HONG KONG OBSERVATORY

Technical Note No. 105

VERIFICATION OF WEATHER FORECASTS FOR THE AERODROME OF THE HONG KONG INTERNATIONAL AIRPORT

by

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ABSTRACT

This note describes the objective verification system developed by the Hong Kong Observatory for the verification of aerodrome forecasts issued for the Hong Kong International Airport. The accuracy criteria and the verification scheme adopted by the system are discussed. The performance statistics based on data collected since the opening of airport in July 1998 up to the end of 2002 are also presented.

摘要

本報告描述由香港天文台發展，用以驗證提供予香港國際機場使用的機場預報的一套客觀驗證系統。本報告對該系統所採用的準確性準則及驗證計劃作出討論，並刊出自 1998 年 7 月機場啟用以來直至 2002 年底所得的驗證數據。

1. INTRODUCTION

Within the framework of the International Civil Aviation Organization (ICAO), the Hong Kong Observatory (HKO) is the designated meteorological authority in Hong Kong to provide weather service for international air navigation. The Observatory prepares, among other products, weather forecasts for the aerodrome of the Hong Kong International Airport (HKIA) at Chek Lap Kok. The location of HKIA is as shown in Figure 1.

Aerodrome forecasts are issued regularly for use by the aviation community. In order to provide the users with an appreciation of the forecast accuracy and to allow the aviation forecaster to more effectively monitor the accuracy of aerodrome forecasts issued, an automatic objective verification system, namely the Aviation Forecast Verification System (AFVS), has been developed and implemented by the HKO. The system makes reference to the operationally desirable accuracy stated by ICAO and World Meteorological Organization (WMO).

In this report, the accuracy criteria and the verification scheme adopted by the AFVS are described. Performance statistics for the period from the opening of airport in July 1998 up to the end of 2002 are presented. Trends identified in the verification results and the use of these results are also discussed.

2. DATA

HKO routinely issues two types of aerodrome forecasts, one valid for 9 hours (the 'short forecast') and the other for 24 hours (the 'long forecast'). These forecasts are coded in TAF code form as defined in WMO (1995). The short forecast is issued every 3 hours at 00, 03, …, and 21 UTC[1]. The long forecast is issued every 6 hours at 00, 06, 12 and 18 UTC. Both long and short forecasts cover the following elements: surface wind, visibility, weather, cloud, as well as significant changes expected for such elements during the forecast period. The long forecast also gives the minimum and maximum temperature expected for the next 24 hours.

In this study, observations made by the Observatory weather observer at HKIA from July 1998 to December 2002 were used to verify the forecasts. These observations include routine observations at HKIA issued at half-hourly intervals, and special observations issued when there are significant changes in a certain element(s) in accordance with a set of prescribed criteria. The routine and special observations are coded in the METAR and SPECI code forms respectively, as defined in WMO (1995).

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[1] UTC is the Coordinated Universal Time. The Hong Kong Time (HKT) is 8 hours ahead of UTC.

3. VERIFICATION SCHEME

ICAO and WMO have published a joint guidance (extracted in Table 1) on the operationally desirable accuracy of aerodrome forecasts in ICAO (2001)/WMO (2001). According to the guidance, if the accuracy of the forecasts remains within the prescribed accuracy limits for the specified percentage of cases, the effect of forecast errors is considered not serious in comparison with the effects of navigational errors and of other operational uncertainties. Apart from operational considerations discussed below, the AFVS generally follows this guidance in the verification of forecasts.

3.1 Weather elements and operational considerations in the verification

In the verification process, an aerodrome forecast is verified, hour by hour, against the routine and special observations. The AFVS covers the following weather elements: -

(i) Wind direction
(ii) Wind speed
(iii) Visibility
(iv) Precipitation
(v) Cloud amount
(vi) Cloud height
(vii) Air temperature (long forecasts only)

The operational considerations for the verification of each of the weather elements are discussed below.

(i) Wind direction

In respect of wind direction, the ICAO/WMO operationally desirable accuracy is ± 30°. With its tropical and coastal climate, as well as its hilly terrain, winds in Hong Kong can be highly variable in direction, even in the course of a day. Strict adherence to the ICAO/WMO operationally desirable accuracy would result in an unnecessarily complicated forecast for HKIA, and thus contradicts ICAO (2001) paragraph 6.2.4 / WMO (2001) paragraph [C.3.1.] 6.2.4[2] in terms of keeping the length of the forecast to a minimum. In order to minimize the nuisance to users, the HKO adopts a threshold value of 60° for wind direction change, which have been used by air traffic controllers, airline operators and pilots in Hong Kong for many years without negative feedback. Such adoption follows the spirit of ICAO (2001) recommendation 6.2.5, which states that a threshold value should be established for the inclusion of change groups in aerodrome forecasts or for the amendment of aerodrome forecasts when the surface wind is forecast to change through values of operational significance. In the present verification, a forecast wind direction is considered correct if the reported value is within 60° of the forecast value.

From the point of view of day-to-day operations, there is little meaning in verifying the wind direction when winds are light. Thus, when both the forecast and actual wind speeds are force 0 - 2 under the Beaufort Wind Force Scale (corresponding to 'calm', 'light air' and 'light breeze'), or 11 km/h (6 knots) or less, the forecast direction is not verified.

(ii) Wind speed

The verification of the wind speed follows the ICAO/WMO operationally desirable accuracy, namely a forecast wind speed is considered correct if the difference between the forecast and the reported value is within 9 km/h (5 knots) for forecast speeds up to 46 km/h (25 knots) or within 20% for forecast speeds above 46 km/h (25 knots).

(iii) Visibility

The verification of the visibility follows the ICAO/WMO operationally desirable accuracy, namely a forecast visibility is

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[2] The regulatory material contained in ICAO (2001) is identical with that contained in WMO (2001) apart from a few minor editorial differences. Unless otherwise mentioned, references to ICAO (2001) also apply to WMO (2001) hereafter.

considered correct if the difference between the forecast and the reported value is within 200 m for forecast visibilities up to 700 m or within 30% for forecast visibilities between 700 m and 10 km.

(iv) Precipitation

In respect of precipitation, the ICAO/WMO operationally desirable accuracy refers to its occurrence or non-occurrence. ICAO (2001) recommendation 6.2.14 states that moderate or heavy precipitation should be forecast if they are expected to occur at the aerodrome. Accordingly, a forecast is considered correct if the occurrence or non-occurrence of moderate or heavy precipitation is correctly forecast.

