HONG KONG OBSERVATORY

ADDENDUM to

Technical Note No. 105

VERIFICATION OF AERODROME FORECASTS FOR THE HONG KONG INTERNATIONAL AIRPORT ISSUED BY THE HONG KONG OBSERVATORY

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ABSTRACT

This Technical Note Addendum describes the system updates to the aviation forecast verification system by the Hong Kong Observatory. The latest verification scheme adopted by the system is described and the verification results of the aerodrome forecasts issued during 2011-2020 are also presented.

摘要

本附錄補充了天文台對航空預報驗證系所統所作的修訂，詳述該系統採用的最新驗證方案，並刊出 2011 至 2020 年間發出的機場天氣預報的驗證結果。

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LIST OF ABBREVIATIONS

AFVS	Aviation Forecast Verification System
AMO	Airport Meteorological Office
ft	foot/feet (unit)
HKIA	Hong Kong International Airport
HKO	Hong Kong Observatory
ICAO	International Civil Aviation Organization
ISO	International Organization for Standardization
km	kilometre(s) (unit)
kt	knot(s) (unit)
m	metre(s) (unit)
TAF	terminal aerodrome forecast
UTC	Coordinated Universal Time

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1. INTRODUCTION

Within the framework of the International Civil Aviation Organization (ICAO), the Hong Kong Observatory (HKO) is the designated meteorological authority of Hong Kong, China for provision of meteorological service for international air navigation in Hong Kong. HKO, through its Airport Meteorological Office (AMO) at the Hong Kong International Airport (HKIA), issues aerodrome forecasts, amongst others, to support international air navigation. The location of HKIA is shown in Figure 1.

HKO has established a quality management system (QMS) for its aviation weather service since 2002. The latest QMS conforms with International Organization for Standardization (ISO) 9001:2015 requirements, with the purpose of quality management of the meteorological information, including aerodrome forecasts, it provides to users. The QMS has a number of quality objectives and one of them is that the annual average of forecasting accuracy shall comply with the operationally desirable accuracy of forecasts as stated in ICAO ANNEX 3 to the Convention on International Civil Aviation Meteorological Service for International Air Navigation (hereafter ICAO ANNEX 3).

For gauging forecast accuracy, HKO maintains an Aviation Forecast Verification System (AFVS), for verification, by objective means, of the aerodrome forecasts it issues.

This Technical Note Addendum replaces Technical Note No.105 (TN105) published in May 2003 with documentation of system changes since TN105 and the latest verification scheme adopted.

In the subsequent section of this Addendum, the latest verification scheme adopted in AFVS is described. Statistics for the aerodrome forecasts issued during 2011-2020 obtained through the AFVS are also presented to provide users with an appreciation of the forecast accuracy.

2. SYSTEM

HKO has designed, developed, and implemented an Aviation Forecast Verification System (AFVS) to verify its aerodrome forecasts by objective means. The AFVS ensures that aviation forecasters know the accuracy of individual aerodrome forecasts they made, and the management understands the performance of HKO's aerodrome forecast for the purpose of quality planning, monitoring and control.

The AFVS was first implemented in year 2000. With ICAO's changes in TAF format and HKO's adoption of TAF with a 30-hour validity period in 2008, the opportunity was taken to review the system architecture, algorithms, and verification scheme of the AFVS (hereafter termed "AFVS-2000"). The scope of verification was also expanded from TAF to cover trend forecast. A new generation of AFVS (hereafter termed "AFVS-2008") was then developed and implemented to replace AFVS-2000 in November 2008. In comparison with AFVS-2000, AFVS-2008 features enhanced capability, portability, availability and user-friendliness.

From the experience of running AFVS-2000, computation resources required by such a system are not demanding. Rather, a lot of preprocessing steps are required in parsing and translating the forecast bulletins and observation reports that are expressed in code forms in order to construct the forecast-observation pairs for verification. Shell programming language[1] was thus chosen to implement most parts of the packages in AFVS-2008 for portability, robustness and popularity. For maximum flexibility, data is stored as plain text flat files except some final output which are produced in HTML format for visualisation of the daily, monthly and annual verification results.

Verification of aerodrome forecasts is carried out automatically by AFVS-2008 that generates a set of verification reports in the form of webpages every day. Forecast bulletins and observation reports are

[1] The package was implemented using Korn Shell, and tested successfully on AIX as well as Linux platforms.

obtainable both in real-time or from archive of the Aeronautical Fixed Telecommunication Network (AFTN). The results are openly accessible to HKO colleagues on a web server. With its simplicity in design, the system has been ported to over 30 countries/regions.

A system flowchart of AFVS-2008 is shown in Figure 2.

3. DATA

As a routine, HKO issues aerodrome forecasts in the form of trend forecast and 30-hour TAF for HKIA every day. These forecasts are prepared, coded and issued in accordance with the specifications given in ICAO ANNEX 3.

Locally, meteorological observations in the form of METAR is issued every half-hour at the 00th and 30th minute and SPECI is issued whenever the criteria for issuance of SPECI as stipulated in ICAO ANNEX 3 are met. Trend forecast is appended to METAR and SPECI. Trend forecast describes forecast significant changes from METAR/SPECI in the next 2 hours. The criteria for inclusion of meteorological elements in trend forecasts (hereafter termed "trend-criteria") are stipulated in para. 2.2 of Appendix 5 to ICAO ANNEX 3. These elements include:

- wind direction
- wind speed
- visibility (prevailing)
- cloud amount
- cloud height
- precipitation

In case that no significant change in the meteorological elements is expected to occur in the next two hours, trend forecast is issued as "NOSIG", signifying "NO SIGnificant change" with respect to the observations as reported in the corresponding METAR/SPECI.

30-hour TAF is issued every 6-hour, valid for a period of consecutive thirty hours respectively starting at 00, 06, 12 and 18 UTC[2]. 30-hour TAF covers the following meteorological elements as well as significant changes expected in these elements during the validity period.

- wind direction

[2] UTC is Coordinated Universal Time. Hong Kong Time is 8 hours ahead of UTC.

- wind speed
- visibility (prevailing)
- cloud amount
- cloud height
- precipitation
- minimum and maximum temperatures expected within the validity period

The criteria for inclusion of change groups in TAF (hereafter termed “change-criteria”) are stipulated in para. 1.3 of Appendix 5 to ICAO ANNEX 3.

To verify trend forecasts and TAFs, observations reported in METAR/SPECI at HKIA are used. In this document, METAR/SPECI issued during 2011 – 2020 are used to verify the trend forecasts and 30-hour TAFs for the same period.

