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Alerting of Terrain-induced Windshear Using Wind Data Measured over the Mountains

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1. INTRODUCTION

The Hong Kong International Airport (HKIA) is situated in an area of complex terrain. To its south is the mountainous Lantau Island with peaks rising to about 1000 m above mean sea level with valleys as low as 400 m in between. It is surrounded by seas in the other three directions. The complex topography results in low-level windshear encountered by the landing/departing aircraft at HKIA. In aviation meteorology, low-level windshear refers to sustained change of headwind of 15 knots or more at a height of 1600 feet or below. The major type of windshear at HKIA is terrain-induced airflow disturbance when winds from east, southeast through southwest blow over Lantau Island. It accounts for about 70% of the pilot reports of low-level windshear. The next common type is sea breeze, which accounts for about 20% of the pilot reports. The remaining 10% of the windshear reports is caused by gust front, microburst and low-level jet. It should however be noted that pilots tend to avoid penetrating thunderstorms, and so the actual percentage of occurrence of thunderstorm-induced windshear should be higher.

Since the majority of the low-level windshear at HKIA occurs in clear air condition, two Doppler LIght Detection And Ranging (LIDAR) systems are operated by the Hong Kong Observatory (HKO) for the alerting of windshear. Some background materials of low-level windshear at HKIA and its alerting by using LIDAR data could be found in Shun and Chan (2007). Before LIDARs were introduced to HKIA, windshear alerting had been achieved by making reference to anemometer readings inside and around HKIA. Such anemometer-based windshear rules are still useful nowadays at times of the maintenance of the LIDARs and under the weather conditions in which the data coverage of the LIDAR is limited, e.g. in rain and in low cloud-base situations in spring-time.

Among the anemometer-based windshear rules, the crosswind rule, namely, the crosswind component of Nei Lak Shan (NLS, location in Figure 1) with respect to the runway orientation exceeding a certain threshold for the issuance of windshear warnings/alerts, had been developed and adopted for HKIA for a long time (since about 2002). A number of new anemometers have since been set up around HKIA in the recent years. For instance, five weather buoys have been deployed over the seas to the east and west of HKIA in order to measure the winds directly under the flight paths. They have a height of about 8 m above sea level. Moreover, standard 10-m high anemometers are installed on some valleys and hilltops of Lantau Island, such as Pak Kung Au (PKA), Tai Fung Au (TFA), Ngong Ping (NGP) and Sham Wat hilltop (SW1). The locations of these stations could be found in Figure 1. With pilot windshear reports collected during the operation of these weather stations, a systematic analysis is carried out in this paper to find out any benefits of using the wind data from these anemometers in the issuance of windshear alerts and warnings, by comparing their performance with that based on the conventional NLS crosswind rule. Three quantities derived from the anemometer readings are considered, namely, crosswind, gust factor and standard deviation of the wind speed.

For windshear alerting services at an airport, the pilots would be warned through windshear warnings that are broadcast in the Automatic Terminal Information Service (ATIS) and windshear alerts that are relayed to the pilots by air traffic controllers via radio communication. The ATIS warnings last at least half an hour and are issued by aviation weather forecasters after assessing the likelihood of the occurrence of low-level windshear by considering the mesoscale to microscale meteorological patterns. On the other hand, windshear alerts are issued automatically by machine-based algorithms, e.g. in the Windshear and Turbulence Warning System (WTWS) at HKIA. They are updated more frequently than windshear warnings, for instance, an update rate of every 1 minute in WTWS. The frequent updating is necessary because of the transient and sporadic nature of low-level windshear, such as those associated with terrain-induced airflow disturbances.

2. DATA SOURCES

The anemometers considered in the present paper are shown in Figure 1. Their heights above mean sea level are given in Table 1. The anemometers on the ground measure the wind speed and direction by cup-star and wind vane respectively. For the weather buoys, propeller-type wind sensors are used. As a start, 1-minute mean winds from these anemometer stations are considered in the paper. For the gust, the maximum value of the running 3-second mean over every 1 minute interval is taken.

