HONG KONG OBSERVATORY

Technical Note No. 101

CASE STUDY OF A WINDSHEAR

CAUSED BY LOW-LEVEL JET

14 DECEMBER 1998

by

S.Y. Lau & S.T. Chan

摘要

本報告敘述在 1998 年 12 月 14 日數架飛機在香港國際機場〔赤鱲角〕遇上的風切變事件。此次事件是該機場啟用以來其中一次最先發生的顯著風切變事件。本文分析了引致該風切變事件的原因，並探討了天文台的風切變及湍流警告系統和一個數值預報模式對捕捉該風切變事件的能力。

Abstract

This note gives an account of the windshear encountered by several aircraft on 14 December 1998. The windshear was one of the first significant events occurring at the Hong Kong International Airport (Chek Lap Kok) after its opening. The cause of the windshear was analysed and the capability of the Windshear and Turbulence Warning System of the Hong Kong Observatory and a numerical weather prediction model in depicting such events was also studied.

Contents

		Page
	List of Figures	ii
I.	Introduction	1
II.	The Event	1
III.	Synoptic Situation	2
IV.	Weather Condition around Chek Lap Kok	2
V.	On-board Aircraft Data	2
VI.	Causes of the Windshear	3
VII.	Performance of the Windshear and Turbulence Warning System (WTWS)	4
VIII.	Model Simulation of the Low-level Jet	5
IX.	Conclusion	5
	Acknowledgments	5
	References	6

List of Figures

Page

1. Meteorological Equipment for windshear and turbulence detection at and around Chek Lap Kok 7

2. Surface Weather Chart as at 00Z 14 December 1998 8

3. (a) 850 hPa winds valid at 00Z on 14 December 1998 (based on JMA analysis) 9

   (b) 700 hPa winds valid at 00Z on 14 December 1998 (based on JMA analysis) 10

   (c) 500 hPa winds valid at 00Z on 14 December 1998 (based on JMA analysis) 11

4. Surface Winds at Chek Lap Kok on 14 December 1998 12

5. Geographical Situation Display as at 0742Z on 14 December 1998 13

6. Winds measured by Sha Lo Wan Wind Profiler on the afternoon of 14 December 1998 14

7. Winds measured by Sham Shui Po Wind Profiler on the afternoon of 14 December 1998 15

8. Doppler Winds as Measured by TDWR at 0741Z on 14 December 1998 16

9. Variation of Altitude with Time 17

10. Comparison of Winds Measured On-board with those from Sha Lo Wan Profiler 18

11. Variation of Air Speed, Ground Speed, Pitch and Angle of Attack with Time 19

12. Variation of Head Wind with Height 20

13. Variation of head wind with distance for 3 flights arriving between 0635 and 0655 UTC 14 December 1998 21

14. Geographical Situation Display as at 0742Z on 14 December 1998 22

15. Geographical Situation Display as at 0748Z 14 December 1998 23

16. Windshear Gain Magnitude as analysed by WTWS 24

17. (a) RSM Forecast Time Cross Section at HK grid (9812 1318 - 9812 1418 UTC, 60 km model run) 25

(b) RSM Forecast Time Cross Section at HK grid (9812 1318 - 9812 1418 UTC, 20 km model run) 26

I. Introduction

The Hong Kong International Airport (HKIA) located at Chek Lap Kok (CLK) came into operation on 6 July 1998. Being the designated authority to provide meteorological services for international air navigation in Hong Kong, the Hong Kong Observatory has equipped the HKIA with advanced meteorological systems, including a Terminal Doppler Weather Radar (TDWR) and a Windshear and Turbulence Warning System (WTWS), to detect and warn of the occurrence of windshear and turbulence around the airport.

The TDWR is strategically located at Tai Lam Chung, about 12 kilometers northeast of CLK to give it a clear view of the runways, airport approach and departure areas (Fig. 1). It was purposely built to serve the terminal area of the airport and detects microburst and windshear associated with convective storms. Similar TDWRs have been widely deployed for operational use in major U.S. airports.

Owing to the proximity of the hills on Lantau, the HKIA is also susceptible to low-level windshear and turbulence induced by terrain. The WTWS has been specifically developed for detection of such phenomena. The WTWS takes in data from a host of meteorological sensors including the TDWR, a network of over 20 anemometers over Hong Kong and a wind profiler at Sha Lo Wan (one more at Siu Ho Wan around 2000).

An advanced data processing algorithm is applied to the radial winds, spectrum width and signal to noise ratio of the TDWR base data to detect terrain-induced windshear and turbulence in clear air. The WTWS also makes use of the wind data from the 6 anemometers along the 2 runways to detect low-level windshear. This part of the algorithm is similar to the Low Level Windshear Alert System (LLWAS) that is widely used at U.S. airports. It also makes use of anemometers in exposed areas to measure the ambient wind and its fluctuation to determine the intensity of terrain-induced turbulence by correlation. The location and magnitude of any windshear and turbulence that occurred below 1,000 ft (within 3 nautical miles of the airport runways assuming a 3° glide path) are estimated based on all data sources. Through the use of an integrated detection algorithm, a consolidated estimate and thus a coherent alert is generated for the warning area. More detail descriptions of the algorithm are given in WITI 1996[1] and 1997[2].

This note gives an account of the windshear encountered by several aircraft on 14 December 1998. The windshear was one of the first significant events occurring at the HKIA after the opening of the airport. The cause of the windshear was analysed and the capability of the WTWS and a NWP model in depicting such events then followed.

II. The Event

A number of pilots reported encountering severe windshear at around 1,500 ft on departure on 14 December 1998. In particular, the pilot departing at 0655Z reported encountering light windshear at 100 ft which increased to severe windshear of 30 kt above 1,500 ft (6 nm from runway threshold). According to the pilot, the severe windshear abated at around 6,000 ft.

The pilot of another aircraft departing at 0751Z reported severe windshear and moderate turbulence on departure from RWY 07R. The airspeed varied by -15 kt to +25 kt at altitudes of 1,300 to 2,200 ft. Based on Air Traffic Control radar recording, the plane passed through the altitude band of 1,300 to 2,200 ft around 0.75 and 2 nm from the end of the runway.

III. Synoptic Situation

A northerly surge reached Hong Kong on 11 December 1998. The northerlies moderated on 12 and 13 December but strengthened again on 14 December. The surface weather chart is given in Fig. 2. The Strong Monsoon Signal was hoisted at noon and remained in force throughout the day. Fig. 3(a) to (c) show the 850 hPa (around 5,000 ft), 700 hPa (around 10,000 ft) and 500 hPa (around 19,000 ft) upper-air analysis valid at 00Z on 14 December 1998. At 850 hPa, the northerly airstream and the moist southeasterly airstream converged over the South China coastal waters. A 500 hPa westerly trough was approaching Hong Kong with strong south to southwesterly winds over the southern China. There were also strong south to southwesterly winds over southern China at 700 hPa.

IV. Weather Condition around Chek Lap Kok

Surface winds at CLK were northerlies around 10 kt throughout the morning and afternoon (Fig. 4). However, winds on mountain tops on Lantau, namely Nei Lak Shan and Yi Tung Shan were generally gale force (40-50 kt) in the afternoon (Fig. 5). The Sha Lo Wan profiler captured a low-level jet at around 2,000 ft (Fig. 6). The low-level jet is even more prominent at Shamshuipo (Fig. 7). The presence of the low-level jet was also well captured by the Terminal Doppler Weather Radar (TDWR) 6° scan. At 0741Z the core of the low-level jet was observed to have a radial speed of 40 kt or above (coloured in pink to red in Fig. 8) extended from around 800 m to 1,200 m, in fairly good agreement with the Sha Lo Wan profiler data. Above 1,200 m, the radial speed dropped gradually again in good agreement with the Sha Lo Wan profiler data.

Surface winds strengthened to fresh northerlies in the evening. Temperatures at CLK dropped to 13.2°C that afternoon, the lowest in the month. Along with the cooler air, light rain patches set in from the west and 11.3 mm of rain were recorded at CLK. However between 06 and 08Z when windshear was reported, no rainfall was recorded at CLK.

V. On-board Aircraft Data

No on-board flight data was available from the flights at 0655Z and 0751Z. HKO was only able to obtain the data from a flight departing at 0743Z. This flight did not file any windshear report to the HKO. As the windshear experienced by the flights on that day was quite persistent, data from this flight should still be quite representative of the windshear experienced. The on-board data were provided to the HKO in the form of a database file and included data on the position, altitude, airspeed, ground speed, heading, pitch, roll as well as wind direction and speed.

The flight took off at 07:42:48 Z (Fig. 9). Based on the radio altitude, this flight climbed at around 9.6°, slightly steeper than the 7° climb of the flight at 0751Z.