As regards precipitation of light intensity, in accordance with the same ICAO recommendation there is no need to include such in the forecast unless the precipitation is expected to cause a significant change in visibility. For this reason, the occurrence or non-occurrence of light precipitation is not verified. In the event that light precipitation was not forecast, but light precipitation is actually observed and the visibility deteriorates significantly, the forecast will be penalized under the verification for visibility.

(v) Cloud amount

The reported or forecast cloud amount is coded in accordance with the following 5 categories: SKC (sky clear, representing 0 oktas); FEW (few, 1-2 oktas); SCT (scattered, 3-4 oktas); BKN (broken, 5-7 oktas); and OVC (overcast, 8 oktas). As the ICAO/WMO operationally desirable accuracy is ± 2 oktas, a forecast cloud amount is considered correct if it is within one category of the reported amount. For example, a forecast cloud amount of 'BKN' is considered correct if the reported cloud amount is either 'SCT', 'BKN' or 'OVC'.

In accordance with ICAO (2001) recommendation 4.9.5, only clouds below 1 500 m (5 000 ft) are of operational significance.

As such, only those clouds forecast or reported at or below 1 500 m (5 000 ft) are verified.

(vi) Cloud height

The ICAO/WMO operationally desirable accuracy is for the difference between the forecast and reported value to be within 30 m (100 ft) for forecast cloud heights up to 120 m (400 ft) or within 30% for cloud heights between 120 m and 3 000 m (10 000 ft). In the present verification, the maximum cloud height is limited to 1 500 m (5 000 ft) instead of 3 000 m, following the same consideration as in (v) above. If clouds below 1 500 m are neither forecast nor reported, the forecast is considered correct.

(vii) Air temperature

The verification of the air temperature follows the ICAO/WMO operationally desirable accuracy, namely a forecast is considered correct if the reported value is within 1ºC of the forecast value.

3.2 Handling of change, time indicators and probability groups in forecasts

Under the TAF code format (WMO 1995), four different types of indicators are available for use in describing a change or the probability of occurrence of an alternative value of a certain weather element within a sub-period of the forecast period. The verification of a forecast involving such indicator or indicators is performed in the following manner: -

(i) 'FM' indicator

A 'FM' indicator is used to describe a significant change in a weather element(s) (where applicable) starting from a specified time. In the forecast verification, the forecast value following the 'FM' indicator takes effect at the time specified after the ‘FM’ indicator.

(ii) 'BECMG' indicator

The 'BECMG' indicator and the associated time group are used to describe changes where the weather conditions are expected to reach or pass through specified threshold values at a certain time within the time period indicated by the time group.

In the forecast verification, the forecast value following the 'BECMG' indicator takes effect after the time period indicated by the time group. This transition period is short (normally not exceeding 2 hours) and the change in the weather conditions concerned could be rather sudden (i.e. change from one discrete state to another discrete state), such as a wind direction change during the passage of a cold front or a sudden drop in visibility due to the onset of showers. Having considered the above, a forecast is considered correct if the reported value within the transition period is within the prescribed accuracy range of the forecast value before the change or after the change. For example, if the visibility is forecast to change from 5 000 m to 3 000 m, and the reported visibility during the transition period indicated by the 'BECMG' time group is 2 000 m, the portion of forecast covered by this period will be considered incorrect because the reported value is outside the 30% accuracy range of both the forecast values of 5 000 m and 3 000 m. However, if the reported visibility is 6 000 m, the portion of forecast covered by the transition period will be considered correct as the reported visibility is now within 30% of 5 000 m.

(iii) 'TEMPO' indicator

The 'TEMPO' indicator and the associated time group are used to denote temporary fluctuations expected in a weather element(s) during the period indicated by the time group.

The scheme employed by AFVS in verifying aerodrome forecasts involving the 'TEMPO' indictor is described in Appendix A. In essence, the scheme takes into consideration ICAO (2001) recommendation 6.2.9 that the expected weather fluctuations should, in the aggregate, last less than one-half of the time period specified by the ‘TEMPO’ groups. Thus, the number of hours correctly forecast by a 'TEMPO' group should not exceed one-half of the time period.

However, the other condition stated in the same ICAO recommendation, namely that the 'TEMPO' condition should last less than an hour in each instance, is not considered in view of inherent limitations in the time resolution of the weather observations, which render the accurate determination of the duration of 'TEMPO' condition not possible. To compensate for this, a penalty is imposed in the present verification if the 'TEMPO' condition is not observed. Specifically, the penalty for non-occurrence is that up to one-third of the forecast hours covered by the time period will be counted as incorrect.

(iv) 'PROB30' or 'PROB40' indicators

The 'PROB' indicators describe the probability of occurrence (30% for 'PROB30' and 40% for 'PROB40') of an alternative value for a weather element(s). They constitute probabilistic forecasts that need to be verified differently from those categorical forecasts currently dealt with by the AFVS. They are, however, rarely used by the HKO and are therefore not verified at present. The verification of ‘PROB’ forecasts will be taken into account in the future enhancement of AFVS.

3.3 Construction of ‘weather history’ for verification

For each of the weather elements, ICAO (2001)/WMO (2001) gives a minimum percentage of cases within the stated operational desirable accuracy (termed “accuracy percentage” in this report) as a guidance for meeting the accuracy criterion (Table 1). For instance, for air temperature the accuracy percentage is 70% of cases within 1ºC of the reported value.

In the present verification, the ‘hour’ is taken as the basic unit in computing the percentage of cases of accurate forecast. For any period of verification, such as a day, a month or a year, the percentage of correct forecasts is the total number of correct forecast hours divided by the total number of hours verified. To determine the total number of correct forecast hours, the AFVS first builds up a 'history' of weather conditions that were observed for each of the forecast hours. The weather history is constructed as follows: -

(i) As the routine observations are made on the half-hour and on the hour, each routine observation is therefore taken to be valid for half an hour from the reporting time unless there is a special observation issued in the course of the next half hour, in which case the routine observation is taken to be valid up to the time of the special observation.

(ii) Each special observation is valid for the period from the reporting time to the time of next routine observation or special observation.