4. VERIFICATION SCHEME

ICAO has published guidance on the operationally desirable accuracy of aerodrome forecasts in Attachment B to ICAO ANNEX 3. For ease of reference, the latest operationally desirable accuracy for trend forecast and TAF and the criteria adopted in AFVS-2008 are extracted into Table 1 and Table 2 respectively. In line with the change in the operationally desirable accuracy stated by ICAO, the basis against which forecasts are considered to be within limits have been changed accordingly. The old and new operationally desirable accuracies are tabulated in Table 2a.

For each of the meteorological elements covered in trend forecast and TAF, Attachment B to ICAO ANNEX 3 gives a minimum percentage of cases of accurate forecast (i.e. forecast within the specified operational desirable range) as guidance for meeting the accuracy criterion (see Tables 1 and 2). Pursuant to ICAO ANNEX 3, if accuracy of forecasts falls within the prescribed operationally desirable range for the prescribed percentage of cases, the effect of forecast errors is considered acceptable in comparison with the effects of navigational errors and of other operational uncertainties. Apart from operational considerations discussed below, AFVS-2008 generally follows such guidance in the verification of aerodrome forecasts.

In the verification, the observations reported in METAR/SPECI are regarded to be valid from the time of the METAR/SPECI till the time of the next METAR/SPECI that had been issued. Forecasts for individual meteorological elements covered in the aerodrome forecast, i.e. trend forecast and TAF, are separately verified on a piecewise basis against the observations.

4.1 Construction of "Weather Profile" for Verification

In the verification, cases of accurate forecast are counted on a

time basis. For any verification period, such as a day, a month or a year, the percentage of accurate forecasts is the aggregate duration of accurate forecasts (in minutes) divided by the aggregate duration of all verified aerodrome forecasts over the verification period (also in minutes). To determine the duration of accurate forecasts, AFVS-2008 builds up a "weather profile" of actual weather conditions for each of the meteorological elements that were reported during the validity period of the concerned aerodrome forecast. The "weather profile" is constructed as follows:-

(a) As routine observations (i.e. those reported in METAR) are made on the half-hour and on the hour, each routine observation is regarded to be valid for half an hour from the reporting time unless there is a special observation (i.e. the observation reported in SPECI) issued during that half-hour period, in which case the routine observation is taken to be valid up to the time of the special observation.

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

For temperatures, only maximum and minimum temperatures are given in TAF and verified. The "actual" maximum and minimum is located by searching through the "weather profile", which is a collection of METAR and SPECI at discrete time, hence understandably can be different from the "absolute" maximum/minimum recorded by conventional means.

4.2 Verification Schemes

4.2.1 Trend Forecast

The verification scheme for trend forecast is composed of two sub-schemes, namely N-scheme and T-scheme. The two sub-schemes and their applicability are described below.

(a) N-scheme (NOSIG scheme)

The N-scheme is applied to forecasts of "no significant change" with respect to the reported meteorological condition. Such forecast is signified by the "NOSIG" code (in case of no significant change for all meteorological elements) or is implied by the exclusion of individual meteorological elements in the trend forecast. Since forecast for a certain element is only given if it exceeds the corresponding trend-criteria, the N-scheme is verified based on trend-criteria stipulated in para. 2.2 of Appendix 5 to ICAO ANNEX 3.

In the verification by the N-scheme, a forecast of "no significant change" is considered accurate for *N* minutes if trend-criteria are not met during *N* minutes in the validity period of the trend forecast.

(b) T-scheme (change group scheme)

T-scheme is applied to the part of the forecasts when a change in weather condition is explicitly stated in the trend forecast (i.e. forecast indicated in the change groups, see section 4.3). The T-scheme is verified based on the operationally desirable accuracy of trend forecast as stipulated in Attachment B to ICAO ANNEX 3.

In the verification by the T-scheme, a forecast is considered accurate for *N* minutes if the forecast is within the operationally desirable accuracy for *N* minutes in the validity period of the trend forecast.

The separation of trend forecast verification into N-scheme and T-scheme is a consideration from the forecast operation point of view: when the forecaster makes an explicit forecast of the weather condition, that 'forecast' should satisfy the desirable accuracy in compliance with ICAO requirement; on the other hand if NOSIG is issued, then the forecaster is effectively forecasting that the weather condition will not

exceed the trend-criteria, and therefore the forecast should be validated as such. Examples illustrating application of the N-scheme and the T-scheme are given in Appendix A.

4.2.2 TAF

The verification scheme for TAF is based in general on the operationally desirable accuracy of TAF as stipulated in Attachment B to ICAO ANNEX 3. In the verification of TAF, a forecast is considered accurate for *M* minutes if the forecast is within the operationally desirable accuracy for *M* minutes in the validity period of the TAF.

4.3 Handling of Change Groups

In accordance with para. 1.3 and para. 2.3 of Appendix 5 to ICAO ANNEX 3, two change indicators, namely "BECMG" and 'TEMPO", can be used for trend forecast; and three change indicators, namely 'BECMG", "TEMPO" and "FM" can be used for TAF. The "FM" indicator is recommended for use when one set of prevailing weather conditions is expected to change significantly and more or less completely to a different set of conditions. The handling of "BECMG" and "TEMPO" in trend and TAF verification are elaborated in more detail below.

4.3.1 Handling of "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 at a regular or irregular rate within the transition time period. In line with ICAO ANNEX 3, the time periods are taken as follows in the verification:

For trend forecast

"BECMG FM$n_1n_1n_1n_1$ TL$n_2n_2n_2n_2$"	the change is forecast to	commence at $n_1n_1n_1n_1$ UTC and be completed by $n_2n_2n_2n_2$ UTC
"BECMG TLnnnn"		commence at the beginning of the trend forecast period and be completed by nnnn UTC
"BECMG FMnnnn"		commence at nnnn UTC and be completed by the end of the trend forecast period
"BECMG ATnnnn"		occur at nnnn UTC (specified time)
"BECMG"		commence at the beginning of the trend forecast period and be completed by the end of the trend forecast period

For TAF forecast

"FM $n_dn_dn_hn_hn_mn_m$"	- change occurring at n_dn_d day, n_hn_h hours and n_mn_m minutes (UTC)
"BECMG $n_{d1}n_{d1}n_{h1}n_{h1}$/$n_{d2}n_{d2}n_{h2}n_{h2}$"	- change to commence at $n_{d1}n_{d1}$ day and $n_{h1}n_{h1}$ hours (UTC) and be completed by $n_{d2}n_{d2}$ day and $n_{h2}n_{h2}$ hours (UTC)

During the transition, the forecast meteorological condition is regarded to take effect partially or occur as temporary fluctuations. For simplicity, the forecast meteorological condition within the period is verified in the same way as it is given by the "TEMPO" indicator (see 4.3.2 below).

After the indicated time period, the forecast meteorological condition is regarded to be as specified by the "BECMG" indicator and to take effect fully.