It is noted that the winds measured on-board had a greater easterly component than those from the Sha Lo Wan profiler (Fig. 10). Based on the wind measured on-board, winds were 10 kt or less from near the surface up to around 800 ft. Winds then increased rapidly and were the strongest at around 3,350 ft, reaching 50 kt. Between 1,600 and 3,350 ft, the winds observed on-board were generally larger than those measured by the Sha Lo Wan profiler. The wind speed recorded by the aircraft then dropped sharply to around 15 kt at 3,800 ft which was much sharper than that detected by the Sha Lo Wan profiler and TDWR. As a result of the sudden drop in wind speed and thus the head wind, the pitch attitude decreased by 6.7° (0.12 rad) in 11 seconds (Fig. 11).

A very useful parameter often quoted for indicating the severity of the windshear and vertical velocity on aircraft performance is the F-Factor,

$$F = g^{-1} DU/Dt - w/V_a$$

where DU/Dt is the rate of change of the horizontal wind component along the aircraft flight path, g is the acceleration due to gravity, w is the vertical wind speed and V_a the airspeed of the aircraft. The first term on the right hand side represents the contribution due to head wind change while the second term represents the contribution due to vertical wind.

Due to the rapid increase in the wind speed, there was a rapid increase in head wind component, from 13 kt at 1,420 ft to 39 kt at 3,100 ft (Fig. 12). The average head wind gain over the period was 1.6 kt per 100 ft. Using the on-board flight data and considering only the head wind change component, the F-Factor (head wind change component) was 0.027.

As the wind speed measured on-board dropped sharply from 3,350 to 3,800 ft, the corresponding head wind change and F-Factor (head wind change component) were -5.7 kt per 100 ft and -0.168 respectively. This F-Factor value is slightly larger than the threshold for triggering on-board windshear alarm which is set to -0.15 for most aircraft.

VI. Causes of the Windshear

The shear experienced by the departing aircraft was due to vertical shear as the plane passed through a low-level jet. Based on the Sha Lo Wan profiler data at 0740Z, the vertical shear at around 1,100 ft was close to 8 kt per 100 ft (Table 1). Although this was lower than the 8 kt per 100 ft which had been used in the Windshear Warning System at the old Kai Tak Airport or the old ICAO recommendation of 10 kt per 100 ft for reporting of vertical shear for Category I operations, the increase in head wind was significant due to the steeper climb angle and that the shear was encountered very close to the end of the runway. Meanwhile for arriving flights, which descended at a lesser angle (3°), no significant shear was experienced within 9 nm from touchdown (Fig. 13).

VII. Performance of the Windshear and Turbulence Warning System (WTWS)

The WTWS windshear algorithm, which uses the radial winds measured by the TDWR for windshear detection, was operational at the time. No windshear alert was generated by the WTWS for the southern runway. The WTWS did generate moderate turbulence alert temporarily for RWY 07RD at 0730Z. The WTWS also detected lifting windshear over RWY 07D and a windshear shape was generated on the graphical situation display at 0742 and 0748Z close to the time when the aircraft reported windshear (Fig. 14 and 15). However, the shear magnitude was not strong enough and no alert was generated.

From the TDWR base data, an area of weak radial wind away from the radar was detected over CLK out to Tai Mo To. This feature was prominent in the low elevation scans (0.6° - 2.4° scans) but became less prominent from 6° scan upwards. At the surface, winds at Tai Mo To were northwesterlies instead of the prevailing northeasterlies (Fig. 4). However near the TDWR, the radial wind away from the radar was strong. The shear derived by the WTWS based on TDWR 0.6° scan data was 0.0039 m/s per m, or 15 kt over 2 km distance (Fig. 16). However when resolved along the runway, the shear became less and no alert was generated. The location of this shear region was out at 3 nm and did not correspond well with the location where windshear was experienced by the departing aircraft. Furthermore, this shear region was at low level and could not explain the shear encountered by the departing aircraft which was some 1,500 ft above ground.

The TDWR and WTWS were designed to detect low-level windshear within 3 nm from the end of the runway assuming a typical ascend/descend profile of 3°. In order to capture the low-level windshear, both systems use the lowest scan (0.6°) to deduce the shear magnitude. Higher scan angles would have to be used to detect windshear associated with elevated low level jets and the WTWS is simply not designed to warn of such windshear. Furthermore, since the location of the shear associated with elevated low level jets depends very much on the location where the aircraft encounters the jet and thus the ascend / descend profile, it would be difficult for the WTWS to give a warning on the location of windshear caused by such elevated low-level jets.

Empirical rules have subsequently been developed so that the aviation forecasters can issue windshear alerts manually based on Sha Lo Wan profiler data to cover these cases. If the Sha Lo Wan wind profiler indicates a low-level jet with maximum speeds greater than 30 kt at two or more consecutive levels below 1,500 m while the surface winds (all of the runway anemometers) were 15 kts or less, the aviation forecasters should issue a windshear alert manually for departing flights.

VIII. Model Simulation of the Low-level Jet

Since the aviation forecasters have to issue windshear alerts manually to cover windshear caused by low-level jets, a 20-km Regional Spectral Model (RSM) with 36 vertical levels was specially run to see if it could provide some guidance to aviation forecaster of the occurrence of the low-level jet. The RSM was adapted from the Japan Meteorological Agency (JMA) in 1997 and was tuned for the application in Hong Kong. The 20-km RSM, was put into semi-operation in 1999. It is nested into a 60-km RSM which became semi-operational in mid-1998. The lateral boundary conditions are taken from the JMA Global Spectral Model. Details of the model configurations and formulation can be found on the intranet and in NPD/JMA (1997)[3].

Fig. 17(a) and 17(b) show the time cross-section of the 60-km and 20-km model run initialized at 18Z 13 December 1998. Both runs successfully captured the strengthening of winds to 40 kts at 940 hPa at around 06Z on 14 December 1998, providing more than 6 hours of early warning to forecasters that a low-level jet would affect Hong Kong. The winds at Sha Lo Wan and Kings Park, however, had a more northerly component than the winds forecast by the model.

IX. Conclusion

The windshear experienced by departing flights on 14 December 1998 was mainly due to vertical shear associated with a low-level jet. The wind profilers proved to be very useful in depicting such low-level jets. The RSM forecast can also provide very useful guidance for forecasting the occurrence of this low-level jet. Although the vertical shear was weaker than the old ICAO recommendation for reporting vertical shear, the wind change experienced by departing flights was nonetheless significant due to the steep climb angle. More work would be done to explore ways to warn pilots of such windshear. However as this would involve the development of new detection algorithms and possibly changes in the design of the WTWS, it would take some time before improvements could be implemented. Meanwhile the aviation forecasters should monitor the Sha Lo Wan profiler winds closely and issue windshear alerts in accordance with the criteria given in the windshear forecasting rules.

Acknowledgments. The Hong Kong Observatory (HKO) gratefully acknowledge the support of Cathay Pacific Airways Ltd. which provided the flight deck data used in this study for the purpose of enhancing flight safety. The HKO would also like to thank pilots for filing windshear reports to the HKO. Special thanks to Miss C.C. Lam who conducted a special 20-km run of the RSM for this investigation.

References

[1] WITI, 1996, "Operational Windshear Warning System : Design Specification Document"

[2] WITI, 1997, "Operational Windshear Warning System : Technical Description"

[3] NPD/JMA, 1997, "Outline of the Operational Numerical Weather Prediction at the Japan Meteorological Agency. Appendix to Progress Report on Numerical Weather Prediction", pp. 48-63.

Figure 1.   Meteorological Equipment for windshear and turbulence detection at and around Chek Lap Kok