3.4 Computation of the percentage of accurate forecasts

The AFVS compares the weather history (constructed in the manner described in Section 3.3 above) with the forecast to determine: (a) the fraction of the hour in which the weather has been accurately forecast; and (b) the percentage of correct forecasts, based on the total number of forecast hours. Appendix B shows a hypothetical case of precipitation forecast verification to demonstrate how the number of correct forecast hours is determined based on the constructed weather history.

4. VERIFICATION RESULTS

A system flowchart of the AFVS is given in Figure 2. The verification of the aerodrome forecasts is carried out automatically to generate a verification report everyday. Apart from this, the AFVS also provides an interactive user-interface to permit flexible entry of parameters of interest for special verification (Figure 3).

In this study, verification was carried out for all long forecasts issued since the airport opening in July 1998 up to December 2002. Table 2 presents a summary of the results for the different weather elements. Taking into account various operational considerations as described in Section 3.1 and summarized in Table 1, the figures in Table 2 show that the overall performance for the period exceeds the ICAO/WMO accuracy percentage for each of the seven weather elements.

The verification results for the seven weather elements are plotted, month by month, in Figures 4 to 10 respectively. Each of the plots is overlaid with past 12-month running averages to reveal long-term trend if any in the performance.

General observations about the performance of the forecasts and the long-term trend are given in Table 3 for each of the elements. In brief, with the availability of verification results like these it has been possible to identify areas requiring attention or improvement. For instance, some deterioration in the forecasting of wind speed was observed during the period, and subsequently HKO implemented in 2002 several measures to address the difficulties faced by the forecaster in forecasting the wind speed. These measures include the automatic identification of past cases with a similar weather pattern and the introduction of more numerical prediction products for reference by the forecaster. The effectiveness of these measures is being monitored. Also, the shortcomings in forecasting the air temperature in the cooler months have been addressed with the introduction of a number of forecasting rules developed in 2001 after studying failure cases.

5. DISCUSSION AND CONCLUSIONS

A forecast verification system, the Aviation Forecast Verification System, has been developed for the automatic verification of aerodrome forecasts issued for HKIA. The system covers seven weather elements (wind speed, wind direction, visibility, precipitation, cloud height, cloud amount and air temperature) and follows the ICAO/WMO guidance on the operationally desirable accuracy of aerodrome forecasts apart from some modifications on the basis of operational considerations.

The verification results for the aerodrome forecasts issued during the period from July 1998 to December 2002 show that the forecast accuracy for all the seven weather elements exceeded the ICAO/WMO accuracy percentages. Results like these have also enabled areas requiring improvement to be identified, and corresponding improvement measures to be introduced. The long-term trends in the performance statistics of the aerodrome forecasts reveal that there has been improvement in the forecasting of most of the seven elements over 2001 and 2002. Efforts to improve the forecasting of other elements are ongoing, so are efforts to improve forecasting in general.

The system will be expanded to verify both landing and take-off forecasts for the airport. The verification of forecasts against user-specified operating minima of different weather elements is also in the future plan.

REFERENCES

1.	ICAO / WMO	2001	Annex 3 to the Convention on International Civil Aviation – Meteorological Service for International Air Navigation, International Civil Aviation Organization, 14th Edition / Chapter C.3.1, Technical Regulations (WMO-No.49), Volume II, World Meteorological Organization.
2.	WMO	1995	Manual on Codes (WMO-No.306), Volume I, World Meteorological Organization.

Appendix A

Dealing with the 'TEMPO' indicator in the verification of forecasts

The AFVS determines the contribution of a 'TEMPO' forecast to the total number of correct forecast hours, H(corr), using the following scheme.

For a 'TEMPO' forecast covering a period of N hours, first define the following variables:

H(M): number of hours the main forecast condition is correct (i.e. the forecast value is within the prescribed accuracy range of the reported value)

H(T): number of hours the 'TEMPO' forecast condition is correct

H(T&notM): number of hours the main forecast condition is incorrect but the 'TEMPO' forecast is correct

(i) if H(T) > 0,
contribution of the main forecast is H(M)
contribution of the TEMPO forecast is min (N/2, H(T&notM)),

H(corr) = H(M) + min (N/2, H(T&notM))

(ii) if H(T) = 0,
contribution of the main forecast is H(M)
contribution of the TEMPO forecast is -N/3

H(corr) = max (0, H(M) – N/3)

Appendix B

Hypothetical case to illustrate the calculation of number of correct forecast hours

Consider the following hypothetical aerodrome forecast in TAF code form valid from 00 UTC to 24 UTC on the 27th of the month issued at 22 UTC the previous day (the 26th):

‘TAF VHHH 262200Z
270024 09010KT 9000 FEW 010 SCT 016 BKN 060
TEMPO 0306 4000 RA
BECMG 0911 4000 RA
FM 1800 9000 NSW’

The meaning of each element of the forecast can be found in WMO (1995). Let us focus on the precipitation forecast, which says in plain language:

> ‘From 00 UTC to 09 UTC, no precipitation; temporarily between 03 UTC and 06 UTC, moderate rain; becoming between 09 UTC and 11 UTC, moderate rain; from 18 UTC to 24 UTC, no precipitation.’

Suppose that there was moderate precipitation only during the periods from 08:45 UTC to 10:30 UTC and from 12:00 UTC to 20:15 UTC on the 27th. The total number of correct forecast hours in respect of precipitation can then be obtained as follows:

Time (UTC)	Forecast	Actual	Contribution to number of correct forecast hours
	Moderate/heavy precipitation forecast? (Yes/No)	Moderate/heavy precipitation occurred? (Yes/No)	
0000-0300	No	No	3
0300-0600	Yes (TEMPO)	No	2[a]
0600-0845	No	No	2.75
0845-0900	No	Yes	0

0900-1030	Yes (BECMG)	Yes	1.5[b]
1030-1100		No	0.5[b]
1100-1200	Yes	No	0
1200-1800	Yes	Yes	6
1800-2015	No (FM)	Yes	0[c]
2015-2400		No	3.75
Total number of correct forecast hours:			19.5

(a) The main forecast condition is 'without precipitation' and the 'TEMPO' forecast condition is 'with precipitation'. Referring to and using the notation in Appendix A,

H(M) = 3 and H(T) = 0

H(corr) = max (0, 3 – 3/3) = 2

(b) Forecast condition before the change is 'without precipitation' and that after the change is 'with precipitation'. Following Section 3.2(ii), the forecast is considered correct no matter whether there is precipitation or not.