4.3.2 Handling of "TEMPO" Indicator

The "TEMPO" indicator and the associated time group are used to describe temporary fluctuations in the forecast meteorological conditions which are expected to reach or pass specified values during the period indicated by the time group. The fluctuations are expected to last for a period of less than one hour in each instance and, in the aggregate, cover less than one-half of the period during which the fluctuations are forecast to occur. In line with ICAO ANNEX 3, the time periods are taken as follows:

For trend forecast[3]

"TEMPO FM$n_1n_1n_1n_1$ TL$n_2n_2n_2n_2$"	temporary fluctuations are forecast to	commence at $n_1n_1n_1n_1$ UTC and cease by $n_2n_2n_2n_2$ UTC
"TEMPO TLnnnn"		commence at the beginning of the trend forecast period and cease by nnnn UTC
"TEMPO FMnnnn"		commence at nnnn UTC and cease by the end of the trend forecast period
"TEMPO"		commence at the beginning of the trend forecast period and cease by the end of the trend forecast period

[3] Extracted from Table A3-3 of ICAO ANNEX 3

For TAF forecast[4]

"TEMPO $n_{d1}n_{d1}n_{h1}n_{h1}/n_{d2}n_{d2}n_{h2}n_{h2}$"	- temporary fluctuations are forecast to commence at $n_{d1}n_{d1}$ day and $n_{h1}n_{h1}$ hours (UTC) and cease by $n_{d2}n_{d2}$ day and $n_{h2}n_{h2}$ hours (UTC)

Within the time period specified by the "TEMPO" indicator, the weather element(s) could be fluctuating temporarily. The detail scheme employed is described in Appendix B. In essence, taking into consideration para. 1.3.5 in Appendix 5 of ICAO ANNEX 3 that the expected weather fluctuations should, in the aggregate, last for a period of less than one-half of the time period specified by the "TEMPO" indicator, thus the forecast should not be considered as accurate for a period longer than one-half of the time period.

However, the other condition that "the fluctuations should last for a period of less than an hour in each instance" is not considered in view of inherent limitations in the time resolution of weather observations, which render accurate determination of the duration of fluctuations not possible. To compensate for this, a penalty is imposed if the expected fluctuations are not observed. Specifically, up to one-third of the forecast duration covered by the "TEMPO" indicator is considered inaccurate in case the expected fluctuations are not observed.

After the indicated time period, the forecast meteorological condition is regarded to be as it was before the "TEMPO".

4.4 Handling Probability Groups in TAF

Guidance on the use of probability indicators in TAF is provided in para. 1.4 in Appendix 5 to ICAO ANNEX 3.

"PROB" indicators are recommended for use to describe the

[4] Extracted from Table A5-2 of ICAO ANNEX 3

probability (more specifically, "PROB30" for a 30% probability; "PROB40" for a 40% probability) of occurrence of an alternative value of a forecast element or elements. Besides, "PROB" indicators can be used in combination with the change indicator "TEMPO" in the forms "PROB30 TEMPO" and "PROB40 TEMPO".

In the verification, the forecast meteorological condition given after a "PROB" indicator (i.e. "PROB30", "PROB40") or a "PROB" indicator in combination with the "TEMPO" indicator (i.e. "PROB30 TEMPO" and "PROB40 TEMPO") is verified in the same way as it is given after the "TEMPO" indicator[5] in TAF (see 4.3.2 above).

4.5 Special Handling of Weather Elements due to Operational Considerations

A forecast should not be unduly penalized without considering the operational rules imposed on its issuance. While the schemes are based on ICAO ANNEX 3, a number of additional treatments arisen from operational considerations have been prescribed for each element as elaborated below.

For a fair verification, the rules for forecast production should be taken into account. As the criterion for inclusion of change group of a number of weather elements is less stringent compared with the desirable accuracy, the change group criterion is adopted as the criterion for accurate forecast under such situations. Other operational considerations for verification of the various weather elements are elaborated below. Full details of the verification scheme for each element are given in Appendix C.

4.5.1 Wind Direction

Under light or gentle wind conditions, the wind direction is often varying. Moreover, under such wind condition, the change group criterion would never be met. Given the actual wind direction might be

[5] Such a treatment has been adopted for retrospectively verifying 24-hour TAFs issued in the past years using AFVS-2008.

significantly different from that of forecast, it would not be proper to consider the forecast as accurate. Thus, under light or gentle winds, the forecast wind directions, except where variable winds were forecast and/or observed, is not verified under certain conditions (see Appendix C for detail).

Apart from under light wind conditions, variable winds might be forecast in association with thunderstorms due to its expected variability. If variable winds are forecast and thunderstorms are observed (present or recent), the forecast will be considered accurate regardless of the observed wind directions.

4.5.2 Wind Speed

Wind speeds are verified against the ICAO operational desirable accuracy except for change group consideration.

4.5.3 Visibility

Visibility is verified against the ICAO operational desirable accuracy except for change group and forecast resolution considerations. Since forecast should be expressed in steps of specified resolution, the forecast is still considered accurate if the observed visibility is not more than one resolution mark from ±30% of the forecast visibility.

4.5.4 Precipitation

Precipitation is verified against the ICAO operational desirable accuracy, viz. occurrence or non-occurrence of moderate or heavy precipitation is correctly forecast. Light precipitation and other weather phenomena, such as freezing fog are not verified explicitly. That said, visibility forecast accuracy could provide hints on the performance of predicting the occurrence or non-occurrence of these phenomena, especially where they cause a significant change in the visibility.

4.5.5 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).

In accordance with ICAO ANNEX 3, clouds with the height of cloud base below 5 000 ft are considered to be of operational significance. Thus, for TAF, only those clouds forecast or reported at or below 5 000 ft are verified. The verification follows the ICAO operational desirable accuracy except for change group consideration.

4.5.6 Cloud Height

Similar to cloud amount, only cloud ceilings below 5000 ft are verified. Cloud heights are verified against the ICAO operational desirable accuracy.

4.5.7 Temperature

Trend forecast does not include temperature forecast. For TAF with a validity period of up to 30 hours, there could be multiple maximum (minimum) temperatures given in the TAF. Since the ICAO operational desirable accuracy has no specific requirement on the accuracy of the timing of occurrence of maximum and minimum temperatures, the time of occurrence of maximum / minimum temperatures is not considered. Also, only the highest (lowest) of the two maximum (minimum) temperature will be verified. Maximum and minimum temperatures are then verified against the ICAO operational desirable accuracy.

4.6 Computation of the Percentage of Accurate Forecasts

AFVS-2008 compares the “weather profile” (constructed in the manner described in section 4.1 above) of each of the meteorological elements with the forecast to determine the number of minutes in which the weather condition has been accurately forecast. Accordingly, the percentage of accurate forecast for individual meteorological elements is computed based on the total number of minutes of accurate forecast and

the total number of minutes of the forecast being verified. For temperature forecasts in TAF, the total number of minutes of verified forecast is deemed to be the whole validity period of the TAF concerned.