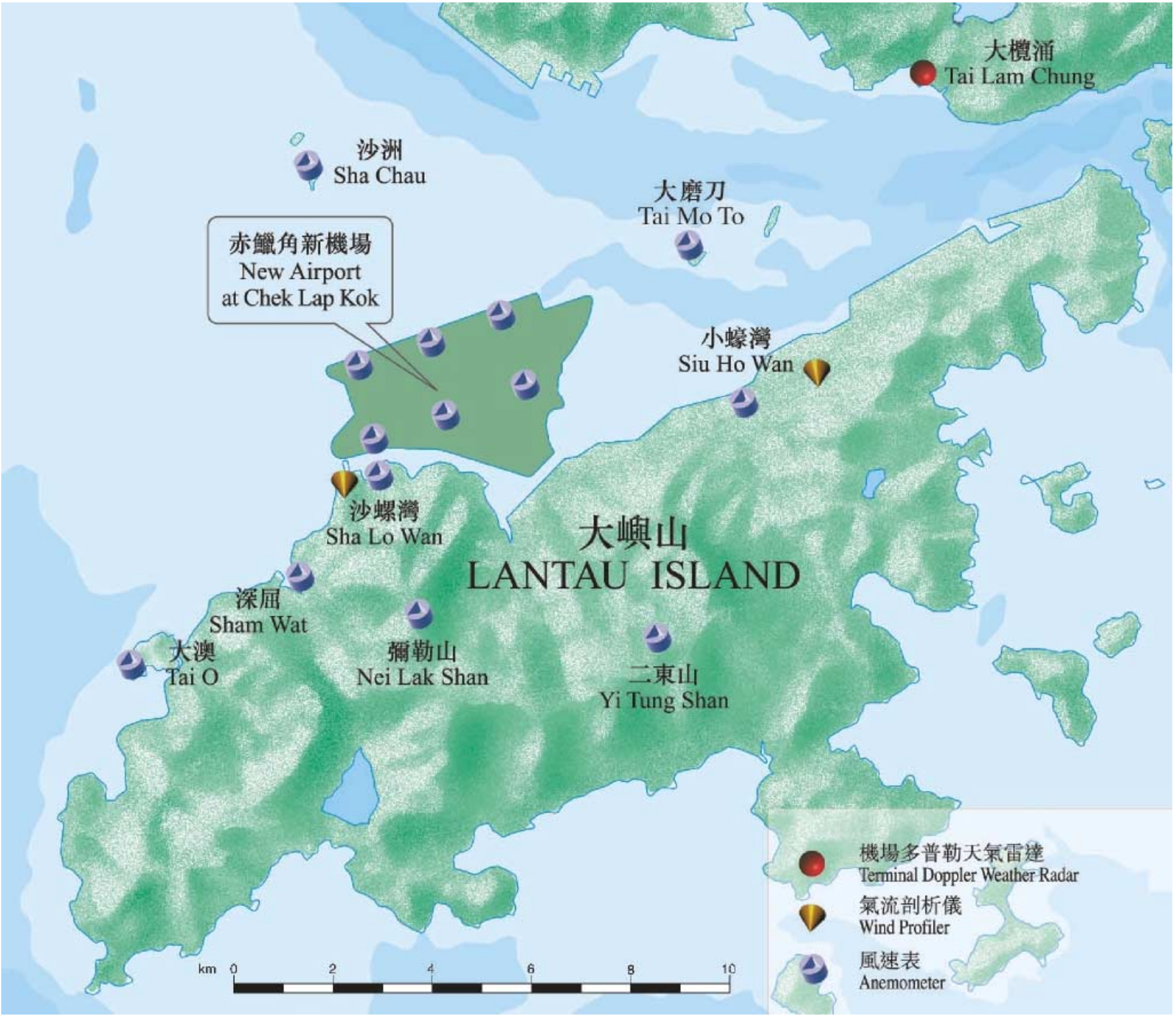

Figure 2. Surface Weather Chart as at 00Z 14 December 1998

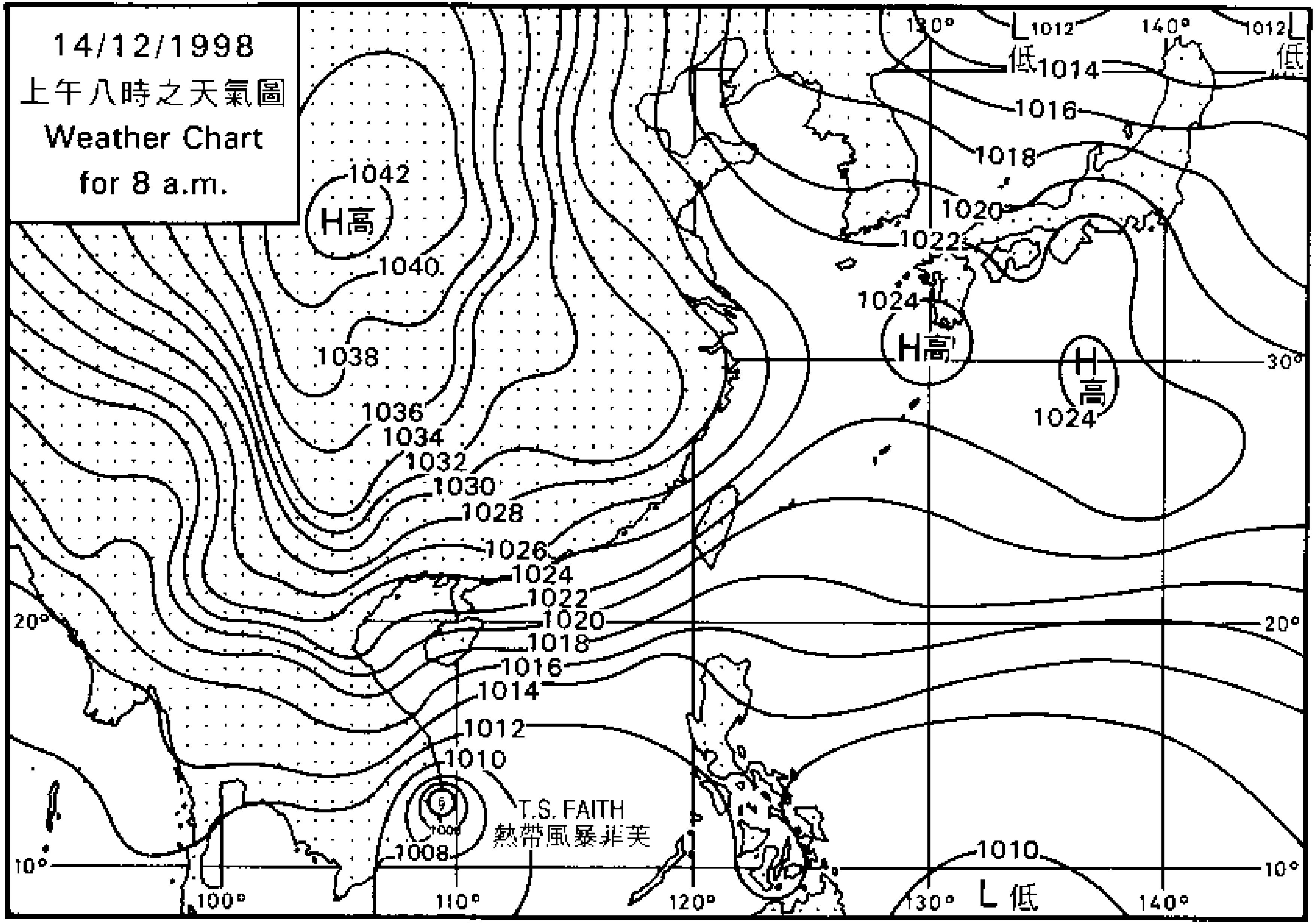

Figure 3(a). 850 hPa winds valid at 00Z on 14 December 1998 (based on JMA analysis)

