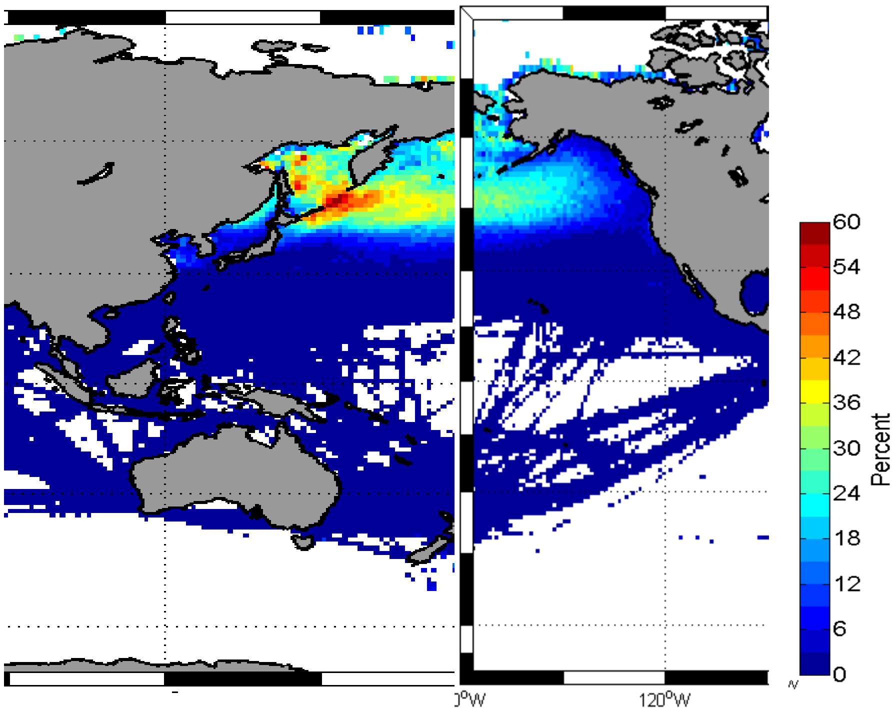
# Rule Based Fog Forecast for 30 Dec 2010 (From Burrows and Toth, 2011)