Appendix D shows a hypothetical case of verification of precipitation forecast to illustrate how the duration of accurate forecast is determined based on the constructed "weather profile". The illustration is based on a hypothetical TAF but the principle is the same for a trend forecast.

For aerodrome forecast as a whole, an "overall" percentage of accurate forecast is computed by time-weighted averaging the percentage of accurate forecast for each of the meteorological elements covered in the aerodrome forecast based on the duration of forecast verified.

Daily/monthly/yearly percentage of accurate forecast is computed by weighted averaging the percentage of accurate forecasts over the day/month/year based on the duration of forecasts being verified as covered in aerodrome forecasts issued on that day or during that month/year.

5. VERIFICATION RESULTS

At the time AFVS-2008 was declared operational in November 2008, it was configured to handle both trend forecast and 30-hour TAF.

While one of the reasons for the creation of AFVS-2008 to replace AFVS-2000 was the adoption of 30-hour TAF, the new system was implemented in a way that it can handle both 24-hour and 30-hour TAF automatically.

The performance of HKO's aerodrome forecasts as verified by AFVS-2008, viz., annual verification results for the six meteorological elements covered in trend forecast and comparison with ICAO requirements during 2011 to 2020 are given in Table 3a and Table 3b respectively, and those for the seven meteorological elements covered in TAF are given in Table 4a and Table 4b respectively. From the statistics, it can be seen that during 2011-2020, the percentage of accurate forecast is generally above "ICAO minimum percentage of cases within range" for all the meteorological elements covered in trend forecast and TAF for HKIA. By looking at the difference between the percentage of accurate forecast and the ICAO operationally desirable accuracy for each element, one can identify the meteorological elements, namely wind direction, visibility (and temperature applicable to TAF only) in that order, as areas that are most challenging to forecast accurately at HKIA.

6. DISCUSSION

The guidance on the operationally desirable accuracy of aerodrome forecasts stipulated in Attachment B to ICAO ANNEX 3 is the basic framework for the verification scheme. Due to operational requirements on issuance of trend forecast and 30-hour TAF and other practical constraints such as succinctness of the forecast, additional considerations are required in designing the verification scheme. For example, in respect of wind direction, the operationally desirable accuracy provided in the guidance does not take variable winds (coded with "VRB") into account.

With the enhanced capability of AFVS-2008, verification results of trend forecasts can be obtained. The enhancement is important as it enables HKO to obtain a more comprehensive picture on the accuracy of forecasts (TAF covers a longer range with a validity period up to 30 hours whereas trend forecast covers a shorter range with a validity period of only 2 hours) for HKIA.

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LIST OF REFERENCES

1. ICAO 2018 ICAO ANNEX 3 to the Convention on International Civil Aviation — Meteorological Service for International Air Navigation, International Civil Aviation Organization, 20th Edition (effected on 10 November 2018)

APPENDIX A

Examples illustrating application of the N-scheme and the T-scheme in the verification of trend forecast

For illustration purpose, let us focus on the forecast of visibility in all examples below.

Example 1

```
METAR VHHH 040000Z 09010KT 9000 FEW025 22/16 Q1018 NOSIG=
```

This is a forecast of "no significant change" with respect to the reported meteorological condition for all the meteorological elements, including visibility. In plain language, the forecast of visibility says:-

> "During 00:00-02:00 UTC on the 4th day of the month, the visibility will remain at 9 km."

The N-scheme is applied to verify the forecasts of all the meteorological elements, including visibility.

Example 2

```
METAR VHHH 040030Z 09010KT 9000 FEW025 22/16 Q1018 TEMPO 4000=
```

This is a forecast of "no significant change" for all the meteorological elements apart from visibility. In plain language, the forecast of visibility says:-

> "During 00:30-02:30 UTC on the 4th day of the month, the visibility will remain at 9 km but will temporarily fall to 4 000 m."

The N-scheme is applied to verify the forecasts of all the meteorological elements, including the forecast visibility of 9 km. However, the T-scheme is applied to verify the forecast visibility of 4 000 m indicated by the "TEMPO" indicator, and the contribution of the "TEMPO" group is determined in the way as explained in Appendix B.

Example 3

```
METAR VHHH 040100Z 09010KT 9000 FEW025 22/16 Q1018 BECMG
FM0130 TL0230 4000=
```

This is a forecast of "no significant change" for all the meteorological elements apart

from visibility. In plain language, the forecast of visibility says:-

> "During 01:00-01:30 UTC on the 4th day of the month, the visibility will remain at 9 km. The visibility will fall from 9 km to 4 000 m during 01:30-02:30 UTC and the change will be completed at 02:30 UTC. Then, the visibility will remain at 4 000 m till 03:00 UTC."

The N-scheme is applied to verify the forecasts of all the meteorological elements, including the forecast visibility of 9 km, for the period 01:00-02:30 UTC. The "BECMG" indicator is treated as a "TEMPO" indicator for the period 01:30-02:30 UTC (see section 4.3.2(a)). Accordingly, the T-scheme is applied to verify the forecast visibility of 4 000 m as indicated in this *pseudo* "TEMPO" group, and the contribution of this *pseudo* "TEMPO" group is determined in the way as explained in Appendix B. The N-scheme is also applied to verify forecasts of all other meteorological elements apart from visibility for the period 02:30-03:00 UTC, but the T-scheme is applied to verify the forecast visibility of 4 000 m for this period.

In essence, the process is summarized in the following:

i. For the period of 01:00-01:30, apply N-scheme for all elements, including visibility forecast of 9 000m.
ii. For the period of 01:30-02:30, apply T-scheme for forecast visibility of 4 000 m; N-scheme for all other elements including visibility forecast of 9 000m.
iii. For the period of 02:30-03:00, apply T-scheme for forecast visibility of 4 000m, and N-scheme for all other elements. Note that the visibility forecast of 9 000 m no longer exists within this period.

Example 4

```
METAR VHHH 040130Z 09010KT 9000 FEW025 22/16 Q1018 BECMG
AT0230 4000=
```

This is a forecast of "no significant change" for all the meteorological elements apart from visibility. In plain language, the forecast of visibility says:-

> "During 01:30-02:30 UTC on the 4th day of the month, the visibility will remain at 9 km. The visibility will fall to 4 000 m at 02:30 UTC. Then, the visibility will remain at 4 000 m till 03:30 UTC."