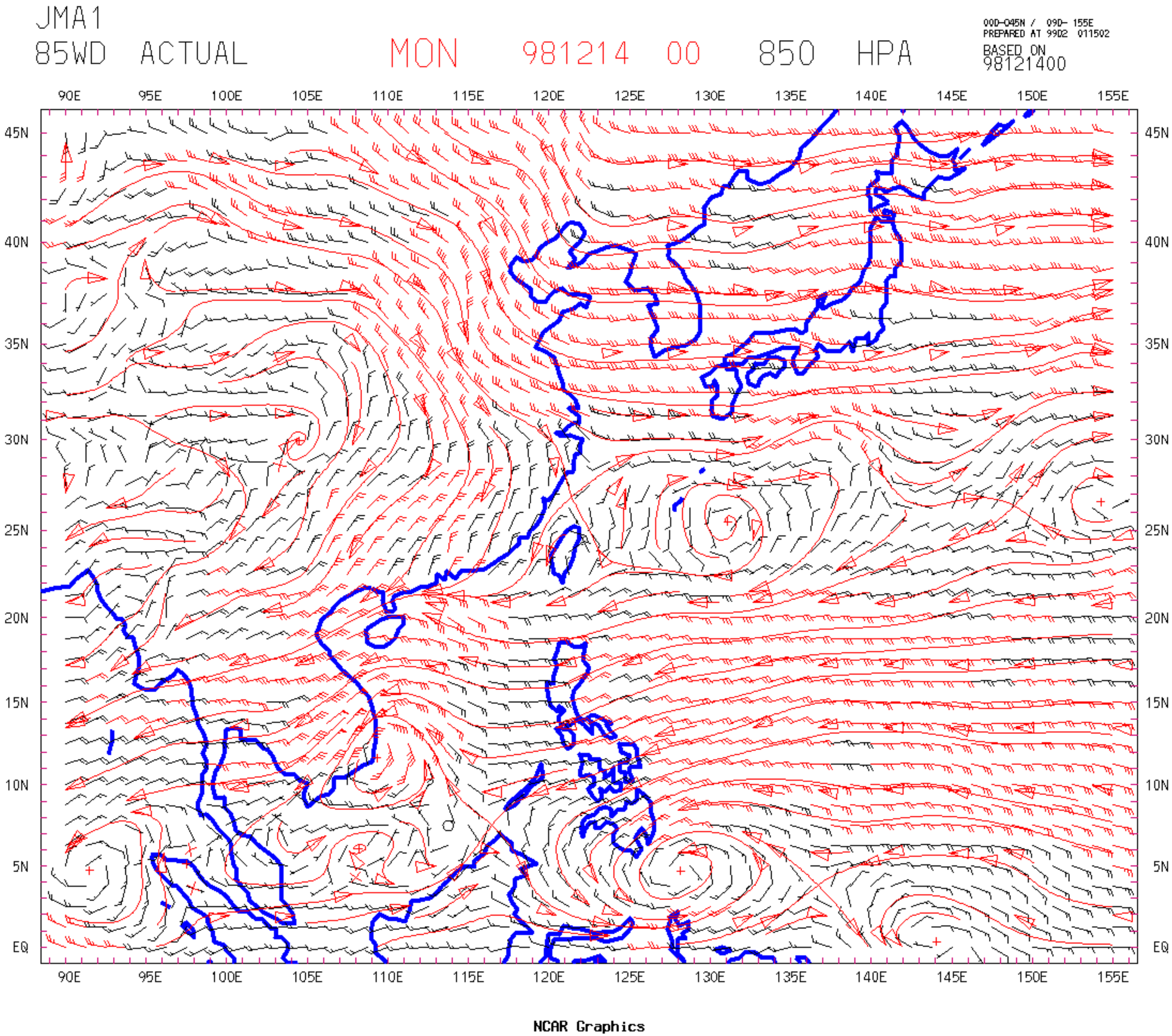

Figure 3(b). 700 hPa winds valid at 00Z on 14 December 1998 (based on JMA analysis)

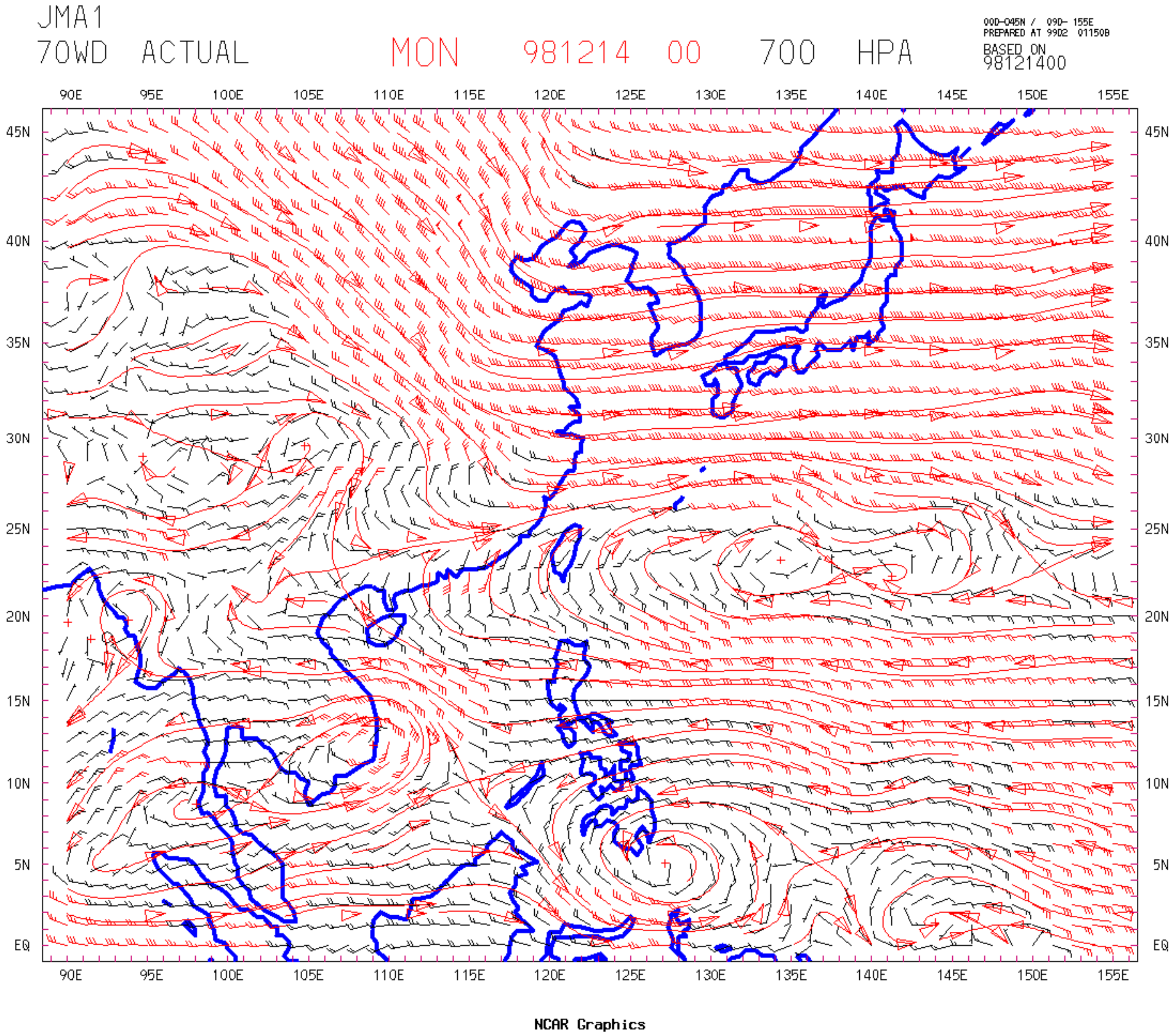

Figure 3(c). 500 hPa winds valid at 00Z on 14 December 1998 (based on JMA analysis)