**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.**

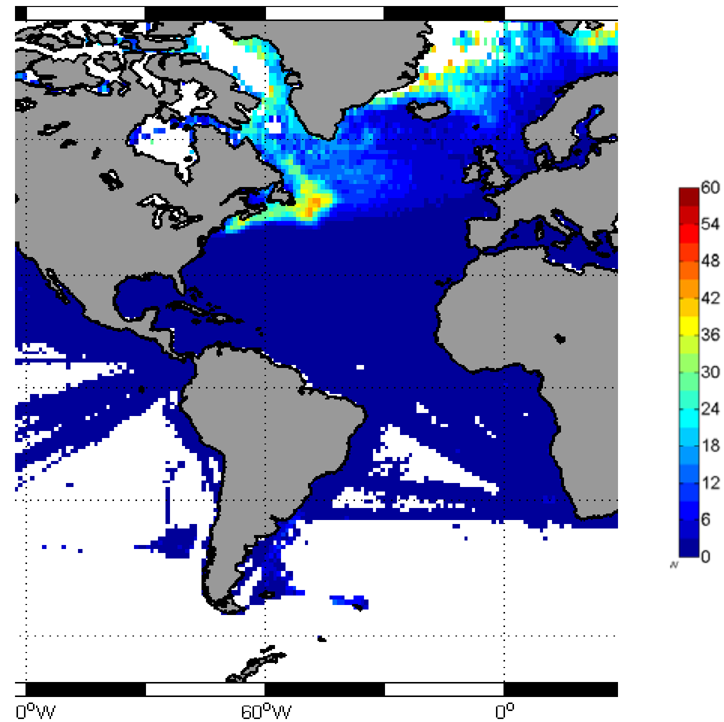
# NW Pacific

**% of Fog Occurrence, JJA, 1950-2007, ICOADS**

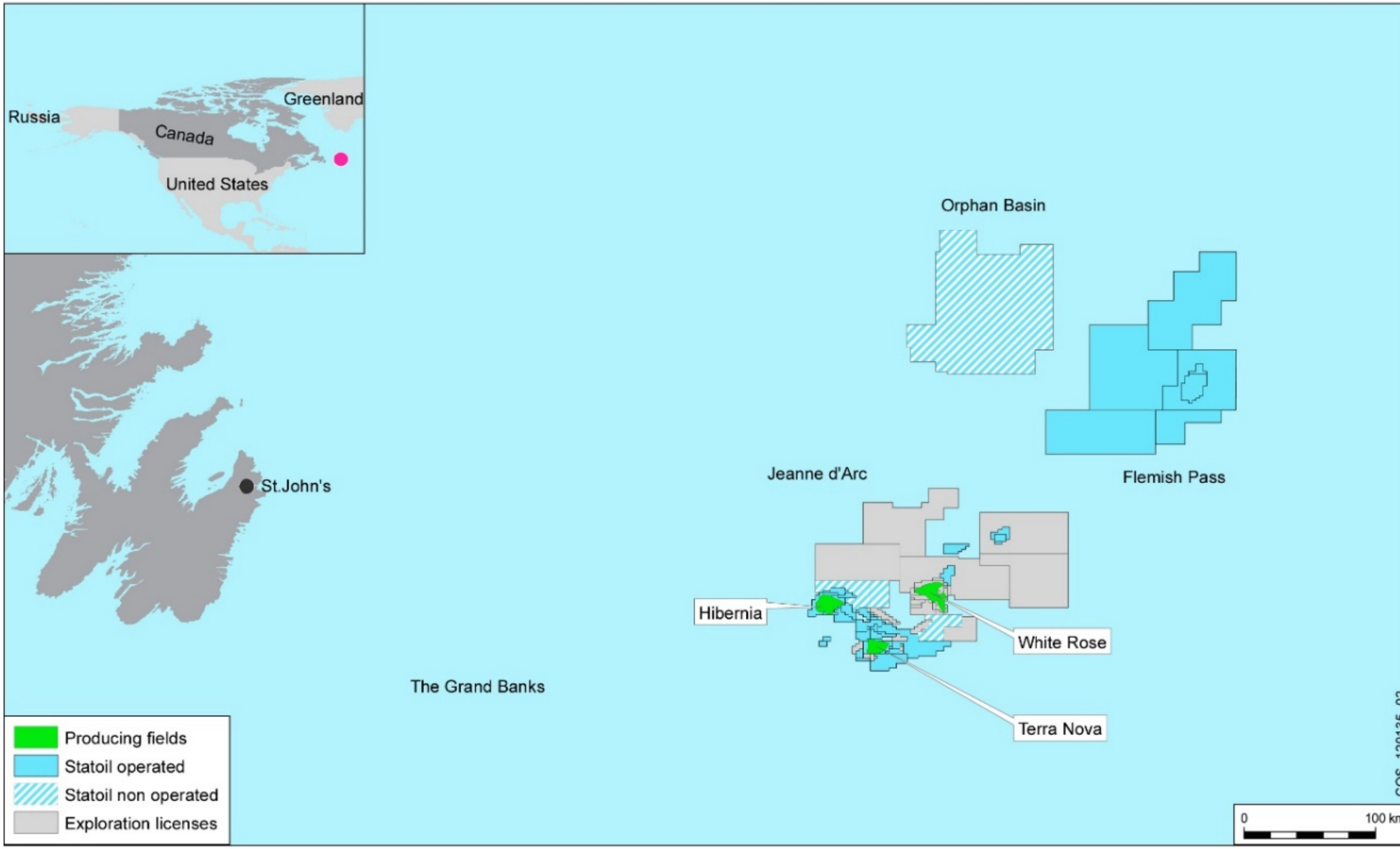



# NW Atlantic

**% of Fog Occurrence, JJA, 1950-2007, ICOADS**




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.

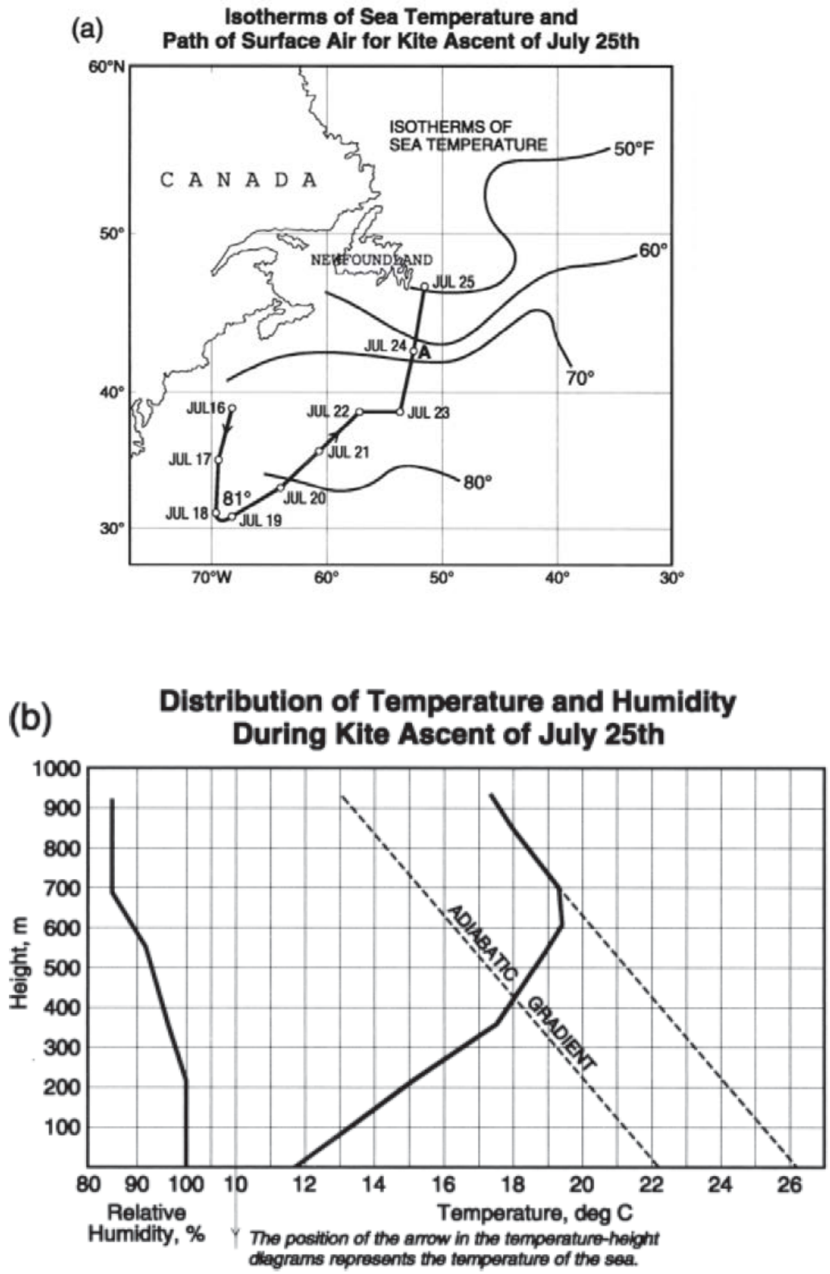



**Jeanne-D'Arc Basin is some 340 kilometers east-southeast of St. John's in 80 m to 100 m of water. This is the location of the Hibernia, White Rose and Terra Nova fields. Recent discoveries of hydrocarbons in the Flemish Pass, some 500 km east of St. John's, and in deeper water (e.g. some 1000 m), have led to increased exploration drilling in that area.**