The N-scheme is applied to verify the forecasts of all the meteorological elements, including the forecast visibility of 9 km, for the period 01:30-02:30 UTC. The N-scheme is also applied to verify forecasts of all other meteorological elements apart from visibility for the period 02:30-03:30 UTC, but the T-scheme is applied to verify the forecast visibility of 4 000 m for the period of 02:30-03:30 which is the remaining time immediately after the AT indicator.

APPENDIX B

Treatment for "TEMPO" groups in the verification

AFVS-2008 determines the contribution of a "TEMPO" group to the total duration (in minute) of accurate forecast, $U(A)$, in the following way:-

For a "TEMPO" group covering a period of N minutes, the following variables are defined:-

$U(M)$:	duration (in minute) of accurate forecast covered in the main group
$U(T)$:	duration (in minute) of accurate forecast covered in the "TEMPO" group
$U(T\overline{M})$:	duration (in minute) of accurate forecast covered in the "TEMPO" group while forecast covered in the main group is inaccurate

(i) Case of $U(T) > 0$:

contribution of the main group is: $U(M)$

contribution of the "TEMPO" group is: $\min(\frac{N}{2}, U(T\overline{M}))$

$$U(A) = U(M) + \min(\frac{N}{2}, H(T\overline{M}))$$

(ii) Case of $U(T) = 0$:

contribution of the main group is: $U(M)$

contribution of the "TEMPO" group is: $-\frac{N}{3}$

$$U(A) = \max(0, U(M) - \frac{N}{3}))$$

For the treatment involving (N/2) in (i), it creates an upper bound considering that the fluctuations *should*, in the aggregate, last for a period of less than one-half of the specified forecast period. For the treatment involving (-N/3) in (ii), a penalty is imposed if the expected fluctuations in weather condition are not observed *at all*.

APPENDIX C

Detailed Verification scheme

Detailed treatment for each of the meteorological elements covered in trend forecast and TAF are described below with details on handling special situation, viz. change group (CG) or other operation consideration (OP), if criteria other than operational desirable accuracy are used.

C.1 Wind Direction

<table>
<tr><th>N-scheme</th><th>T-scheme</th><th>TAF</th></tr>
<tr><td colspan="3">Condition for not carrying out verification</td></tr>
<tr><td>• (CG) If both the forecast and observed wind speeds are less than 10 kt[6], the forecast wind direction is not verified as the change group criteria would not be met.</td><td colspan="2">• (OP) From the point of view of day to day operations, there is little meaning in verifying the wind direction when winds are light. Forecast wind direction is thus not verified if both the forecast and observed wind speeds are equal to or less than 6 kt (i.e. light winds)[7] except for the cases that variable winds are forecast and/or observed</td></tr>
<tr><td colspan="3">Condition if a forecast is considered accurate</td></tr>
<tr><td colspan="3">A forecast wind direction is considered accurate if any one or more of the followings holds:-

• Variable winds are forecast and observed;
• (OP) Variable winds are forecast and thunderstorms (present or recent) are observed, regardless of observed wind direction[8].</td></tr>
</table>

[6] A change in wind direction, no matter how large, would not suffice to meet the trend-criteria in case the wind speed before and after the change is less than 10 kt.

[7] The rationale is that in light wind condition, the wind direction is often indefinite.

[8] The rationale is that variable winds can reasonably be expected at or near the time of thunderstorms.

• (CG) The observed wind direction deviates less than 60 degrees from the forecast	• The observed wind direction deviates less than 20 degrees from the forecast	• (CG) The observed wind direction deviates not more than 60 degrees from the forecast
	• (OP) Variable winds are forecast and the forecast and observed wind speeds are less than or equal to 6 kt, regardless of the observed wind direction[9] • (OP) The wind speed is forecast to be less than or equal to 6 kt, and variable winds are observed with wind speed less than or equal to 6 kt[10]	

[9] The rationale is that in light wind condition, wind direction is often varying and can be regarded as variable.

[10] The rationale is that it is justifiable to forecast variable winds if light winds are expected.

C.2 Wind Speed

N-scheme	T-scheme	TAF
Condition if a forecast is considered accurate		
• (CG) the observed wind speed deviates less than 10 kt from the forecast	• if the observed wind speed deviates not more than 5 kt from the forecast	• (CG) if the observed wind speed deviates not more than 10 kt from the forecast

C.3 Visibility

N-scheme	T-scheme	TAF
Condition if a forecast is considered accurate		
• (CG) the forecast and observed visibility values are within the same range as listed below:- 1. 5 000 m to 9 000 m, and "9999" 2. 3 000 m to 4 900 m 3. 1 500 m to 2900 m 4. 800 m to 1 400 m 5. 600, 650, 700, 750 m 6. 350, 400, 450, 500, 550 m 7. 150, 200, 250, 300 m 8. 0, 50, 100 m	• the forecast visibility is less than or equal to 800 m, and the observed visibility deviates not more than 200 m from the forecast; or • (OP) the forecast visibility is over 800 m and less than or equal to 10 km, and the observed visibility deviates not more than 30%[11] from the forecast	

[11] Since the range between two bounding visibility values above 800 m (i.e. 800 m, 1 500 m, 3 000 m, 5 000 m and 10 km) is not fully covered by the range of 30% above or below any forecast value under the limitation of resolution (in steps of 100 m from 800 m to under 5 000 m; in steps of 1 000 m from 5 km to under 10 km), the forecast visibility is considered accurate if the observed visibility is between the resolution marks at or otherwise just 30% above/below the forecast. This treatment allows the use of one forecast value to cover the situation when the visibility is expected to fluctuate within two marginal visibility values (e.g. 1 500 m to 3 000 m). For example, a forecast visibility of 2 200 m is considered accurate if the observed visibility is between 1 500 m and 2 900 m (30% below and above 2 200 m are respectively 1 540 m and 2 860 m; so 1 500 m and 2 900 m are taken as the lower and upper tolerance limits).

C.4 Precipitation

N-scheme	T-scheme	TAF
Condition if a forecast is considered accurate		
A forecast precipitation is considered accurate if occurrence of any one or more (no matter which one) or non-occurrence of all of the following precipitation types is both forecast and observed:- • Freezing drizzle or rain • Low drifting or blowing snow • Moderate or heavy precipitation (including showers) • Thunderstorm, regardless of occurrence or non-occurrence (and in case of occurrence, the type and intensity) of the associated precipitation where "precipitation" means:- • Drizzle • Rain • Snow • Snow grains • Ice pellets • Ice crystals[12] • Hail • Small hail and/or snow pellets Verification of weather phenomena such as freezing fog are not performed explicitly. Note that the accuracy of visibility forecast is used to gauge the performance of forecasting these weather phenomena which are accompanied by a significant change in visibility.		

[12] When ICAO ANNEX 3 (18th Edition 2013 incorporating Amendment 76) became effective on 14 November 2013, the requirement for reporting ice crystals was deleted.