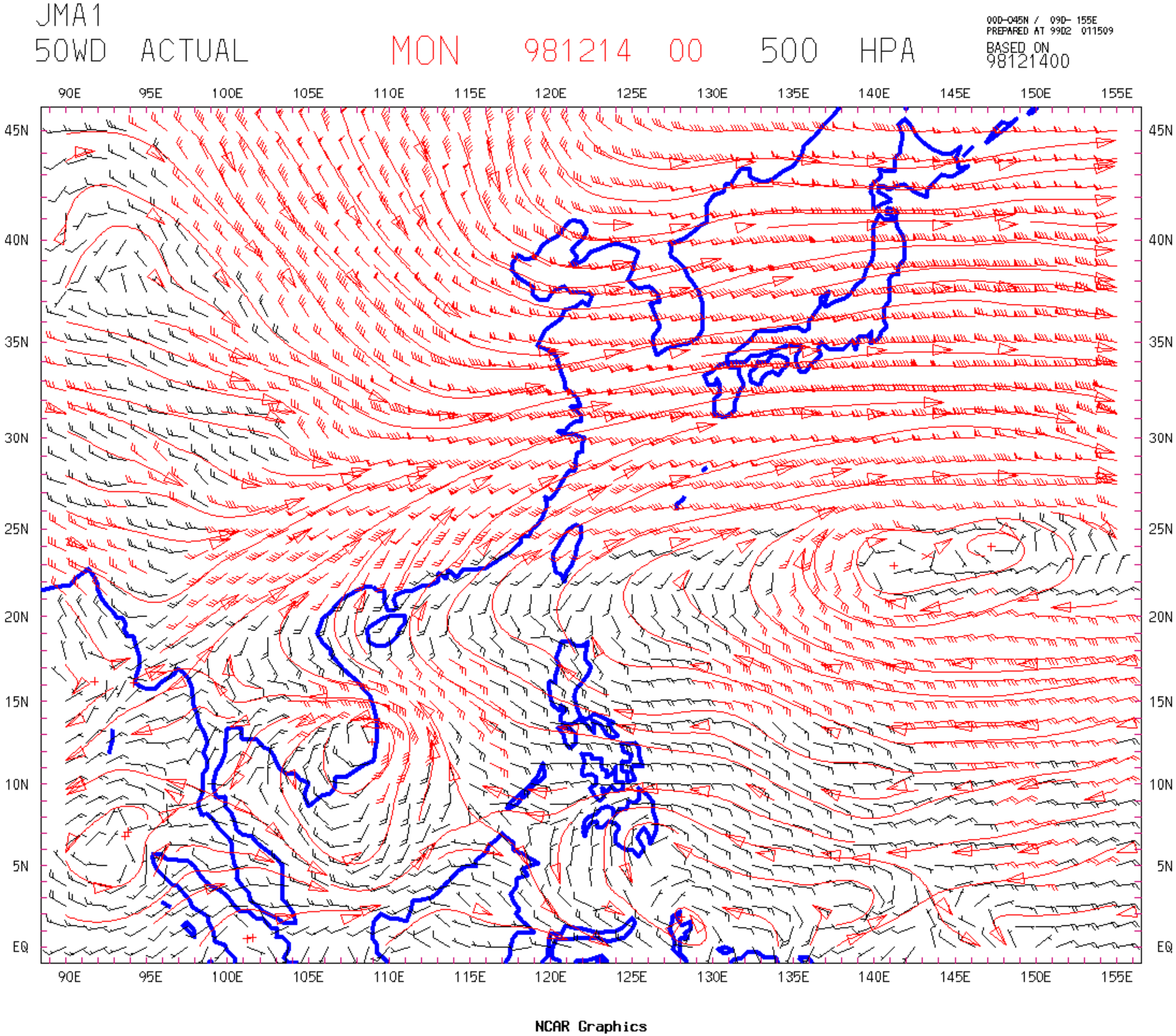

Figure 4.   Surface Winds at Chek Lap Kok on 14 December 1998

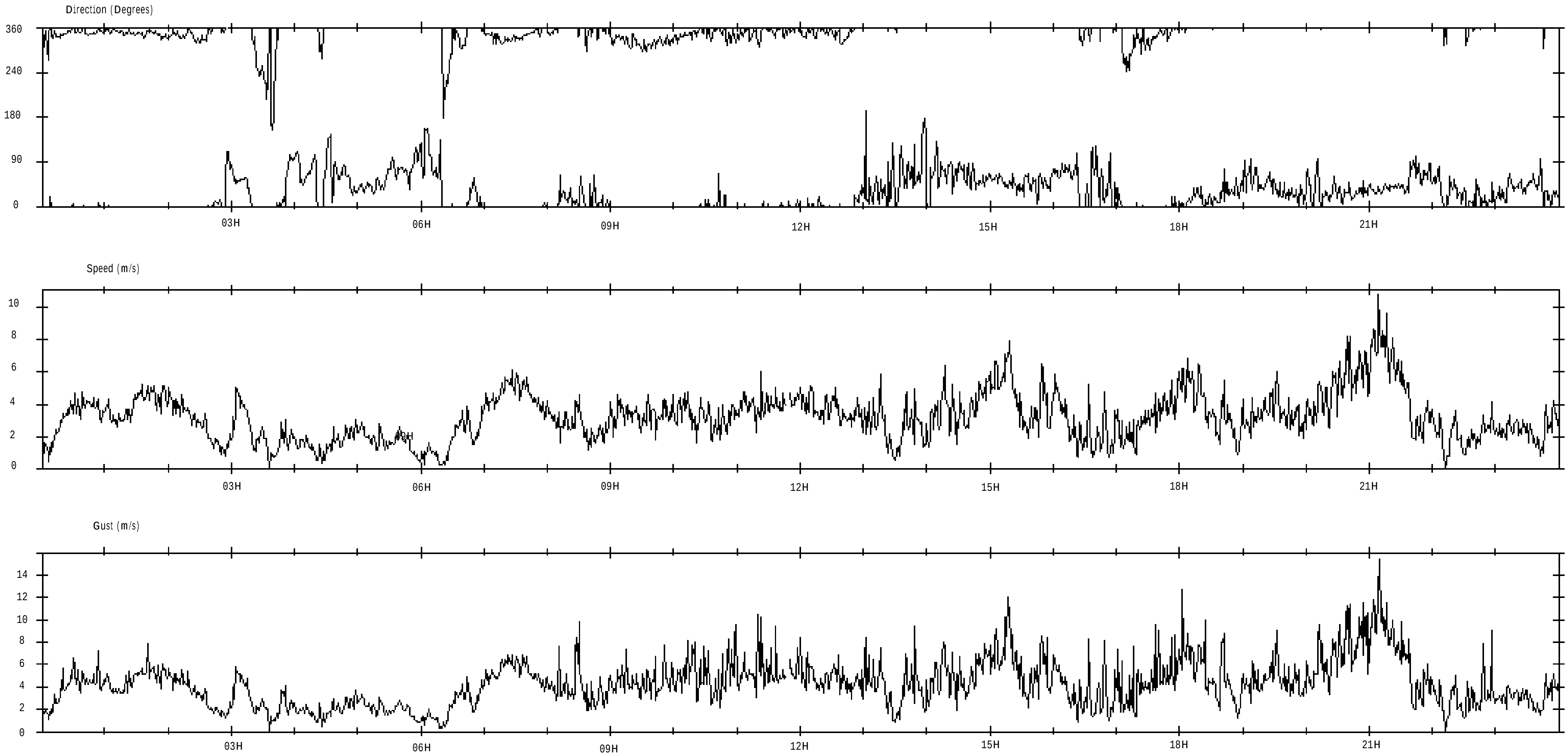

Figure 5. Geographical Situation Display as at 0742Z on 14 December 1998

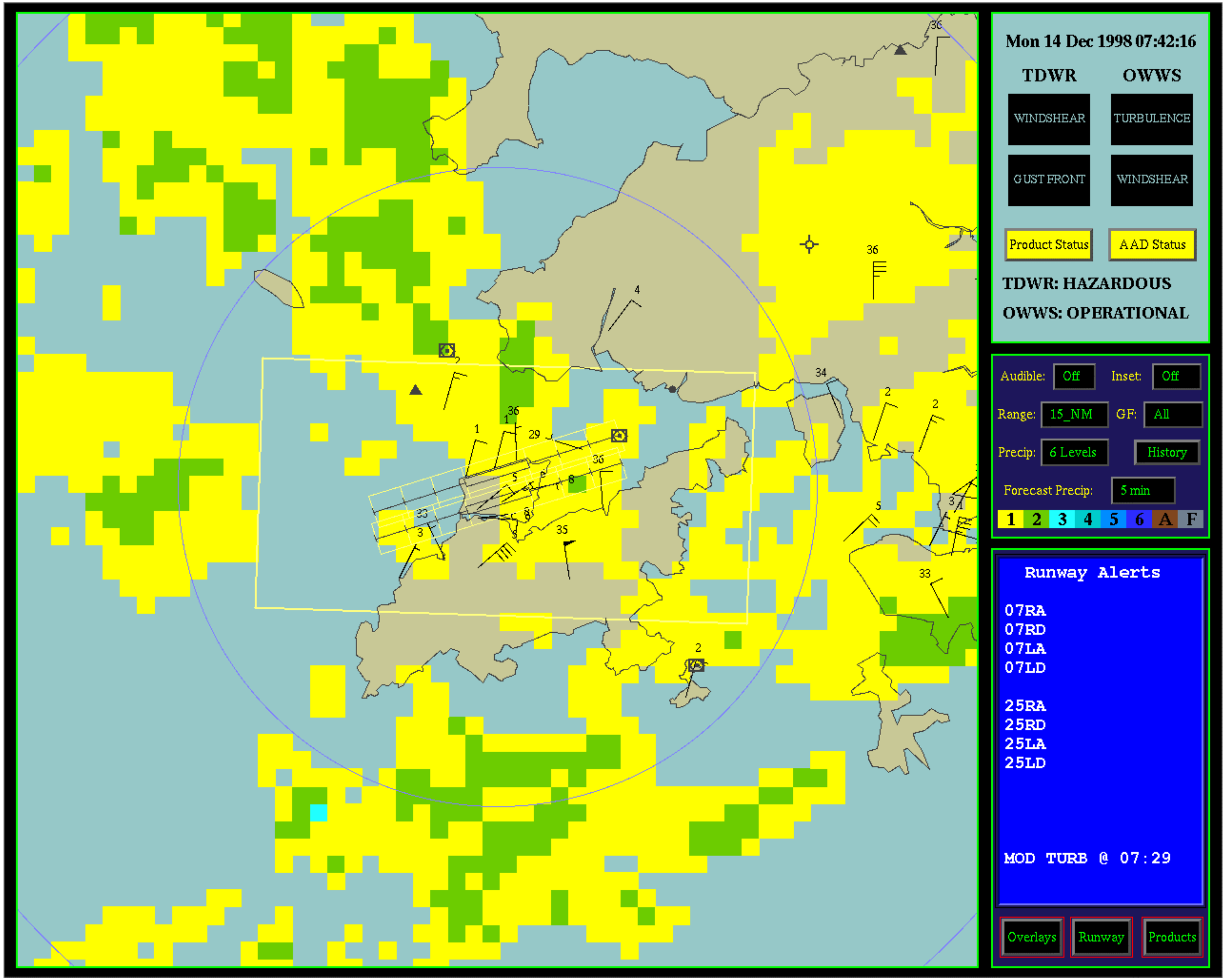

Figure 6. Winds measured by Sha Lo Wan Wind Profiler on the afternoon of 14 December 1998