# Helicopter Stats (Jan to Sept/14)

| Event | 2014 YTD | Comment |
|---|---|---|
| Total industry helicopter flights | 939 | Does not include missed approaches or flight turn arounds |
| Total industry passengers | 22279 | |
| Days all flights cancelled | 73 | |
| Total missed approaches | 91 | |
| | | |

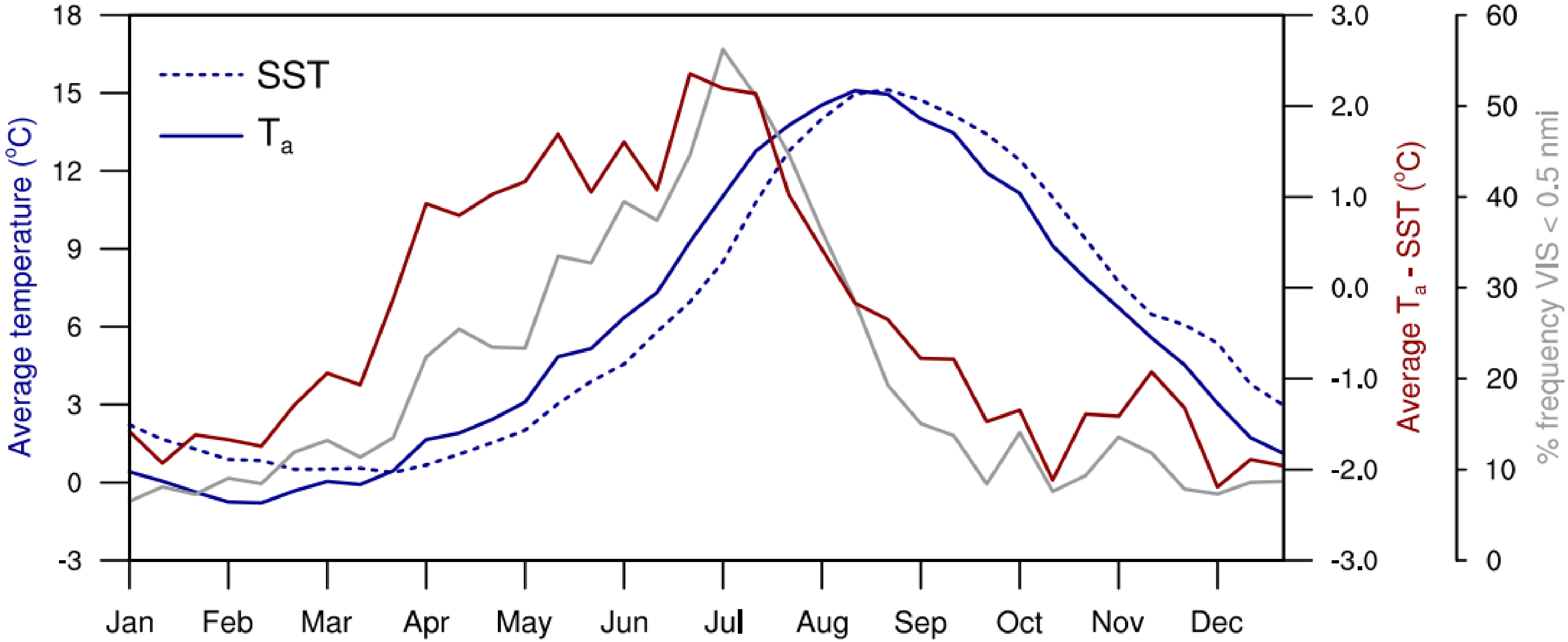
**Len Coughlan, 2014: Industry Perspective, Presentation at HMDC Workshop on Metocean Monitoring and Forecasting for the Newfoundland & Labrador Offshore, 22-24 September, St. John's, Newfoundland**





# Taylor (1917) identified the dominant process forming fog over the Grand Banks was due to warm moist air moving over cold waters (Advection Fog).

Taylor, G.I., 1917.The formation of fog and mist. Q. J. R.Meteorol.Soc.43,241–268