C.5 Cloud Amount

<table>
<tr><td>N-scheme</td><td>T-scheme</td><td>TAF</td></tr>
<tr><td colspan="3">Condition for not carrying out verification</td></tr>
<tr><td colspan="3">(OP) Only occurrence or non-occurrence of cloud of operational significance[13] are verified.</td></tr>
<tr><td colspan="3">Condition if a forecast is considered accurate</td></tr>
<tr><td colspan="3">A forecast cloud amount is considered accurate if</td></tr>
<tr><td>• (CG) the forecast and observed cloud layers of the largest amount below 1 500 ft are in the same class as listed below:-

1. Class 1: NSC/ FEW/ SCT
2. Class 2: BKN/ OVC</td><td colspan="2">• the forecast cloud layer of the largest amount is below 1 500 ft, and the observed cloud layer of the largest amount below 1 500 ft is within one category (NSC/FEW/SCT/BKN/OVC) from the forecast; or

• the forecast cloud layer of the largest amount with operational significance (i.e. below 5 000 ft for HKIA) is at or above 1 500 ft, and the observed cloud layer of largest amount with operational significance at or above 1 500 ft and the forecast are in the same class, as listed below:-

3. Class 1: NSC/FEW/SCT
4. Class 2: BKN/OVC</td></tr>
</table>

[13] Cloud with the height of cloud base below 1 500 m (5 000 ft) or below the highest minimum sector altitude, whichever is greater, or a cumulonimbus cloud or a towering cumulus cloud at any height.

C.6 Cloud Height

<table>
<tr><td>N-scheme</td><td>T-scheme</td><td>TAF</td></tr>
<tr><td colspan="3">Condition for not carrying out verification</td></tr>
<tr><td colspan="3">(OP) As verification of cloud amount is restricted to occurrence/non-occurrence of BKN/OVC, forecast cloud height is not verified if BKN/OVC cloud layer is not both forecast and observed or both the forecast and observed cloud bases of the lowest BKN/OVC cloud layer are above 5 000 ft.</td></tr>
<tr><td colspan="3">Condition if a forecast is considered accurate</td></tr>
<tr><td>• (CG) the forecast and observed cloud bases of the lowest BKN/OVC cloud layer are within the same range as listed below:-

1. 0 ft
2. 100 ft
3. 200, 300 400 ft
4. 500, 600, 700, 800, 900 ft
5. 1 000 ft to 1 400 ft
6. 1 500 ft to 4 900 ft</td><td colspan="2">• forecast cloud base of the lowest BKN/OVC cloud layer is at or below 1 000 ft, and the observed cloud base of the lowest BKN/OVC cloud layer deviates not more than 100 ft from the forecast cloud base; or

• forecast cloud base of the lowest BKN/OVC cloud layer above 1 000 ft and below 5 000 ft, the forecast is considered accurate if the observed cloud base of the lowest BKN/OVC cloud layer deviates not more than 30% from the forecast cloud base.</td></tr>
</table>

C.7 Temperature forecasts in TAF

Temperature forecast includes forecasting maximum and minimum temperatures within the validity period of the TAF. Verification of temperature forecast differs from other meteorological elements in that the accuracy of temperature forecast is checked for the entire forecast period. There could be multiple maximum (minimum) temperatures given a TAF within the 30-hour forecast period. In such case, only the higher (lower) of the two maxima (minima) will be extracted and verified. Time of occurrence of the maximum / minimum temperatures is not considered.

APPENDIX D

Hypothetical case illustrating the determination of duration of accurate forecast and percentage of accurate forecast

1. The hypothetical case

Consider the following hypothetical 30-hour TAF, which was issued at 22:00 UTC on the 17th day of the month, valid from 00:00 UTC on the 18th day of the month to 06:00 UTC on the 19th day of the month:-

```
TAF VHHH 172200Z
      1800/1906 09010KT 8000 FEW010 SCT020 BKN040
      TX22/1807Z TN16/1823Z
TEMPO 1803/1806 4000 RA
BECMG 1809/1811 4000 RA
FM181800 36010KT 9999 FEW010=
```

Focusing on the forecast precipitation which in plain language means:-

"Between 00:00 UTC (start of valid period) to 03:00 UTC on the 18th day of the month, no precipitation;
Between 03:00-06:00 UTC on the 18th day of the month, mainly no precipitation but temporarily moderate rain;
Between 06:00-09:00 UTC on the 18th day of the month, no precipitation;
Between 09:00-11:00 UTC on the 18th day of the month, mainly no precipitation but becoming moderate rain;
Between 11:00-18:00 UTC on the 18th day of the month, moderate rain;
Between 18:00 UTC on the 18th day of the month to 06:00 UTC on the 19th day of the month (end of valid period), no precipitation."

Assuming the corresponding hypothetical observations are:

Moderate precipitation during the periods from 08:45 UTC to 10:30 UTC and 12:00 UTC to 20:15 UTC on the 18th day of the month.

2. Determination of duration of accurate forecast

The duration of accurate forecast in minute in respect of precipitation is determined as follows:-

<table>
<tr><td rowspan="2">Start time (UTC)</td><td rowspan="2">End time (UTC)</td><td rowspan="2">Time elapse (minutes)</td><td colspan="2">Forecast</td><td>Actual</td><td rowspan="2">Contribution to duration of accurate forecast (minutes)</td></tr>
<tr><td colspan="2">Moderate/ heavy precipitation forecast? (Yes/No)</td><td>Moderate/ heavy precipitation forecast? (Yes/No)</td></tr>
<tr><td></td><td></td><td></td><td>Main group</td><td>Change group</td><td rowspan="4">No</td><td></td></tr>
<tr><td>00:00, 18th</td><td>03:00, 18th</td><td>180</td><td>No</td><td>--</td><td>180</td></tr>
<tr><td>03:00, 18th</td><td>06:00, 18th</td><td>180</td><td>No</td><td>Yes (TEMPO)</td><td>120[a]</td></tr>
<tr><td>06:00, 18th</td><td>08:45, 18th</td><td>165</td><td rowspan="2">No</td><td rowspan="2">--</td><td>165</td></tr>
<tr><td>08:45, 18th</td><td>09:00, 18th</td><td>15</td><td rowspan="2">Yes</td><td>0</td></tr>
<tr><td>09:00, 18th</td><td>10:30, 18th</td><td>90</td><td rowspan="2">No</td><td rowspan="2">Yes (TEMPO)[b]</td><td rowspan="2">90[c]</td></tr>
<tr><td>10:30, 18th</td><td>11:00, 18th</td><td>30</td><td rowspan="2">No</td></tr>
<tr><td>11:00, 18th</td><td>12:00, 18th</td><td>60</td><td rowspan="2">No</td><td rowspan="2">Yes (BECMG)[d]</td><td>0</td></tr>
<tr><td>12:00, 18th</td><td>18:00, 18th</td><td>360</td><td rowspan="2">Yes</td><td>360</td></tr>
<tr><td>18:00, 18th</td><td>20:15, 18th</td><td>135</td><td rowspan="2">No</td><td rowspan="2">No (FM)</td><td>0[e]</td></tr>
<tr><td>20:15, 18th</td><td>06:00, 19th</td><td>585</td><td>No</td><td>585</td></tr>
<tr><td colspan="3">Total duration of verified forecast (minutes):</td><td>1 800</td><td colspan="3">Total duration of accurate forecast (minutes):</td><td>1 500</td></tr>
</table>