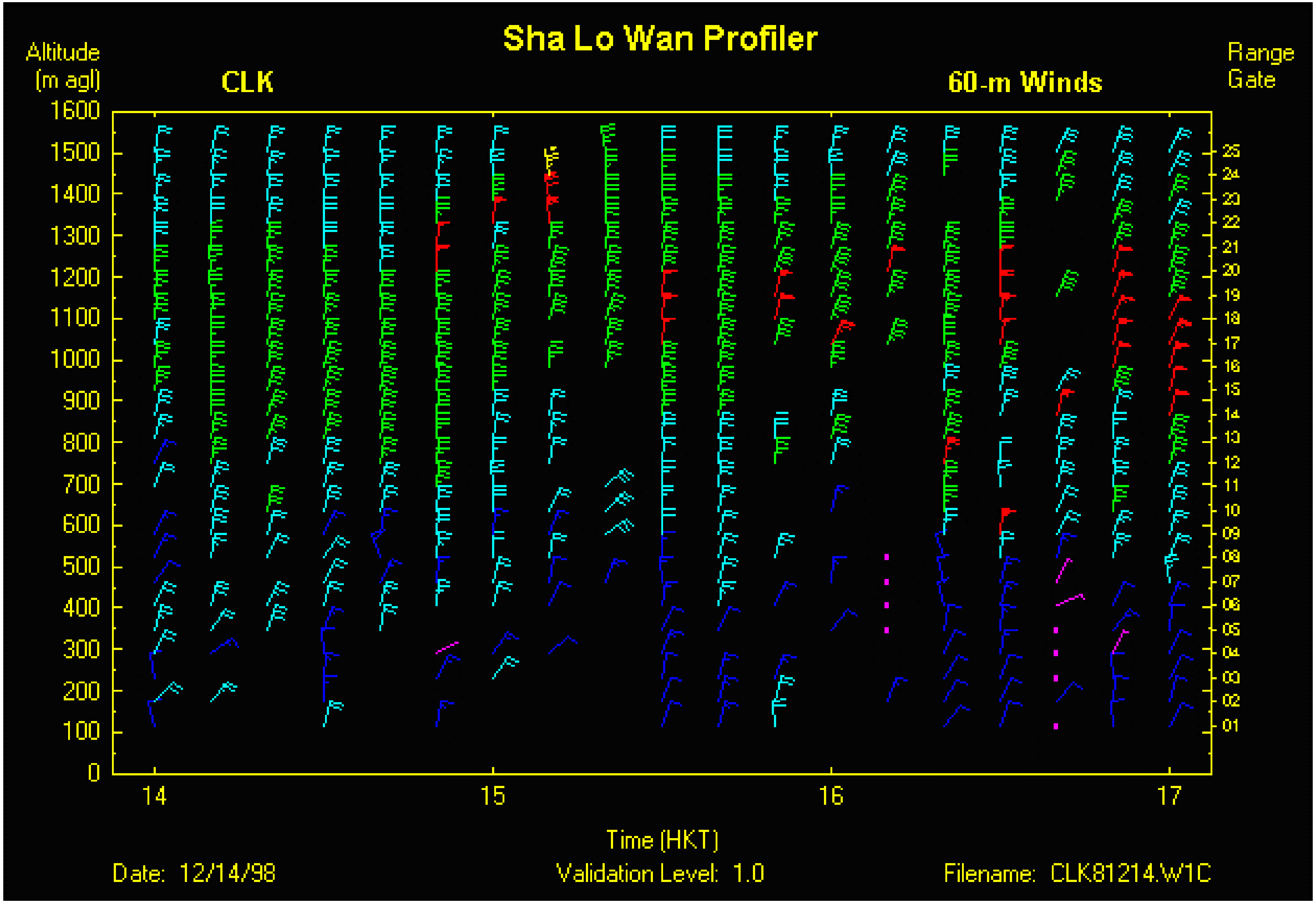

Figure 7. Winds measured by Sham Shui Po Wind Profiler on the afternoon of 14 December 1998