The pilot reports of low-level windshear and turbulence have been used as "sky truth" of the occurrence of windshear. Only those reports of windshear events occurring within 3 nautical miles from the runway ends are considered. As a start, this paper focuses on windshear reports over the most-used arrival runway corridor in the spring-time, namely, arriving at the north runway of HKIA from the

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west (07LA, location in Figure 1). The meteorological reason for each windshear report has been analyzed by examining all the available weather data. Based on the results of this analysis, only the windshear reports arising from terrain-disrupted airflow are studied in the present paper. A total of 519 reports over 07LA are examined here for the spring (February to April) in the years 2004 – 2007. Each windshear alert (when the quantity derived from the anemometer reading meets certain criteria) is taken to last 1 minute in the calculation of total alert duration for a certain anemometer-based windshear rule. It hits a pilot windshear report when there is a windshear alert within 5 minutes backward in time from the moment of windshear occurrence, considering the possible time elapsed between the issuance of the alert and the report by the pilot.

3. CROSSWIND

The conventional crosswind rule is considered, namely, the 1-minute mean crosswind component with respect to the runway orientation exceeds a certain threshold. As a first step, the frequency distributions of all data and during the occurrence of terrain-induced windshear over 07LA are plotted as a function of crosswind component of the various anemometer stations. The results are shown in Figure 2. Moments of windshear are based on the reporting times of low-level windshear by the pilots.

It could be seen from Figure 2 that, for certain anemometers, the frequency distributions of windshear occurrence and non-occurrence appear to have distinct peaks and smaller overlapping areas. Such stations include NLS, YTS (Yi Tung Shan, another hilltop station on Lantau Island, Figure 1), PKA, TFA and SW1. The crosswind threshold is varied to see how well the crosswind data could be used for providing windshear alerts. The performance of the crosswind rules for different anemometers is studied by examining the plot of hit rate versus alert duration (i.e. the percentage of the total alert duration over the total period of times that data are available from the anemometer under consideration). The resulting plot is shown in Figure 3. The ideal performance of the windshear rule appears at the upper left corner of the plot, i.e. a hit rate of nearly 1 and a very short alert duration.

The crosswind thresholds are plotted alongside the data points in Figure 3. It could be seen that the crosswind rule based on NLS anemometer has reasonably good performance, namely, for a crosswind threshold of 10 m/s (about 20 knots), the hit rate over 07LA is about 0.75 and the alert duration is around 17% of the time. This is basically the best compromise (between hit rate and alert duration) that could be achieved using the crosswind rule. For instance, with the use of other stations, such as PKA, TFA and YTS, the performance is very similar. It is interesting to note that similar performance could be obtained for 07LA using either valley or mountain top station.

On the other hand, it is noted that the use of runway anemometer stations gets not-so-good performance. For instance, based on the crosswind of R2C or R2W, the alert duration would be much longer (in the region of 30 – 40%) in order to achieve a hit rate of about 0.75. Though the runway anemometers are directly located under the flight paths of the aircraft, their readings may only be representative of the conditions along the flight paths. On the other hand, the effect of Lantau terrain on the occurrence of airflow disturbances to be encountered by the aircraft over 07LA may be better captured by the anemometers higher up on the mountains or even the valleys of Lantau Island.

4. GUST FACTOR

Gust factor is taken as the ratio between the 3-second gust within a minute and the mean wind speed of the corresponding minute. Similar to Figure 2, the frequency distributions of windshear occurrence and all data for the various gust factor thresholds of some anemometers inside and around HKIA are shown in Figure 4. It could be seen that, for most anemometers, the frequency distributions do not show up having separate peaks except SW (Sham Wat, Figure 1). The resulting plot of hit rate versus alert duration is given in Figure 5. As expected, it turns out that the gust-factor rule based on SW has the best performance. In fact, it works even better than the crosswind rules. For an alert duration of about 17%, the hit rate reaches about 0.82. The present study is based on the pilot reports of a few years only and more data would be necessary to compare the performance of crosswind-based and gust-factor-based rules.

5. STANDARD DEVIATION

The standard deviation of the wind at an anemometer station is calculated based on the 15 numbers of 1-minute mean wind speed in the last 15 minutes ending at the current minute. The frequency distributions of windshear occurrence and all data at different values of the standard deviation are shown in Figure 6. It could be seen that separate peaks are discernible for TFA, SW, SW1 and WB1 (location in Figure 1). Even for the runway anemometers such as R2W and R2C, separate peaks with not-so-large overlapping regions of the two frequency distributions could be found. The airflow disturbances higher up in the air that are encountered by the aircraft may have some degree of correlation with the fluctuations of the wind speed at the stations near the sea level.