(c) The forecast condition 'without precipitation' takes effect from 18:00 UTC.

In the above example, the total number of correct forecast hours for the precipitation forecast adds up to 19.5. For a perfect forecast, this figure would have been 24 (hours).

Figure 1. Location map of Hong Kong International Airport

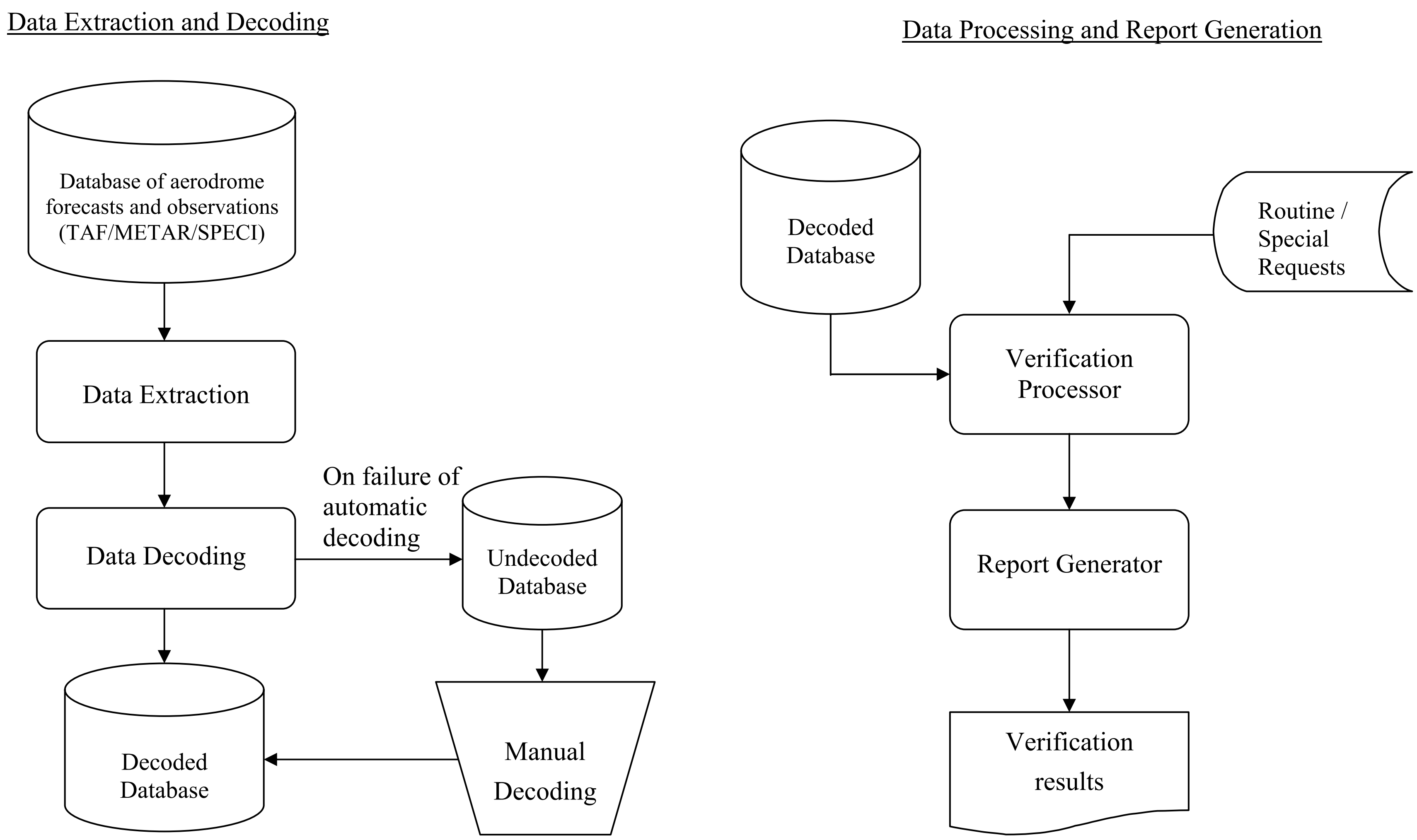

Figure 2. System flowchart of AFVS

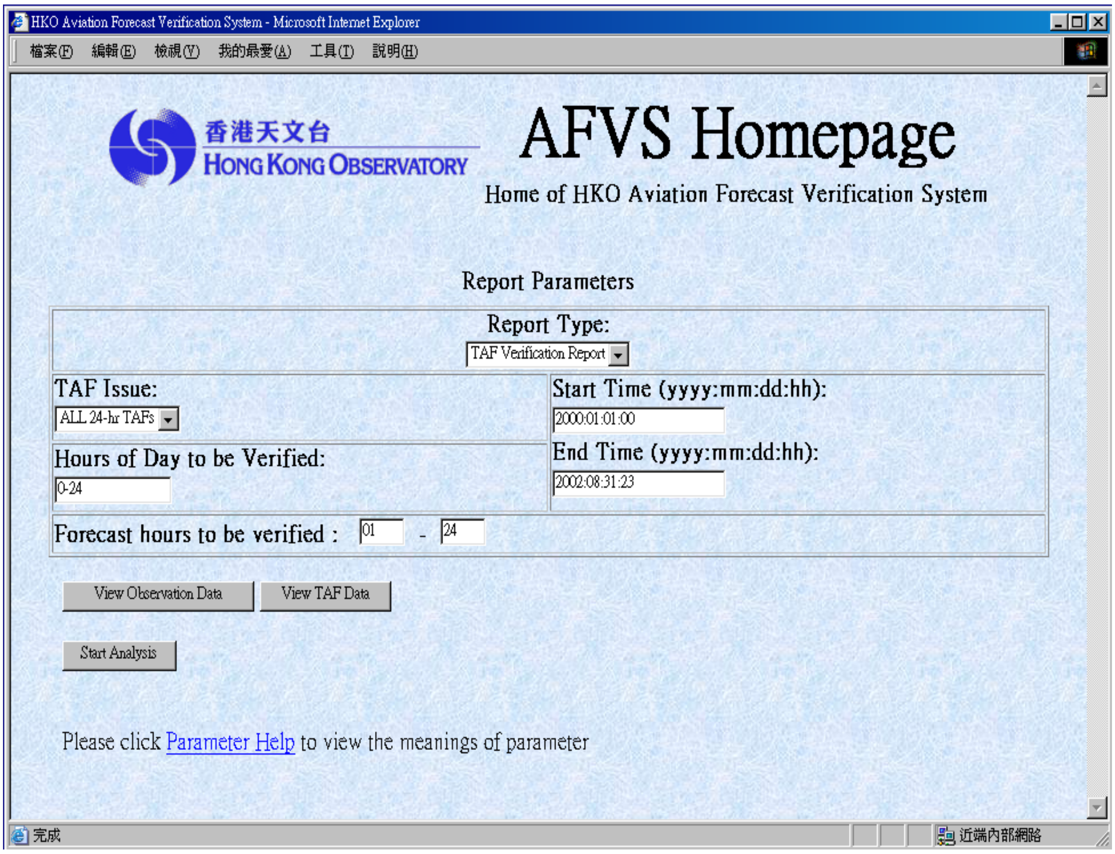

Figure 3. User-interface of AFVS

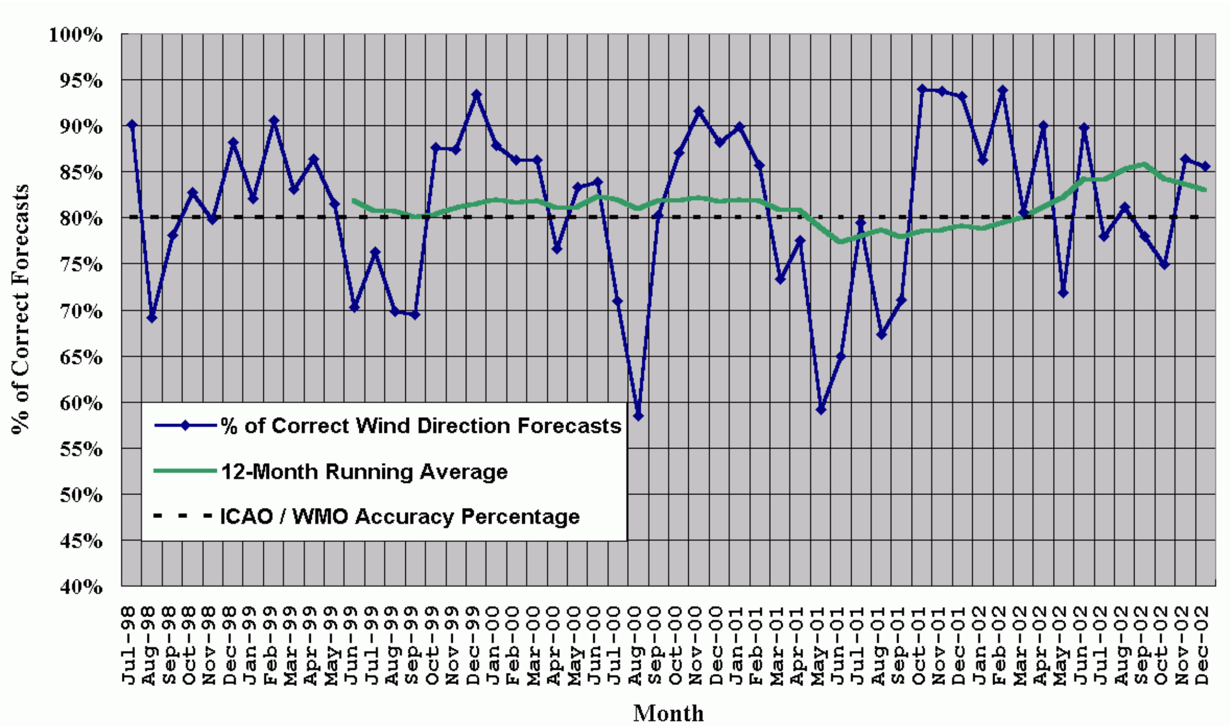

Figure 4. Verification of wind direction forecasts

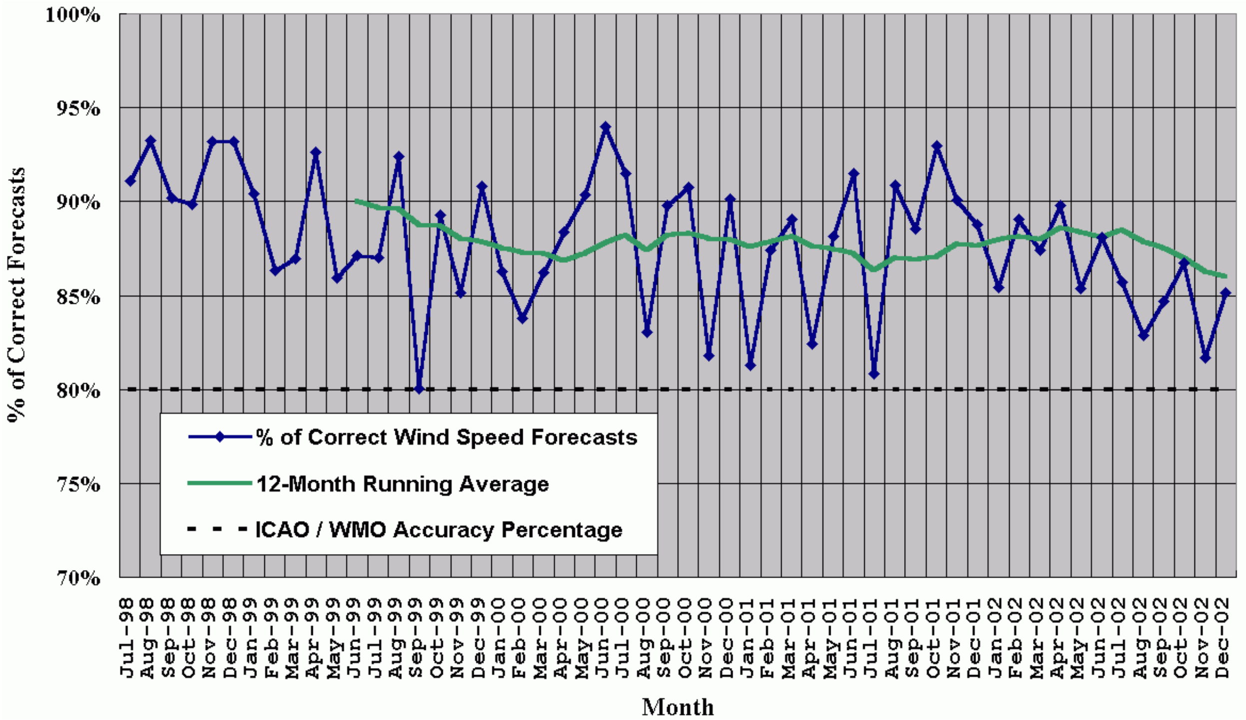

Figure 5. Verification of wind speed forecasts

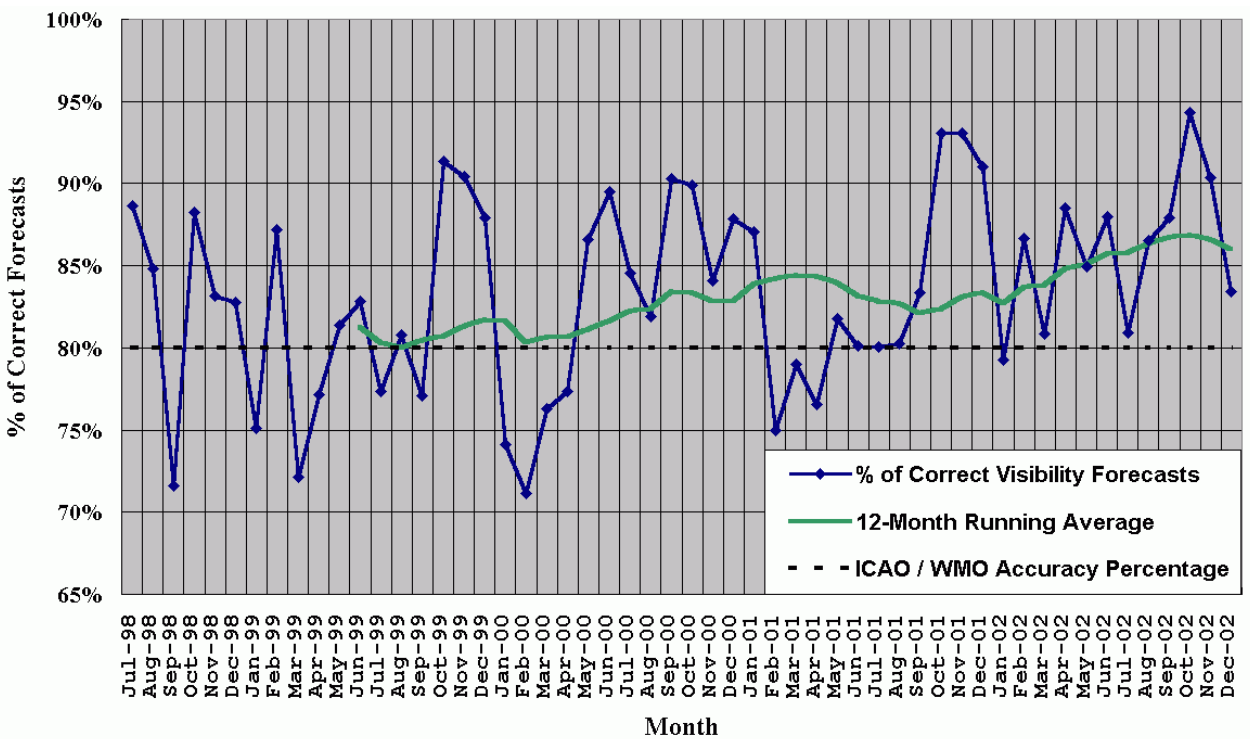

Figure 6. Verification of visibility forecasts

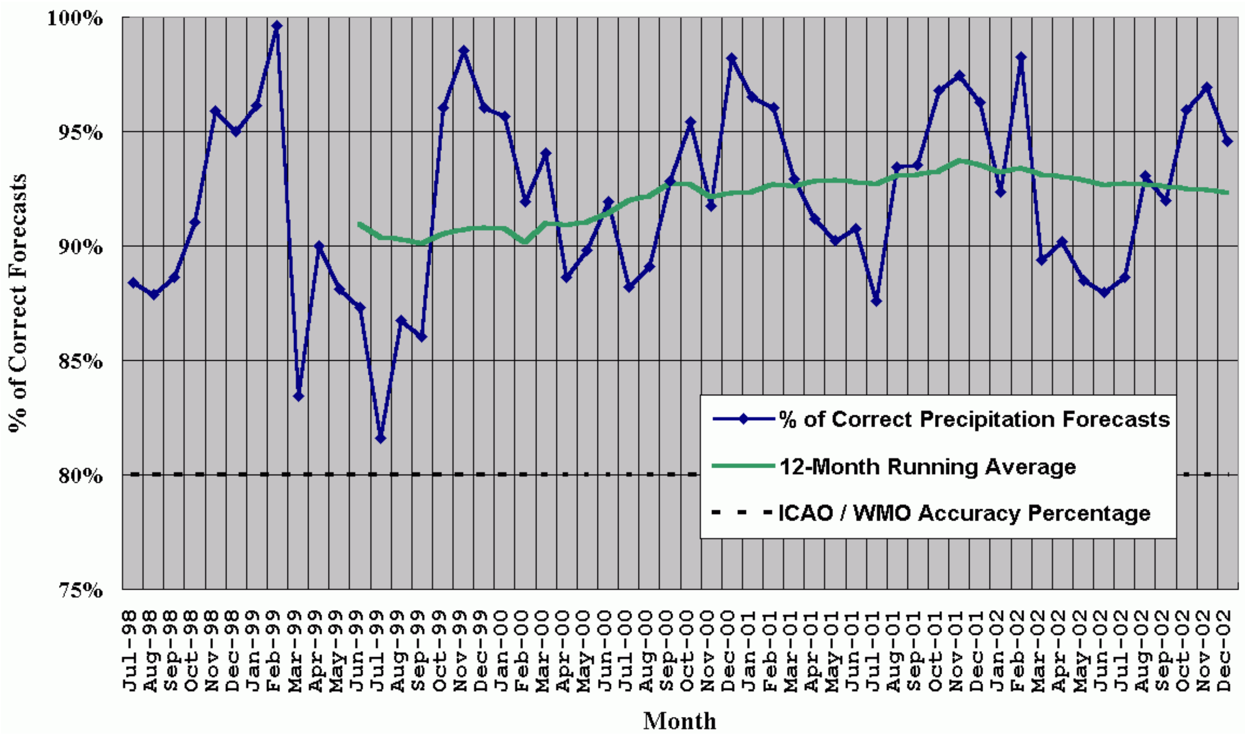