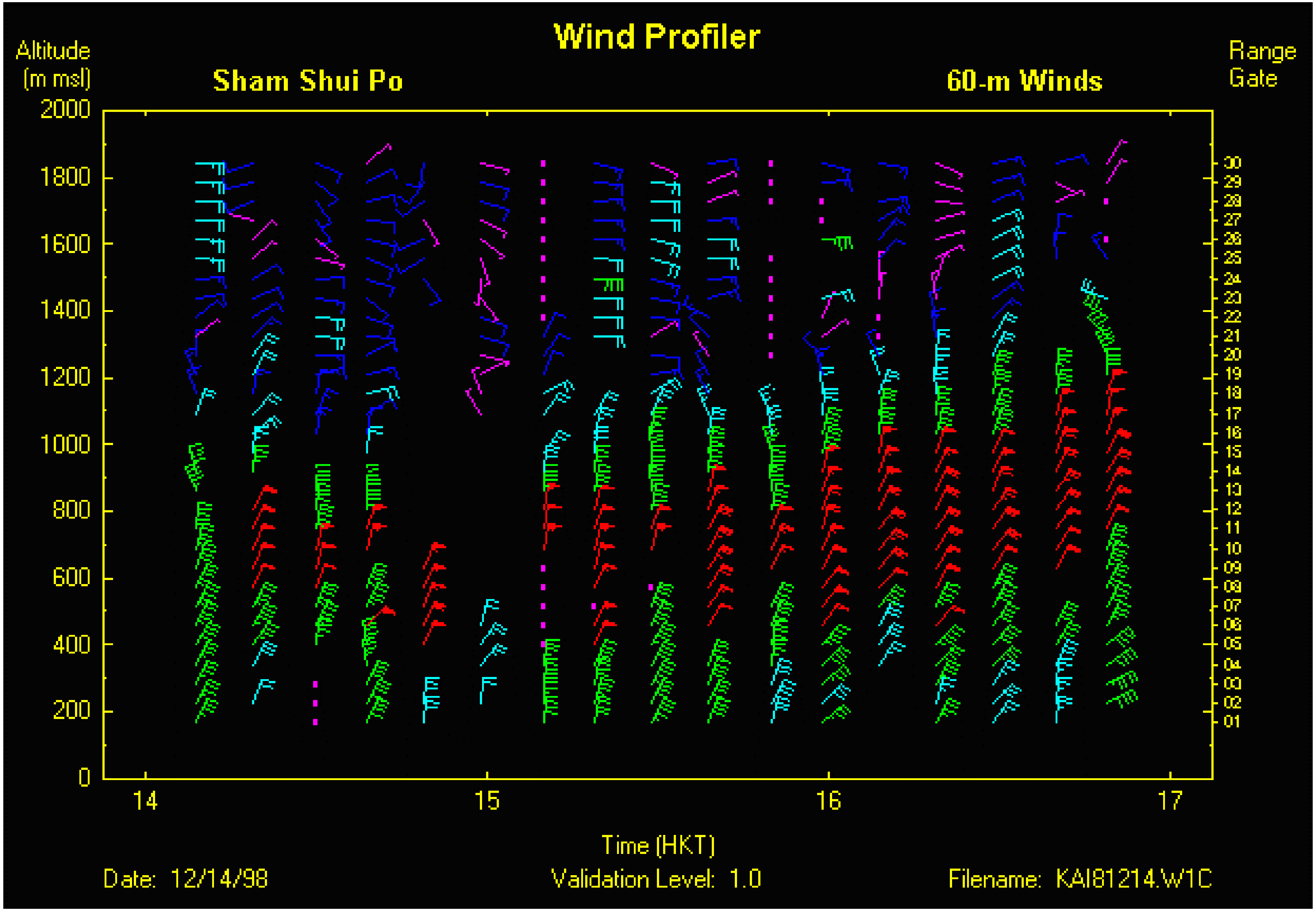

Figure 8. Doppler Winds as Measured by TDWR at 0741Z on 14 December 1998

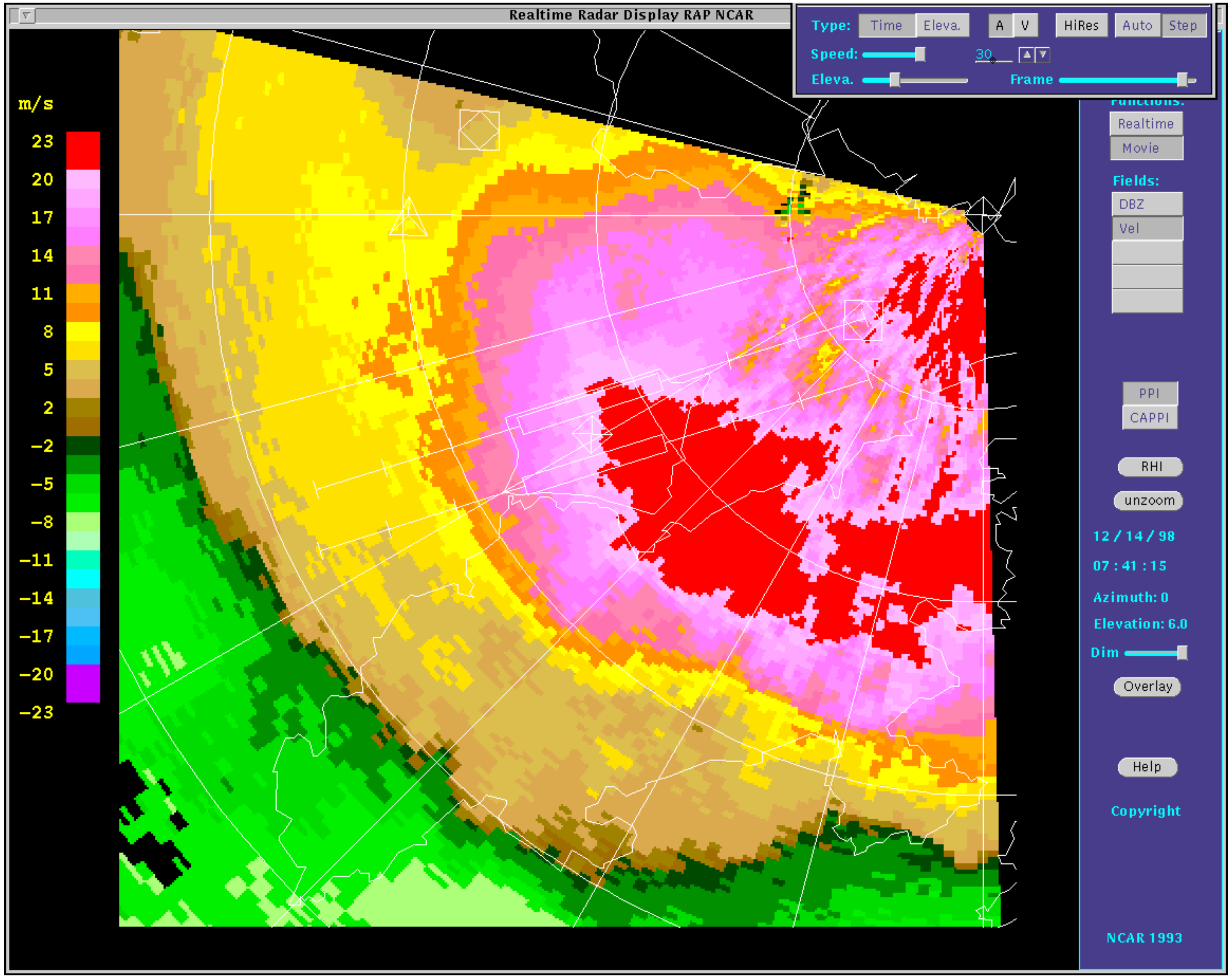

Figure 9. Variation of Altitude with Time

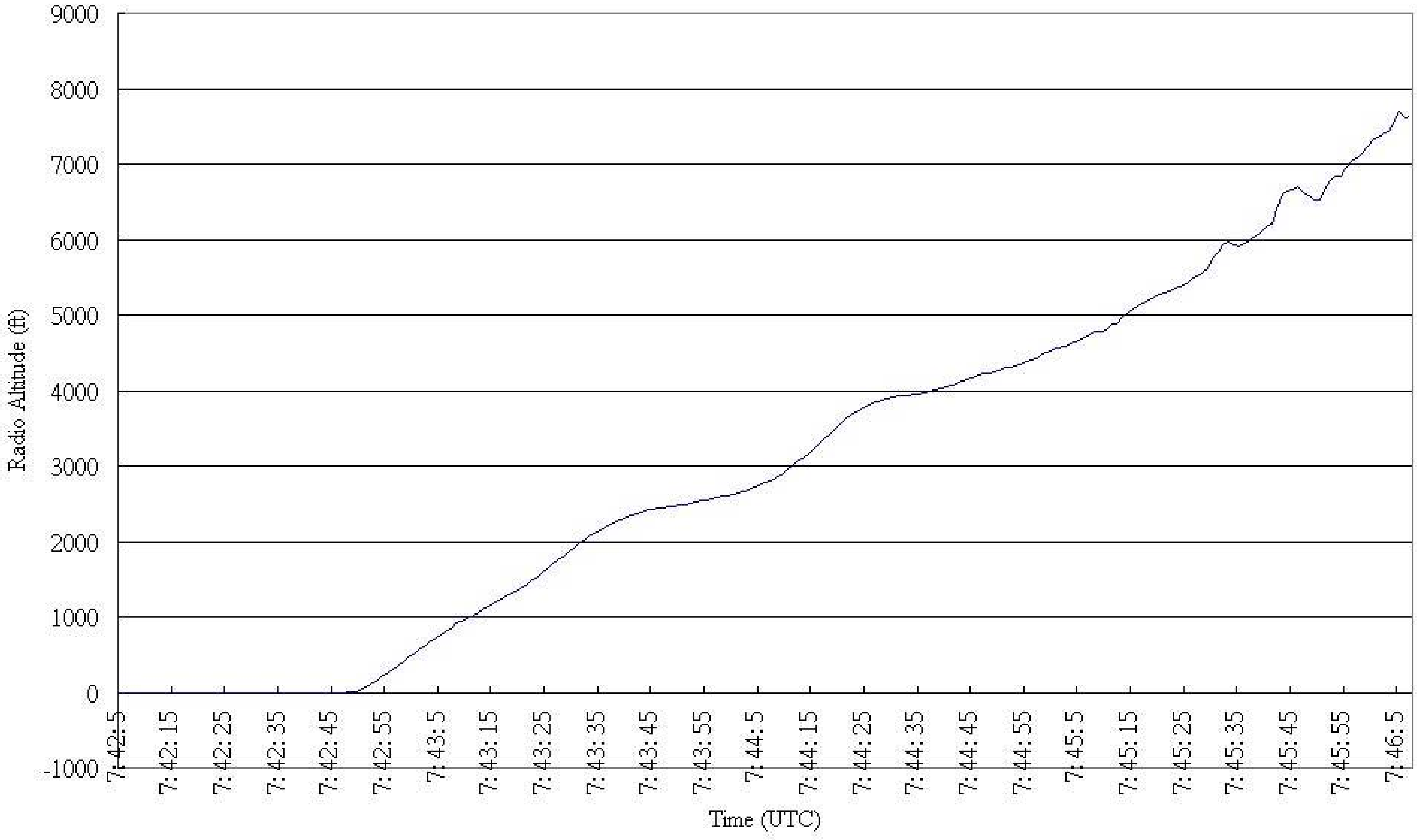

Figure 10. Comparison of Winds Measured On-board with those from Sha Lo Wan Profiler

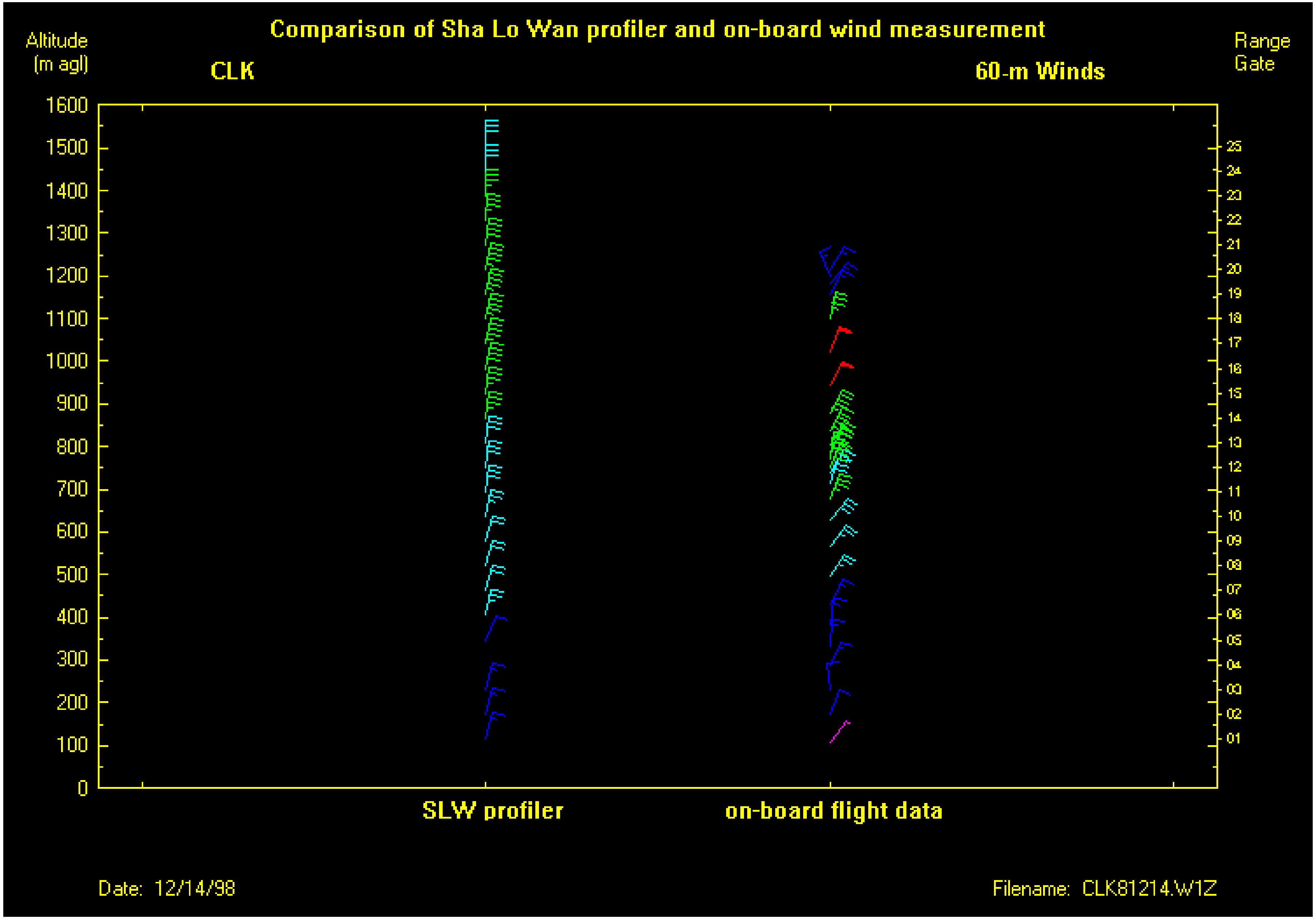

Figure 11. Variation of Air Speed, Ground Speed, Pitch and Angle of Attack with Time