The plot of hit rate versus alert duration for the standard-deviation-based windshear rules is given in Figure 7. It is interesting to note that SW again has the best performance. At an alert duration of about 17%, the hit rate reaches around 0.73. As discussed previously, a larger dataset of pilot windshear reports may be necessary to ascertain the performance of the various rules.

6. CONCLUSIONS

This paper discusses the applications of a number of quantities derived from the anemometer measurements in the warning of low-level windshear over the most-used arrival runway corridor of HKIA, viz. 07LA. Apart from the “crosswind rule” that has been used in the issuance of ATIS windshear warnings and automatic windshear alerts, the gust factor and the standard deviation of the wind speed over a period of 15 minutes could be useful in considering the issuance/cancellation of windshear warnings as well. In particular, the gust factor based on the anemometer station SW appears to outperform the crosswind rule according to the 4-year dataset considered in the present paper. Future studies of the anemometer-based windshear rules would include the followings:

(a) A longer period of study would be considered, for instance, including the data in 2008 and 2009 as well;

(b) Apart from 07LA (which is most used during the spring-time windshear season), the other most used arrival runway corridor, namely, 25RA (arriving at north runway of HKIA from the east) would also be considered. Moreover, apart from spring-time situations when the atmospheric stability is high, separate windshear rules for tropical cyclone cases may need to be developed;

(c) 1-minute data are considered in this paper. The anemometer data are actually updated and archived every second. The 1-second data may be useful in deriving the reference quantities for windshear warning purpose, for instance, in the calculation of standard deviation of the wind speed.

References

Shun, C.M., and P.W. Chan, 2008: Applications of an infrared Doppler LIDAR in detection of windshear. *J. Atmos. Ocean. Tech.*, **25,** 637 – 655.

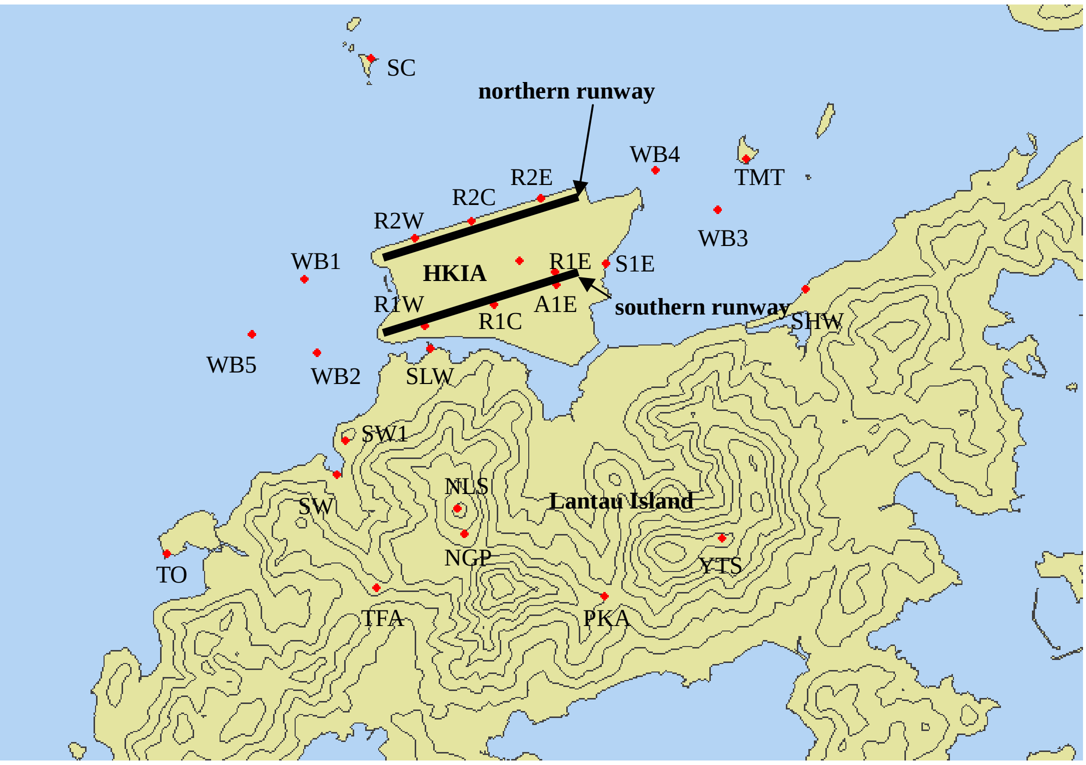

Figure 1 Anemometer stations inside and around the Hong Kong International Airport (HKIA). Station code of the station is given alongside the location of the station. The height contours of terrain are shown every 100 m.