(a) The TAF contains a "TEMPO" group with time period 03:00-06:00 UTC on the 18th day of the month. The forecast condition covered in that "TEMPO" group is "with precipitation" whereas during the same time period, the main group is "no precipitation". Referring to Appendix B, with the notation used therein, the duration of accurate forecast in such a time period is:-

$U(A) = \max(0, 180 - 180/3) = 120$ (as $U(M) = 180$ and $U(T) = 0$)

(b) The TAF contains a "BECMG" group with time period 09:00-11:00 UTC on the 18th day of the month. Pursuant to section 4.3.1, the "BECMG" group is treated as a "TEMPO" group in such a time period.

(c) The forecast condition covered in the *pseudo* "TEMPO" group (see (b) above) is "with precipitation" whereas during the same time period, the main group is "no precipitation". Referring to Appendix B, with the notation used therein, the duration of accurate forecast in such a time period is:-

$$U(A) = 30 + \min(120/2, 90) = 90 \quad (\text{as } U(M) = 30 \text{ and } U(T\overline{M}) = 90)$$

(d) The forecast condition "with precipitation" covered in the "BECMG" group with time period 09:00-11:00 UTC on the 18th day of the month takes effect from 11:00 UTC.

(e) The forecast condition "without precipitation" takes effect from 18:00 UTC on the 18th day of the month.

3. Determination of percentage of accurate forecast

Solely for the forecast precipitation in the hypothetical TAF, the percentage of accurate forecast is: total duration of verified forecast (1 500 minutes) over total duration of accurate forecast (1 800 minutes) in percentage, which equals 83.33%.

Figure 1 Location map of Hong Kong International Airport

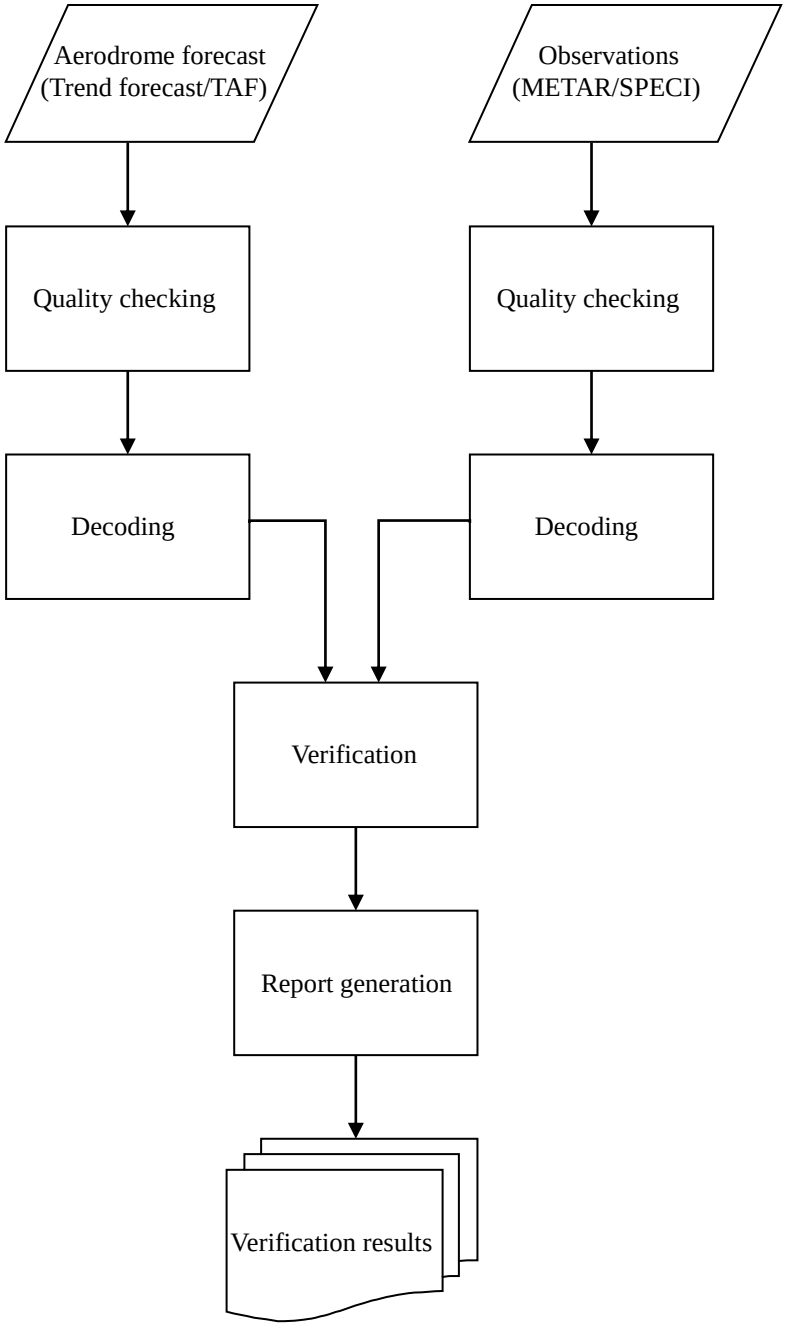

Figure 2 System flowchart of AFVS-2008

Table 1 Operationally desirable accuracy of trend forecast and criteria for accurate forecast adopted by AFVS-2008