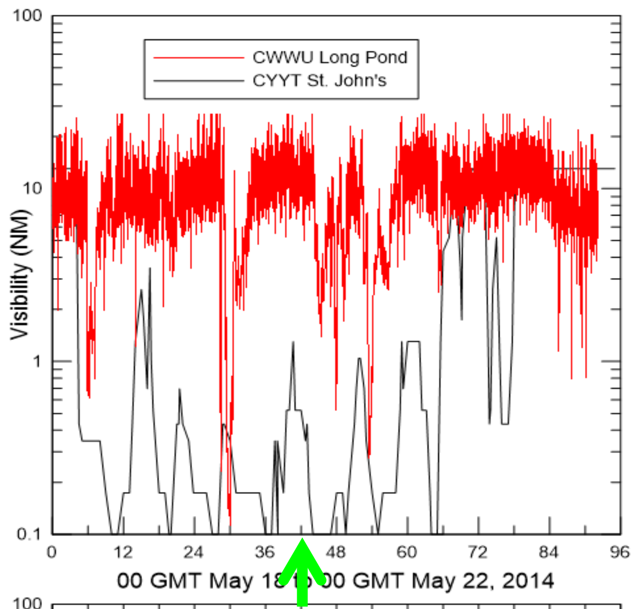


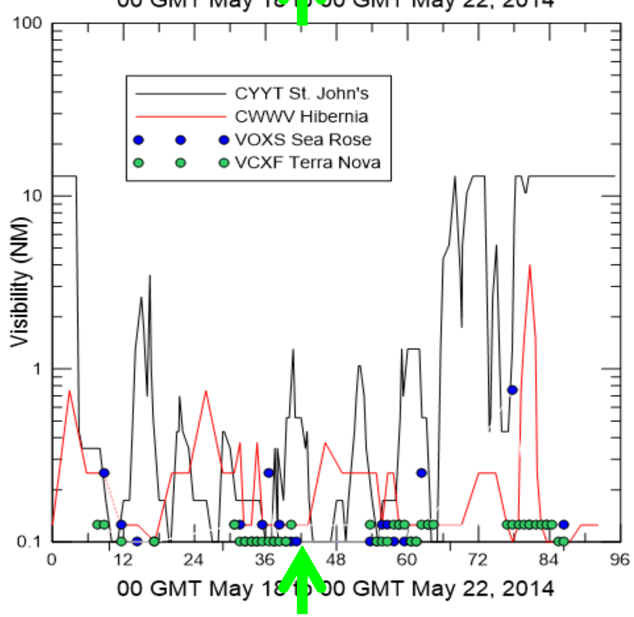

**Climatology of Fog at Hibernia Platform: (from Beale et al., 2016: CMOS Presentation. Work funded by Hibernia Management Development Company (HMDC) and managed by Amec Foster Wheeler.)**

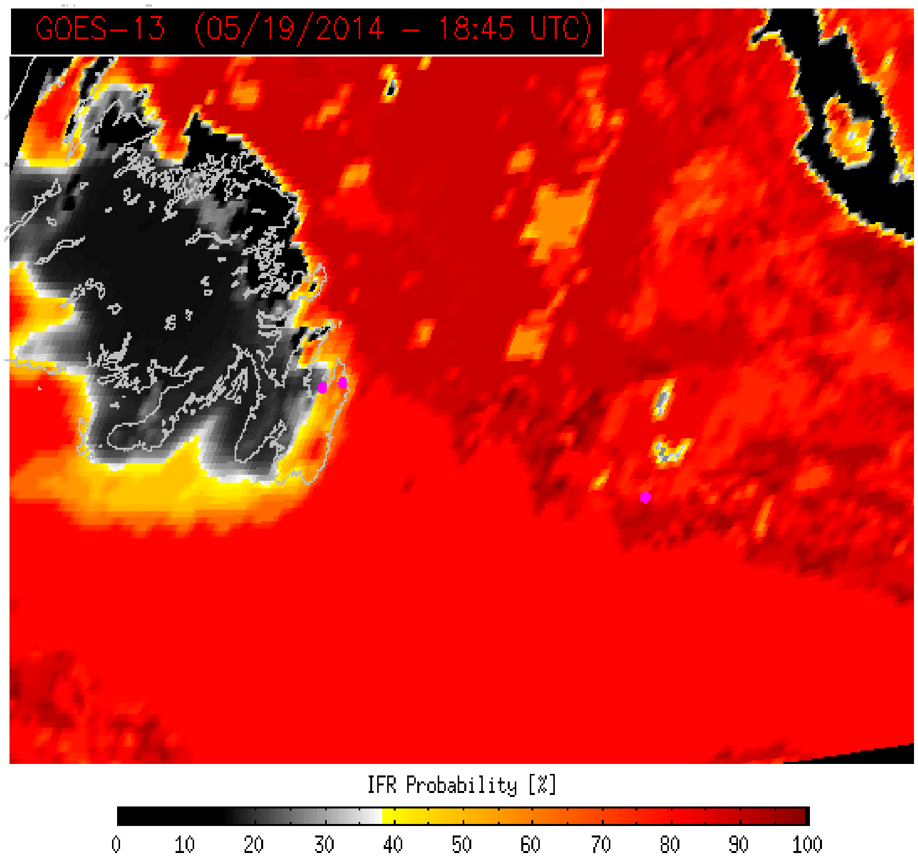
**Koračin et al. (2014) made the following statements:**

***"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."***

Koračin, Darko, Clive E. Dorman, John M. Lewis, James G. Hudson, Eric M. Wilcox, Alicia Torregrosa, 2014: Marine fog: a review. *Atmospheric Research*, *143*, *142-175.*




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 **t**o 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)**

**Huang, L.X., G. A. Isaac, and G. Sheng, 2012: Integrating NWP Forecasts and Observation Data to Improve Nowcasting Accuracy. Weather and Forecasting, 27, 938-953.**