Station name	**Station code**	**Height of wind sensor above mean sea level**
Ngong Ping	NGP	607.4 m
Nei Lak Shan	NLS	757.3 m
Pak Kung Au	PKA	386.2 m
Stations at southern runway	R1E, R1C, R1W	15.0 m, 13.2 m, 15.2 m
Stations at northern runway	R2E, R2C, R2W	15.2 m, 13.7 m, 14.7 m
Sham Wat	SW	12.8 m
Sham Wat 2nd station	SW1	175.6 m
Tai Fun Au	TFA	361.3 m
Weather buoy No 1 - 5	WB1, WB2, WB3, WB4, WB5	about 8 m above sea surface
Yi Tung Shan	YTS	752.2 m

Table 1 List of anemometer stations considered in the present study.

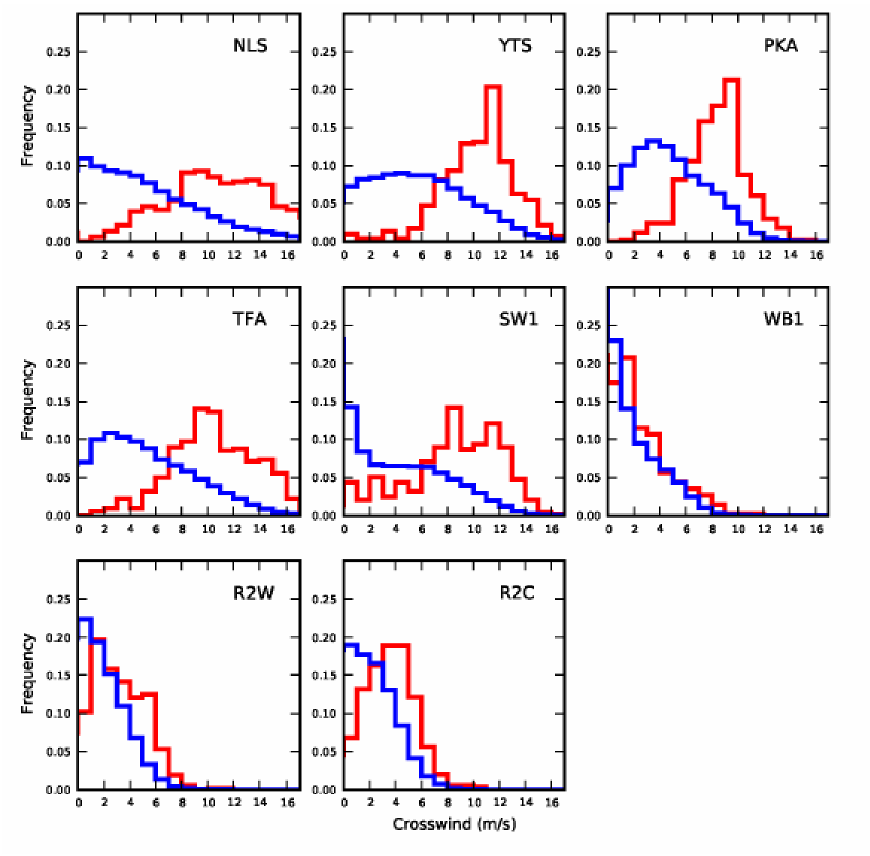

Figure 2 Frequency distribution of crosswind for the whole period (blue) and at times of terrain-induced windshear as reported by the pilots (red).