Meteorological elements	ICAO operationally desirable accuracy (extracted from Attachment B to ICAO ANNEX 3)	Criteria for accurate forecast adopted by AFVS-2008		ICAO minimum percentage of cases within range
		N-scheme	T-scheme	
Wind direction	± 20°	± 60 ° (exclusive) (with extra criteria for verifying VRB)	Same as ICAO operationally desirable accuracy (with extra criteria for verifying VRB)	90%
Wind speed	± 5 kt	± 10 kt (exclusive)	Same as ICAO operationally desirable accuracy	90%
Visibility	± 200 m up to 800 m ± 30% between 800 m and 10 km	In the same categorical range with margins at 150 m, 350 m, 600 m, 800 m, 1 500 m, 3 000 m & 5 000 m	Same as ICAO operationally desirable accuracy (with consideration of limitation of resolution)	90%
Precipitation	Occurrence or non-occurrence	Same as ICAO operationally desirable accuracy except that light precipitation is not verified	Same as ICAO operationally desirable accuracy except that light precipitation is not verified	90%
Cloud amount	One category below 1 500 ft Occurrence or non-occurrence of BKN or OVC between 1 500 ft and 10 000 ft	Occurrence or non-occurrence of BKN or OVC below 1 500 ft	Same as ICAO operationally desirable accuracy for cloud of operational significance	90%
Cloud height	± 100 ft up to 1 000 ft ± 30% between 1 000 ft and 10 000 ft	In the same categorical range with margins at 100 ft, 200 ft, 500 ft, 1 000 ft, 1 500 ft	Same as ICAO operationally desirable accuracy for cloud of operational significance	90%

Table 2 Operationally desirable accuracy of TAF and criteria for accurate forecast adopted by AFVS-2008

Meteorological elements	ICAO operationally desirable accuracy (extracted from Attachment B to ICAO ANNEX 3)	Criteria for accurate forecast adopted by AFVS-2008 (see Section 4.1 for details)	ICAO minimum percentage of cases within range
Wind direction	± 20°	± 60° (with extra criteria for verifying VRB)	80%
Wind speed	± 5 kt	± 10 kt	80%
Visibility	± 200 m up to 800 m ± 30% between 800 m and 10 km	Same as ICAO operationally desirable accuracy (with consideration of limitation of resolution)	80%
Precipitation	Occurrence or non-occurrence	Same as ICAO operationally desirable accuracy except that light precipitation is not verified	80%
Cloud amount	One category below 1 500 ft Occurrence or non-occurrence of BKN or OVC between 1 500 ft and 10 000 ft	Same as ICAO operationally desirable accuracy for cloud of operational significance	70%
Cloud height	± 100 ft up to 1 000 ft ± 30% between 1 000 ft and 10 000 ft	Same as ICAO operationally desirable accuracy for cloud of operational significance	70%
Temperature	± 1° C	Same as ICAO operationally desirable accuracy	70%

Table 2a Comparison of ICAO desirable accuracy requirements on TAF on which AFVS-2000 and AFVS-2008 were based upon

Meteorological elements	AFVS-2000 based on requirements given in ICAO ICAO ANNEX 3 (14th Edition, 2001)	AFVS-2008 based on requirements given in ICAO ANNEX 3 (since 16th Edition, 2007 to 20th Edition, 2018)	Minimum percentage of cases within range
Wind direction	± 30°	± 20°	80%
Wind speed	± 5 kt (9 km/h) up to 25kt (46km/h) ± 20% above 25kt (46km/h)	± 5 kt	80%
Visibility	± 200 m up to 700 m ± 30% between 700 m and 10 km	± 200 m up to 800 m ± 30% between 800 m and 10 km	80%
Precipitation	Occurrence or non-occurrence	Occurrence or non-occurrence	80%
Cloud amount	± 2 oktas	One category below 1 500 ft Occurrence or non-occurrence of BKN or OVC between 1 500 ft and 5 000 ft	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)	± 100 ft up to 1 000 ft ± 30% between 1 000 ft and 5 000 ft	70%
Temperature	± 1° C	± 1° C	70%

Table 3a Annual verification results of trend forecast for HKIA(2011-2020)

Meteorological elements	Year									
Elements	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Wind direction	92.7%	92.6%	91.6%	92.2%	93.2%	92.7%	93.5%	93.3%	92.2%	92.9%
Wind speed	99.3%	99.1%	98.8%	99.0%	99.1%	98.8%	99.2%	99.3%	99.1%	99.2%
Visibility	96.0%	94.6%	94.4%	93.7%	95.3%	93.1%	94.8%	95.1%	94.9%	96.8%
Precipitation	97.6%	96.9%	95.8%	95.8%	96.7%	95.4%	96.6%	96.4%	96.1%	96.9%
Cloud amount	99.9%	99.5%	99.7%	99.7%	100.0%	99.7%	99.9%	100.0%	99.2%	99.7%
Cloud height	99.9%	99.5%	99.7%	99.7%	100.0%	99.8%	99.9%	100.0%	99.2%	99.6%

Table 3b Comparison of annual verification results of trend forecast for HKIA (2011-2020) against ICAO requirements

Meteorological elements	Annual percentage of accurate forecast			ICAO minimum percentage of cases within range (C)	Difference (F-C)
	Lowest	Weighted mean (F)	Highest		
Wind direction	91.6%	92.7%	93.5%	90%	2.7%
Wind speed	98.8%	99.1%	99.3%	90%	9.1%
Visibility	93.1%	94.9%	96.8%	90%	4.9%
Precipitation	95.4%	96.4%	97.6%	90%	6.4%
Cloud amount	99.2%	99.7%	100.0%	90%	9.7%
Cloud height	99.2%	99.7%	100.0%	90%	9.7%

Table 4b Annual verification results of TAF for HKIA
(2011-2020)

	Year									
Elements	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Wind direction	84.4%	86.6%	85.7%	86.8%	88.6%	85.6%	87.4%	87%	83.8%	86.0%
Wind speed	99.1%	98.4%	98.6%	99.2%	99.4%	99.2%	99.2%	99.3%	99.3%	98.9%
Visibility	92.3%	90.6%	92.5%	93.0%	94.1%	91.8%	93.9%	93.2%	92.0%	94.0%
Precipitation	97.5%	96.2%	95.8%	96.9%	97.3%	96.1%	97.4%	96.9%	95.4%	96.4%
Cloud amount	99.3%	97.2%	98.8%	98.3%	99.5%	99.3%	99.4%	99.0%	98.2%	97.8%
Cloud height	99.4%	97.2%	98.9%	98.3%	99.6%	99.4%	99.4%	99.0%	98.2%	97.7%
Temperature	82.5%	82.1%	83.3%	83.9%	83.5%	80.4%	81.9%	86.5%	82.9%	86.4%

Table 4b Comparison of annual verification results of TAF for HKIA
(2011-2020) against ICAO requirements

Meteorological elements	Annual percentage of accurate forecast			ICAO minimum percentage of cases within range (C)	Difference (F-C)
	Lowest	Mean (F)	Highest		
Wind direction	83.8%	86.2%	88.6%	80%	6.2%
Wind speed	98.4%	99.1%	99.4%	80%	19.1%
Visibility	90.6%	92.7%	94.1%	80%	12.7%
Precipitation	95.4%	96.6%	97.5%	80%	16.6%
Cloud amount	97.2%	98.7%	99.5%	70%	28.7%
Cloud height	97.2%	98.7%	99.6%	70%	28.7%
Temperature	80.4%	83.3%	86.5%	70%	13.3%