# Time (h) for Model to Beat Persistence

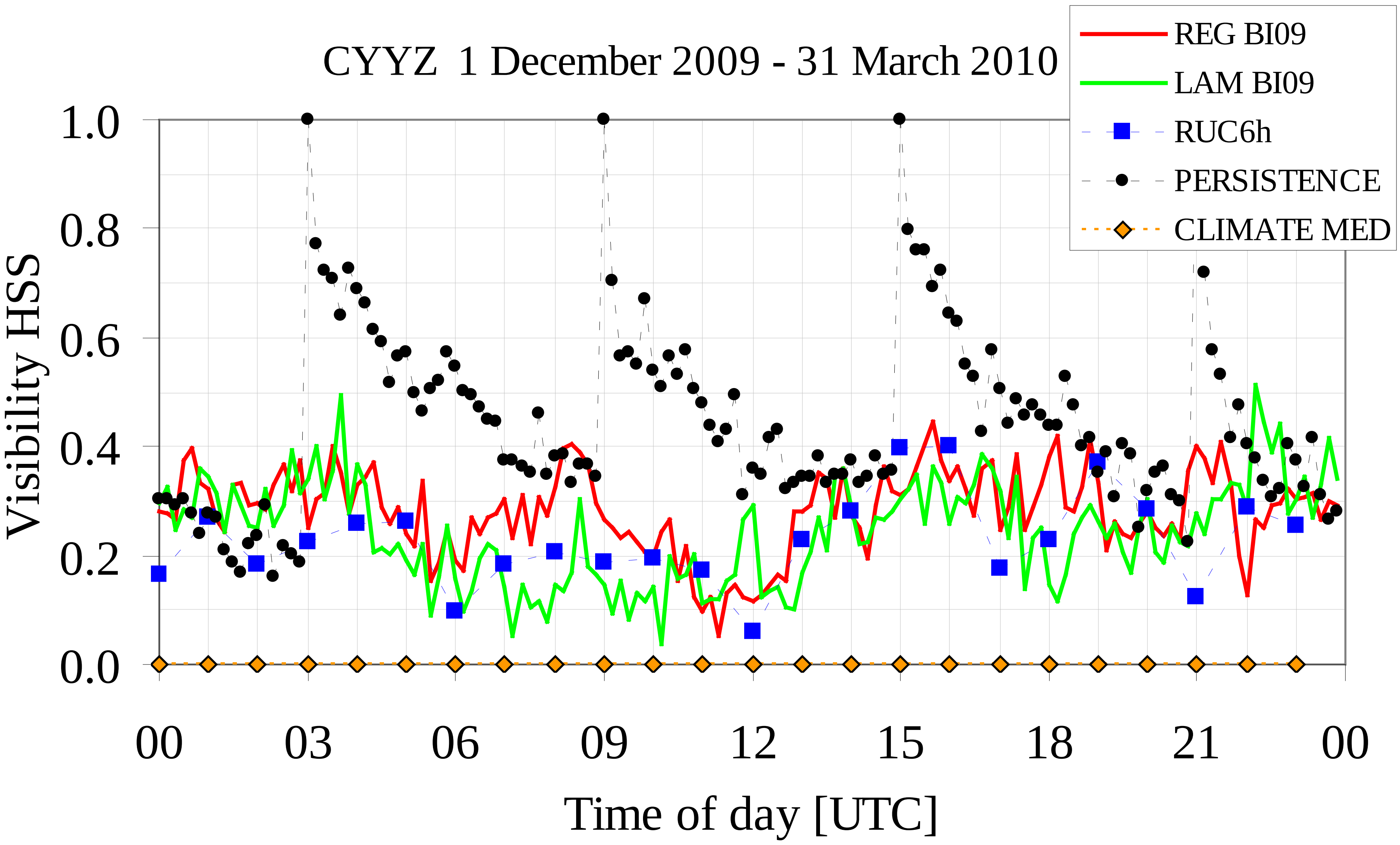
## Winter

| Variable | LAM | | REG | | RUC | | INTW | |
|---|---|---|---|---|---|---|---|---|
| | CYYZ | CYVR | CYYZ | CYVR | CYYZ | CYVR | CYYZ | CYVR |
| **TEMP** | **6** | **3** | **4** | **3.5** | **4.5** | **5** | **2.5** | **0.5** |
| **RH** | **6** | **6** | **no** | **6** | **no** | **no** | **3.5** | **3** |
| **WS** | **2.5** | **3.5** | **4.5** | **3.5** | **3** | **no** | **1** | **2.5** |
| **GUST** | **no** | **no** | **no** | **5** | **3.5** | **no** | **1.5** | **1.5** |

## Summer

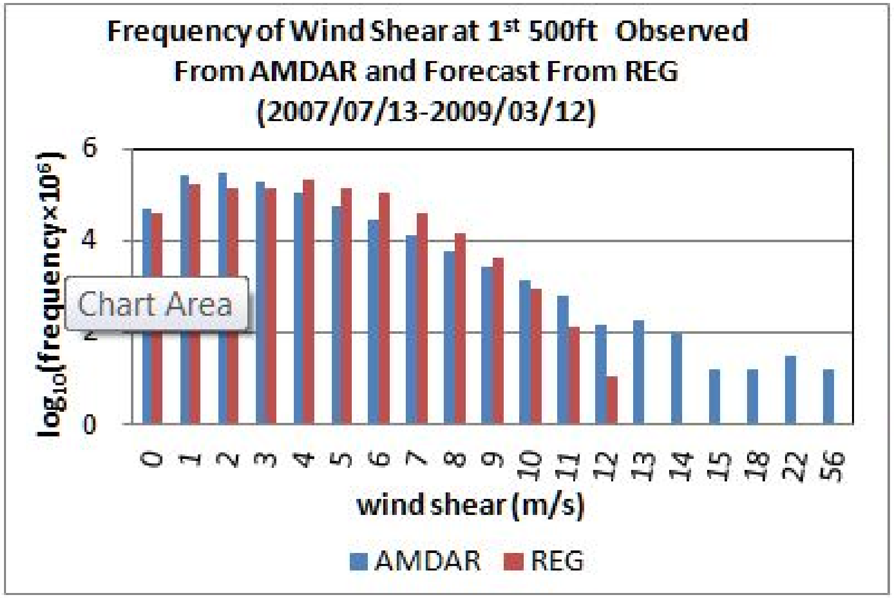
| Variable | LAM | | REG | | RUC | | INTW | |
|---|---|---|---|---|---|---|---|---|
| | CYYZ | CYVR | CYYZ | CYVR | CYYZ | CYVR | CYYZ | CYVR |
| **TEMP** | **2.5** | **2.5** | **2.2** | **2.5** | **1.5** | **no** | **0.5** | **0.5** |
| **RH** | **3** | **3** | **3.2** | **4.5** | **3** | **no** | **1** | **1** |
| **WS** | **3** | **5** | **3.5** | **5** | **2.2** | **no** | **1.5** | **2.5** |
| **GUST** | **no** | **no** | **5.5** | **no** | **2.2** | **no** | **0.5** | **4** |