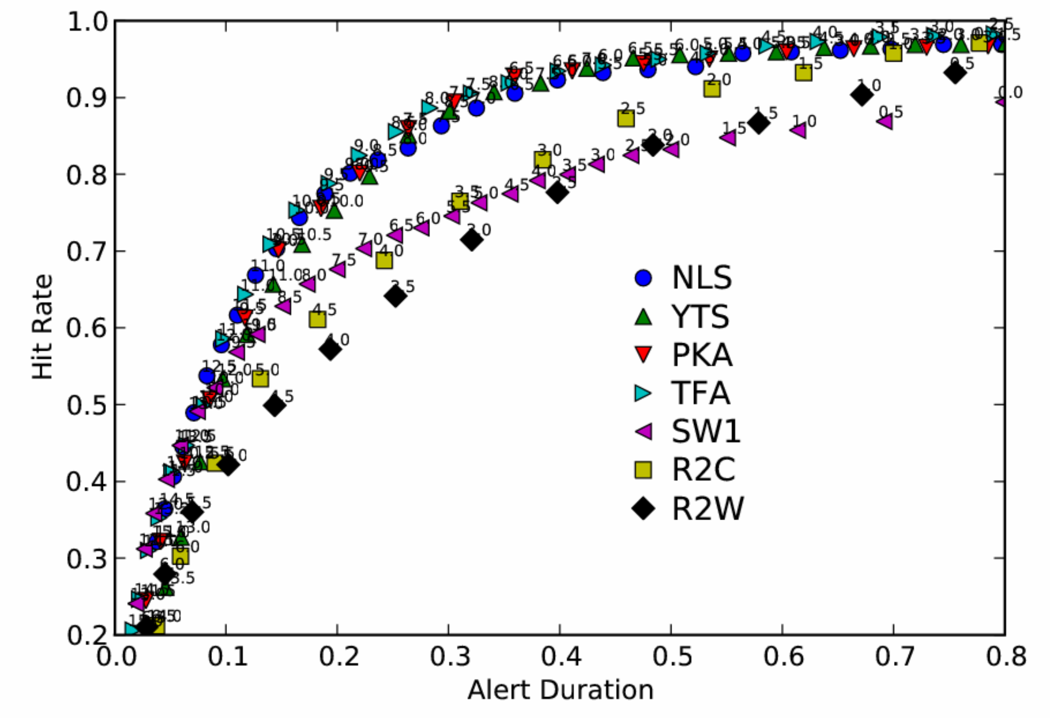

Figure 3 Hit rate versus alert duration for various crosswind thresholds of selected anemometer stations.

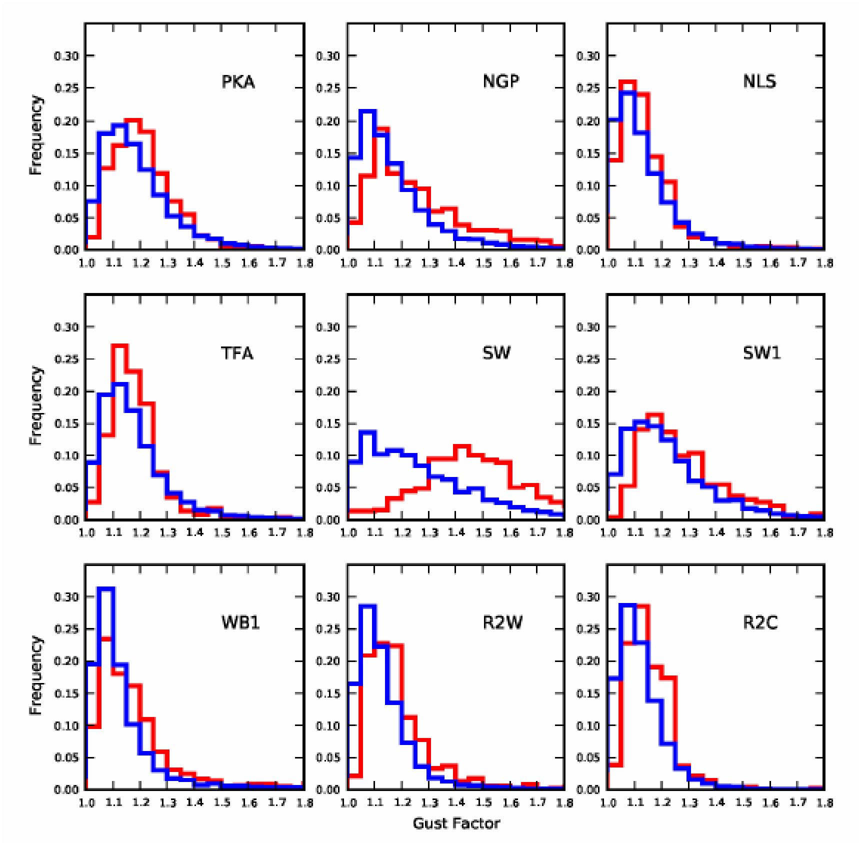

Figure 4 Frequency distribution of gust factor for the whole period (blue) and at times of terrain-induced windshear as reported by the pilots (red).