Figure 7. Verification of precipitation forecasts

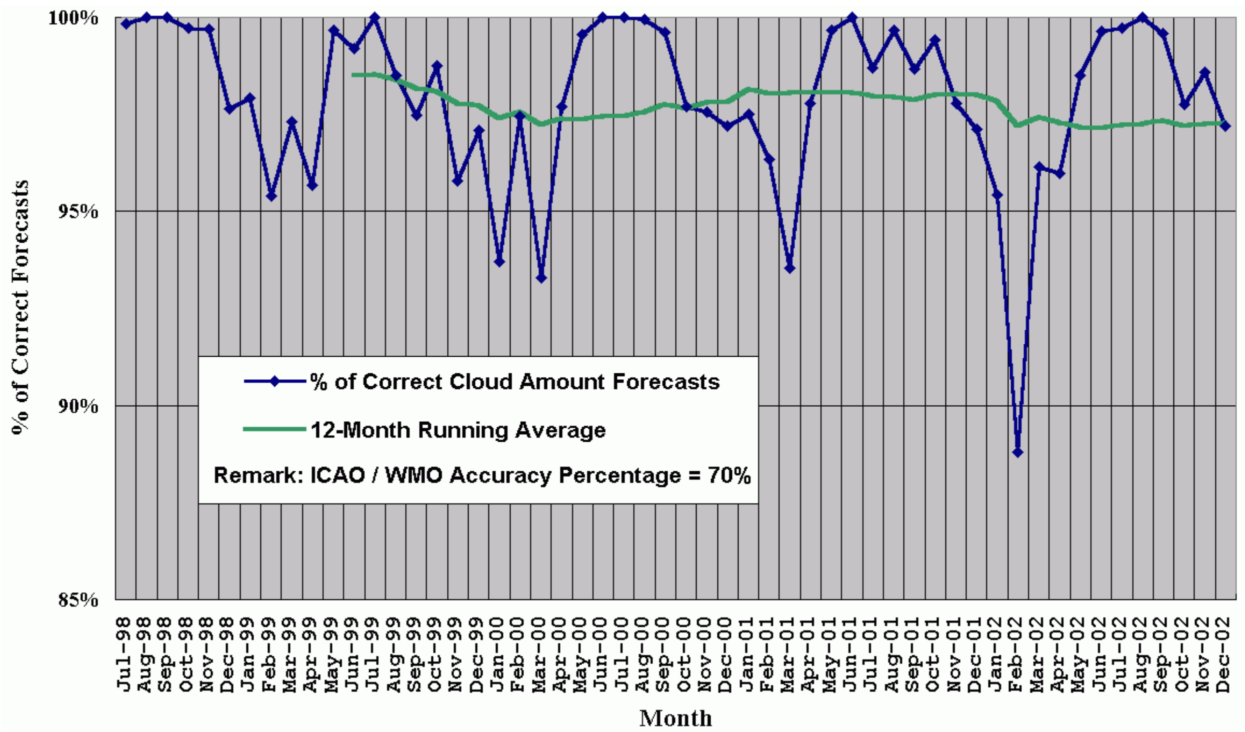

Figure 8. Verification of cloud amount forecasts

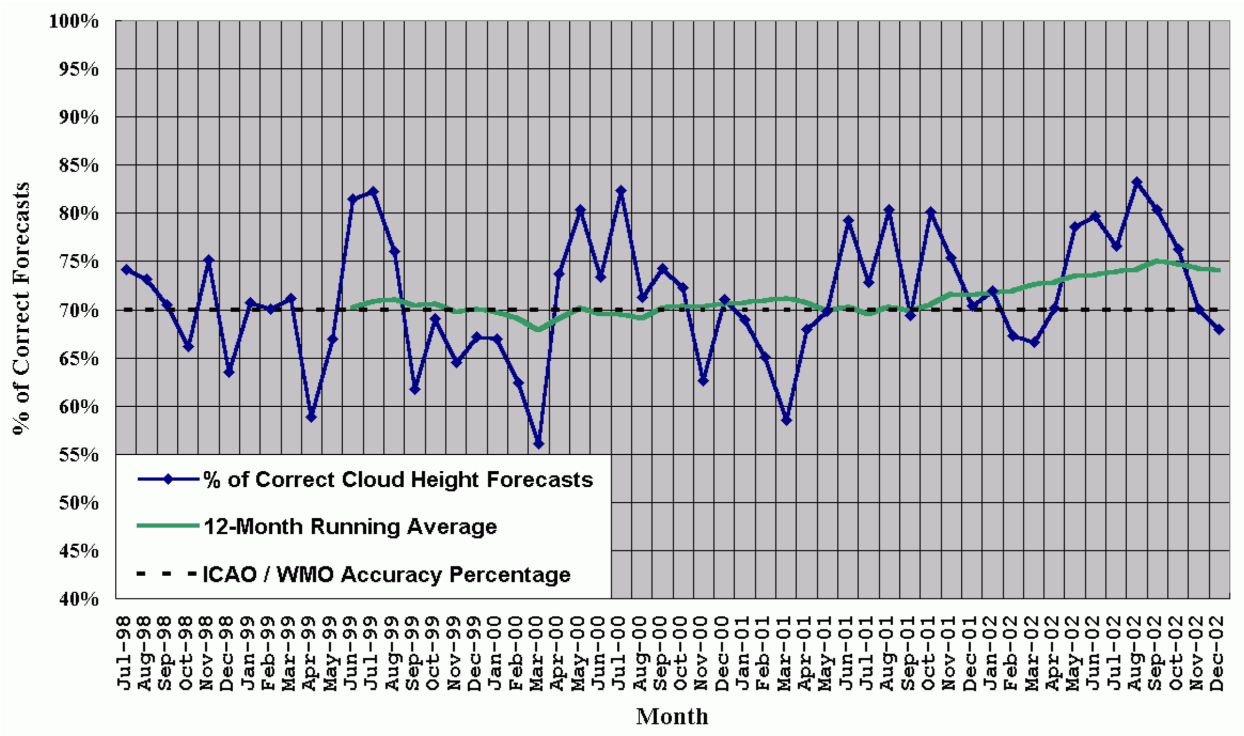

Figure 9. Verification of cloud height forecasts

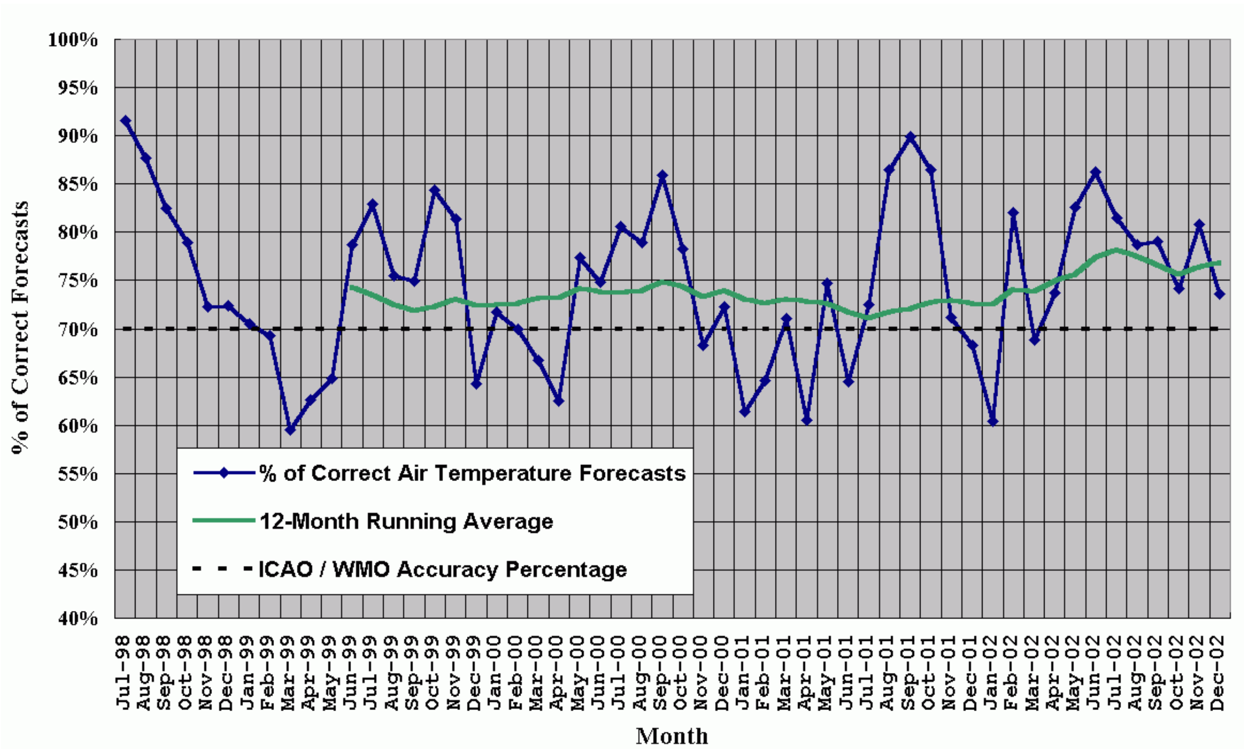

Figure 10. Verification of air temperature forecasts

Table 1. Operationally desirable accuracy of aerodrome forecasts [extracted from ICAO (2001) / WMO (2001)] and accuracy criteria used in the AFVS

Elements	ICAO/WMO operationally desirable accuracy	Accuracy criteria used in the AFVS	ICAO/WMO accuracy percentage (minimum percentage of cases within range)
Wind direction	± 30°	± 60° [see Section 3.1(i)]	80%
Wind speed	± 5 kt (9 km/h) up to 25 kt (46 km/h) ± 20% above 25 kt (46 km/h)	Same as operationally desirable accuracy	80%