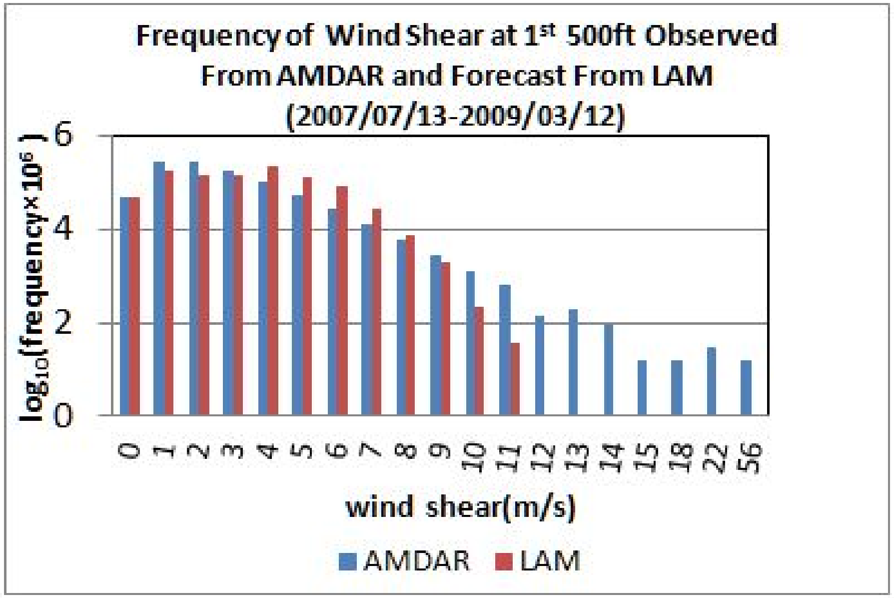
**Huang, L.X., G.A. Isaac and G. Sheng, 2012: Integrating NWP Forecasts and Observation Data to Improve Nowcasting Accuracy, . Weather and Forecasting, 27, 938-953.**

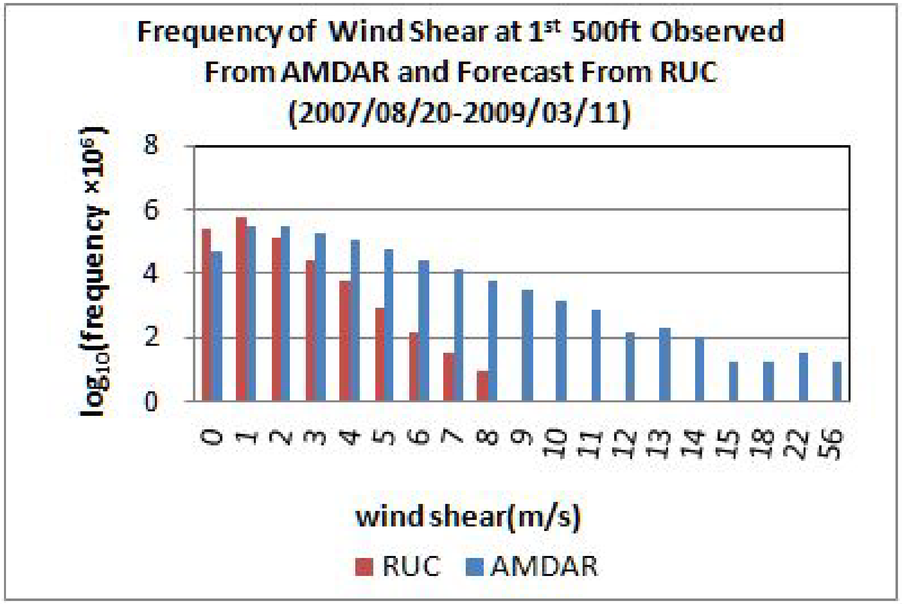


CYYZ 1 December 2009 - 31 March 2010
REG BI09
LAM BI09
RUC6h
PERSISTENCE
CLIMATE MED
Visibility HSS
1.0
0.8
0.6
0.4
0.2
0.0
00
03
06
09
12
15
18
21
00
Time of day [UTC]