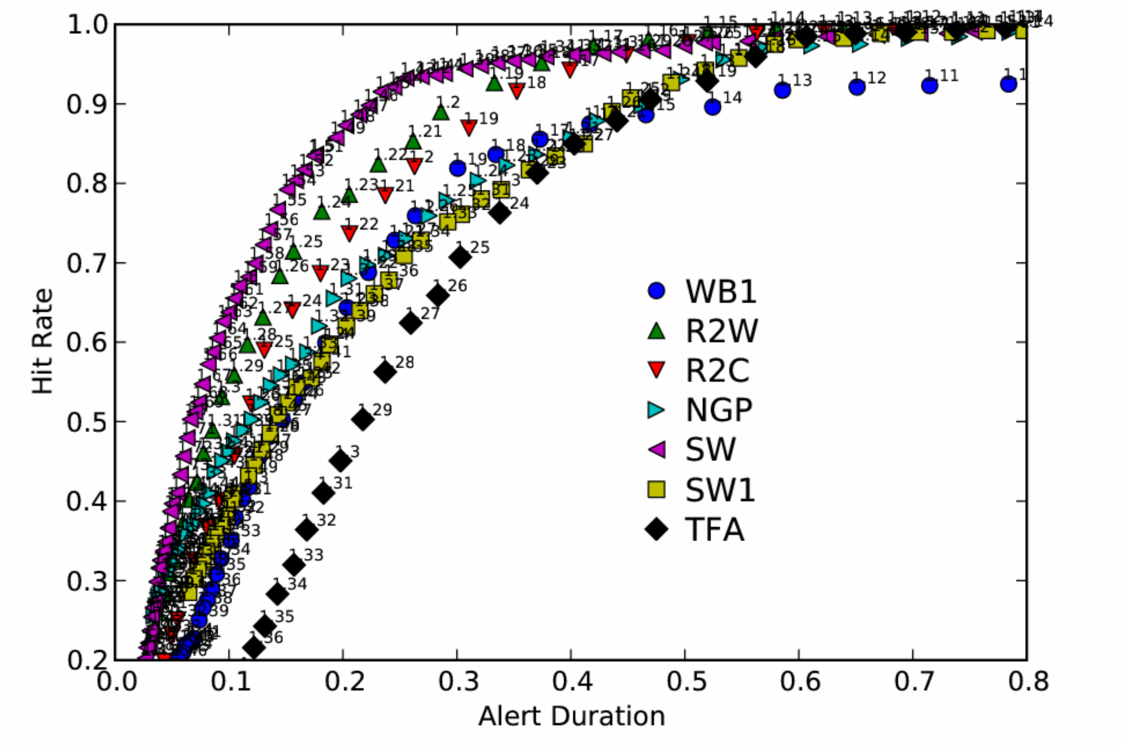

Figure 5 Hit rate versus alert duration for various gust factor thresholds of selected anemometer stations.