Visibility	± 200 m up to 700 m 30% between 700 m and 10 km	Same as operationally desirable accuracy	80%
Precipitation	Occurrence or non-occurrence	Same as operationally desirable accuracy except that light precipitation is not verified [see Section 3.1(iv)]	80%
Cloud amount	± 2 oktas	± 1 category of the reported amount of clouds below 1 500 m (5 000 ft) [see Section 3.1(v)]	70%
Cloud height	± 100 ft (30 m) up to 400 ft (120 m) ± 30% between 400 ft (120 m) and 10 000 ft (3 000 m)	Same as operationally desirable accuracy except that only clouds below 1 500 m (5 000 ft) are verified [see Section 3.1(vi)]	70%
Air temperature	± 1°C	Same as operationally desirable accuracy	70%

Table 2. Verification results of aerodrome forecasts valid for 24 hours (July 1998 – December 2002)

Elements	ICAO / WMO accuracy percentage (C)	Percentage of correct forecasts (F)	Difference (F-C)
Wind direction	80%	81%	+1%
Wind speed	80%	88%	+8%
Visibility	80%	83%	+3%
Precipitation	80%	92%	+12%
Cloud amount	70%	98%	+28%
Cloud height	70%	71%	+1%
Air temperature	70%	75%	+5%

Table 3. General observations about the performance of aerodrome forecasts and the long-term trend

Element	Performance of forecasts	Long-term trend
Wind direction (Figure 4)	Generally above ICAO/WMO accuracy percentage in cool seasons, but below in some warmer months	Improvement observed in 2002 after a dip in 2001
Wind speed (Figure 5)	Consistently above ICAO/WMO accuracy percentage	Slight deterioration after 1999
Visibility (Figure 6)	Above ICAO/WMO accuracy percentage most of the time in 2001 and 2002, but below in Feb – Apr 2001	Generally improving trend since 1999
Precipitation (Figure 7)	Consistently above ICAO/WMO accuracy percentage, but performance in the months April to July generally inferior to other months	Improved performance during 2001-2002, compared with 1998-1999
Cloud amount (Figure 8)	Consistently above ICAO/WMO accuracy percentage, but February and March generally more difficult to forecast	-
Cloud height (Figure 9)	Above ICAO/WMO accuracy percentage in the warmer months, but spring (around February – March) appeared to be worse	Improvement observed since 2001
Air temperature (Figure 10)	Above ICAO/WMO accuracy percentage in the warmer months, but sometimes below in the cooler months	Some improvement observed in 2002