# Wind Shear (Emily Zhou, MSc Thesis York U.)



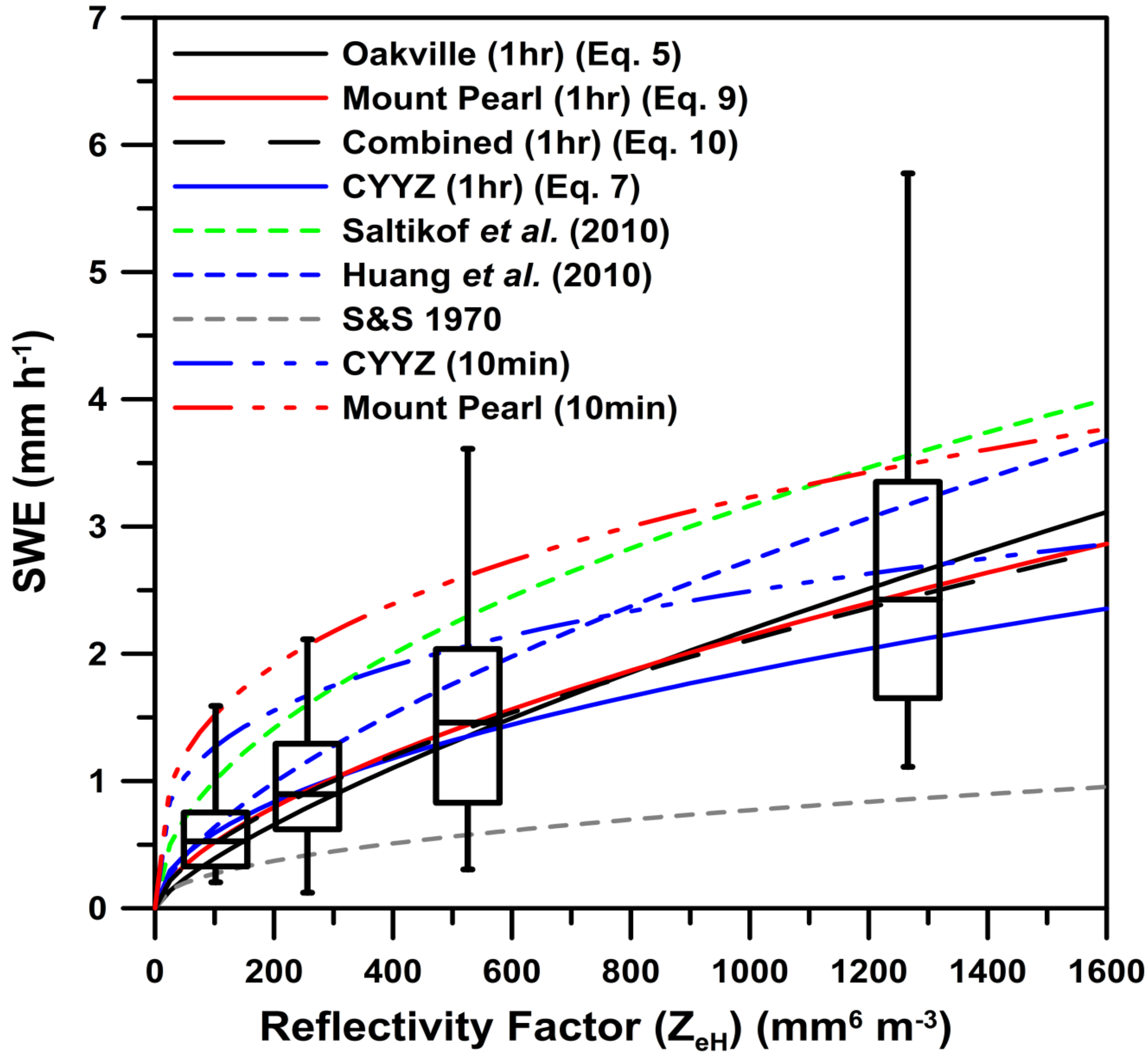



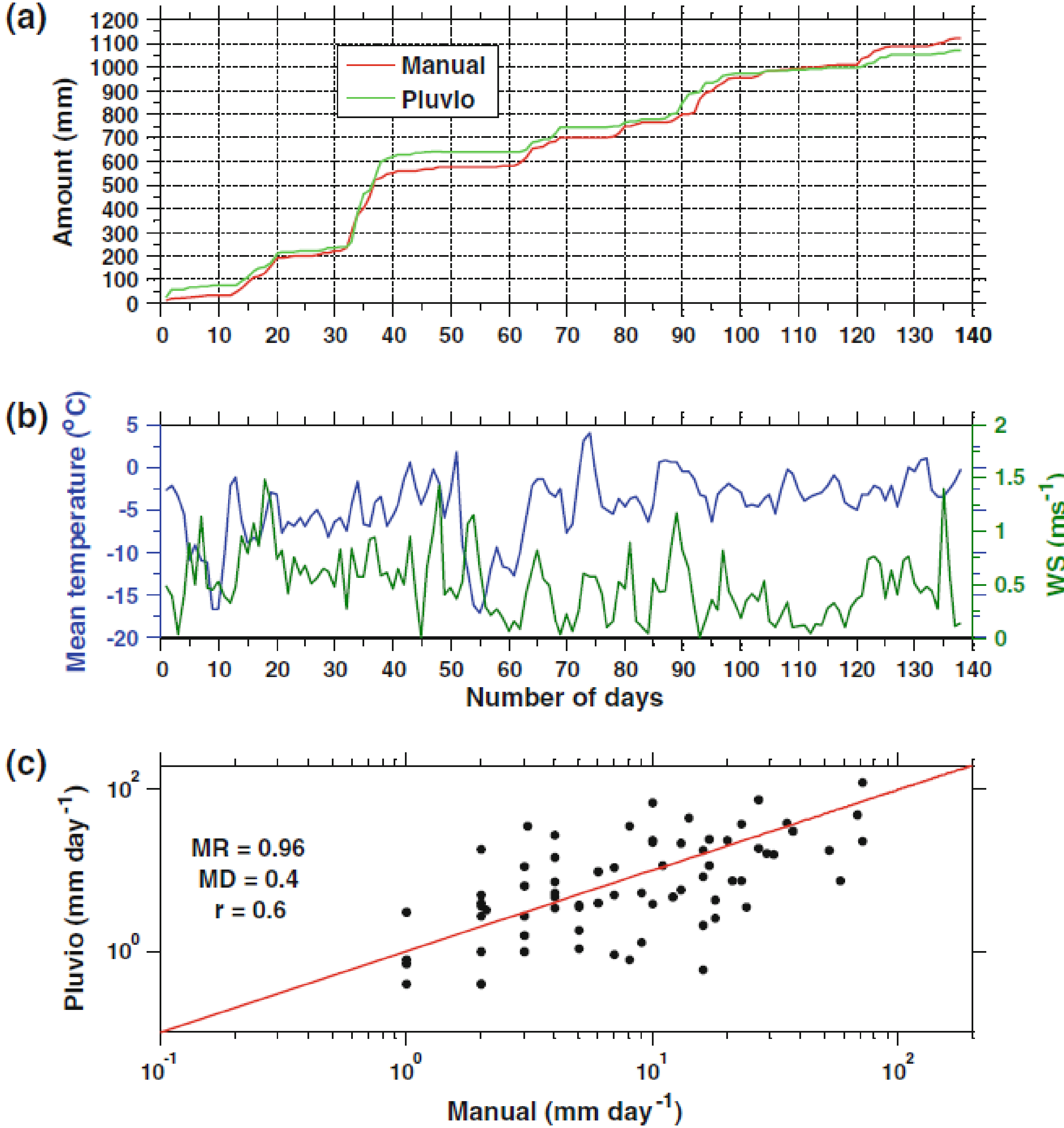

From AMDAR, wind shear cases occur more often in autumn and winter, and during local morning. 70% of wind shear cases are present at 1st 500ft. REG, LAM and RUC are not capable of forecasting low level wind shear directly for Pearson Airport.

Wind Shear Threshold at 500 ft is 25 kts or 12.9 m/s.

VOE
WWB
VOZ
VOG
99
2 km
1
WWA
394
Sea-to-S
Marine Dr