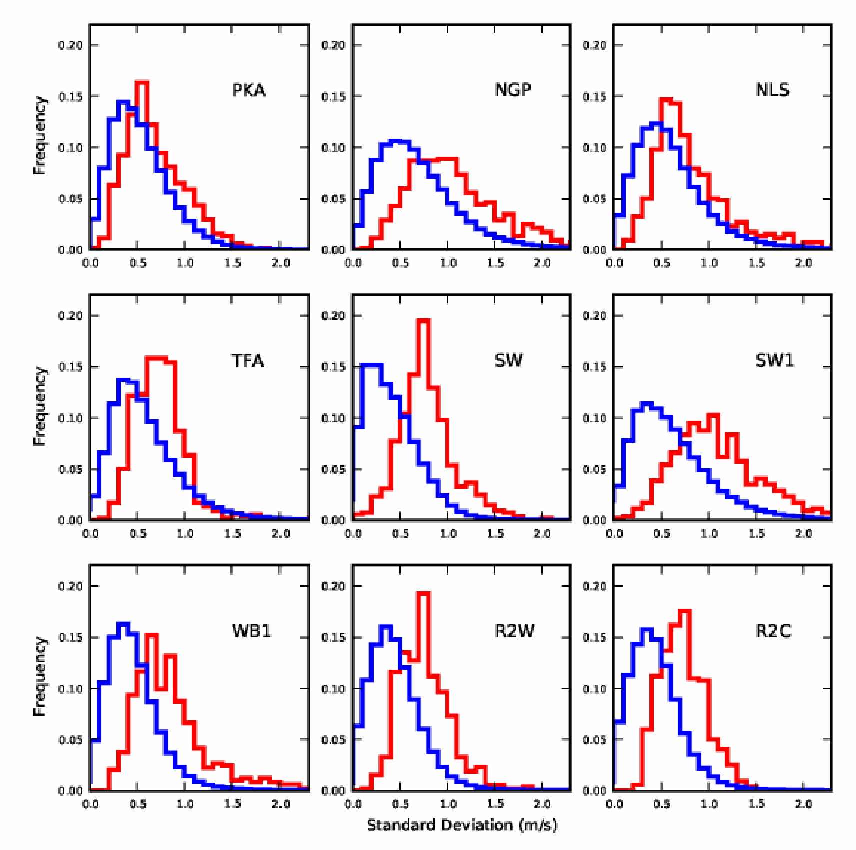

Figure 6 Frequency distribution of standard deviation for the whole period (blue) and at times of terrain-induced windshear as reported by the pilots (red).

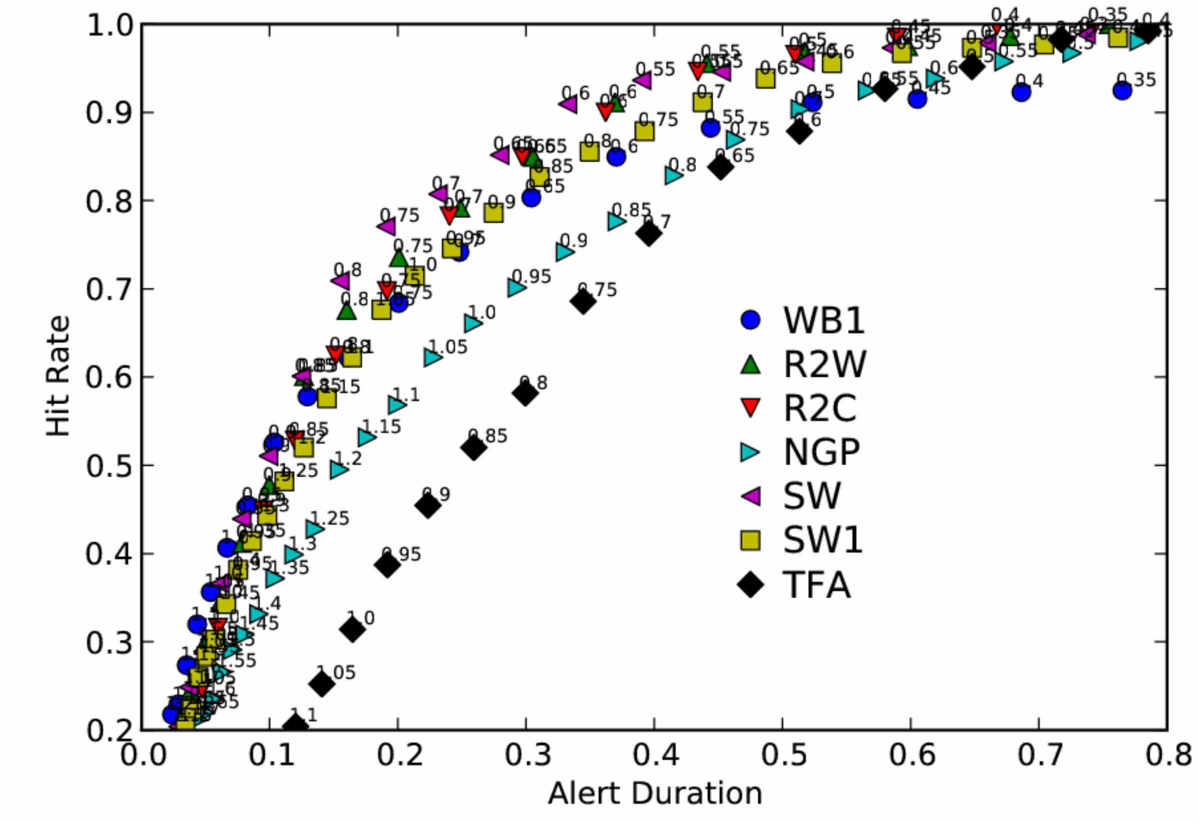

Figure 7 Hit rate versus alert duration for various standard deviation thresholds of selected anemometer stations.