From Hassan, D., P.A. Taylor, and G.A. Isaac, 2016: Snowfall Rate Estimation Using C-Band Polarimetric Radars. Accepted to Meteorological Applications

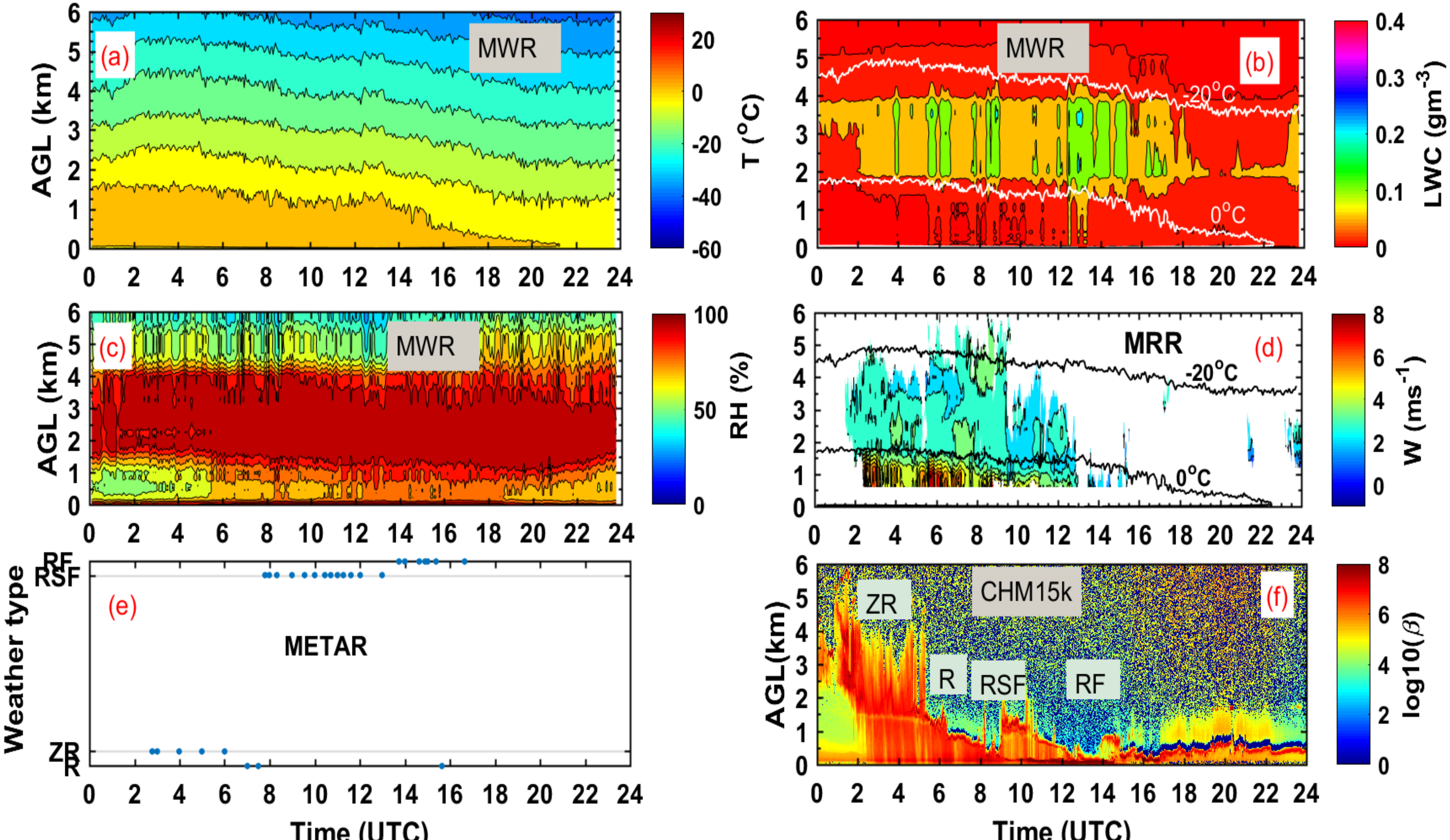



Boudala, F. S., G. A. Isaac, R. Rasmussen, S. G. Cober, and B. Scott (2014), Comparisons of Snowfall Measurements in Complex Terrain Made During the 2010 Winter Olympics in Vancouver. Pure Appl. Geophys. 171, 113–127, (DOI 10.1007/s00024-012-0610-5).

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.