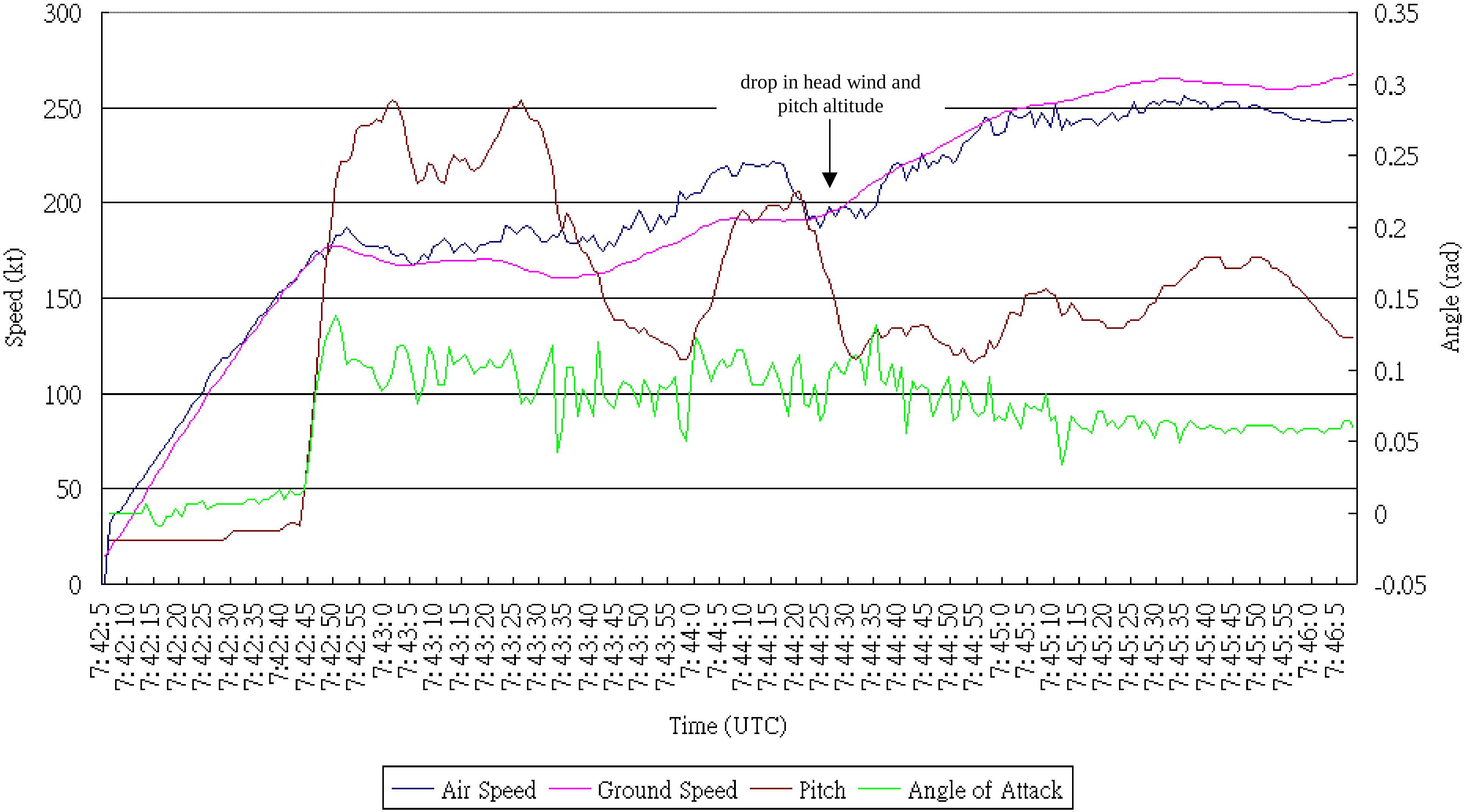

Figure 12.   Variation of Head Wind with Height

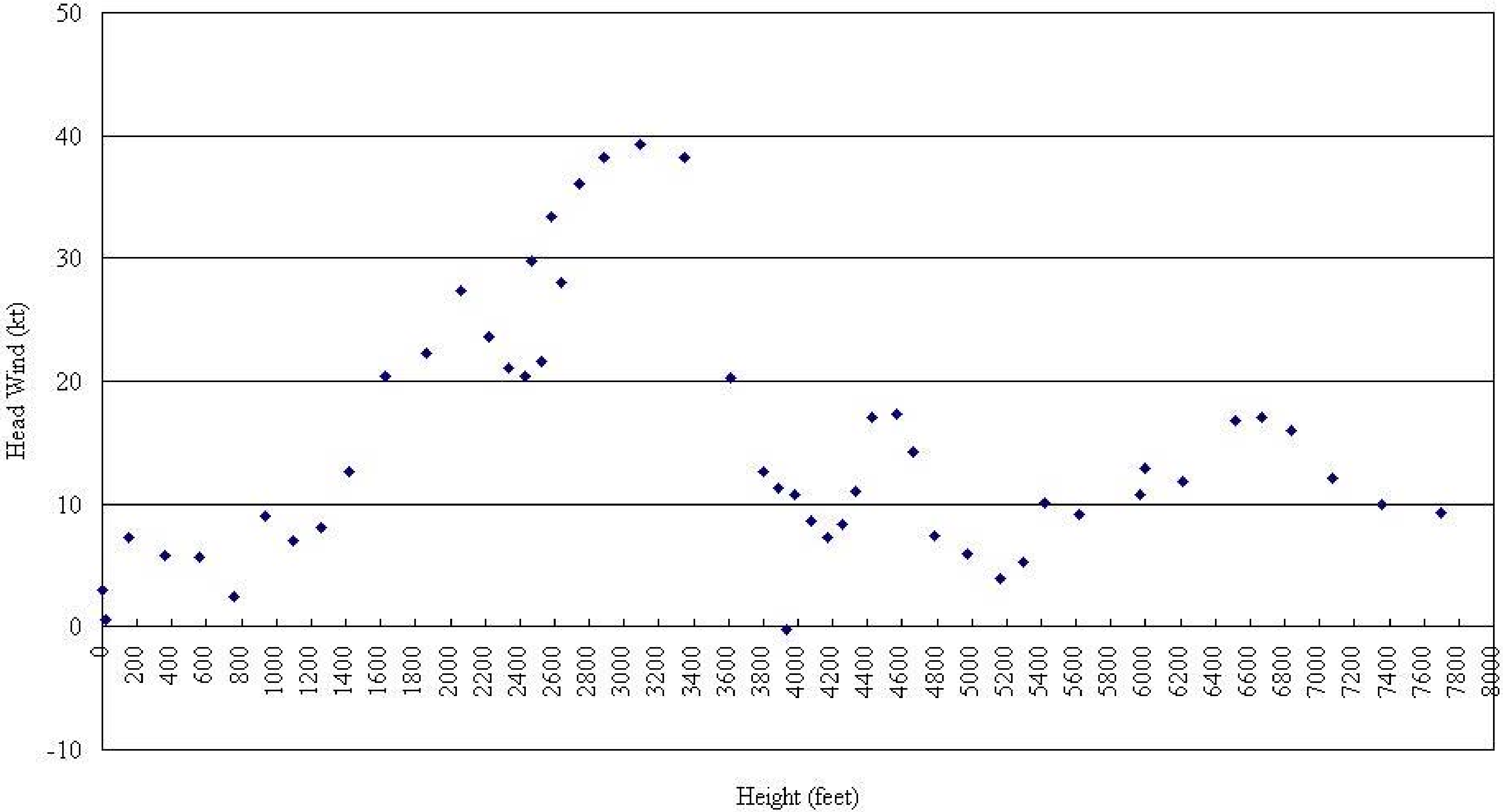

Figure 13. Variation of head wind with distance for 3 flights arriving between 0635 and 0655 UTC 14 December 1998

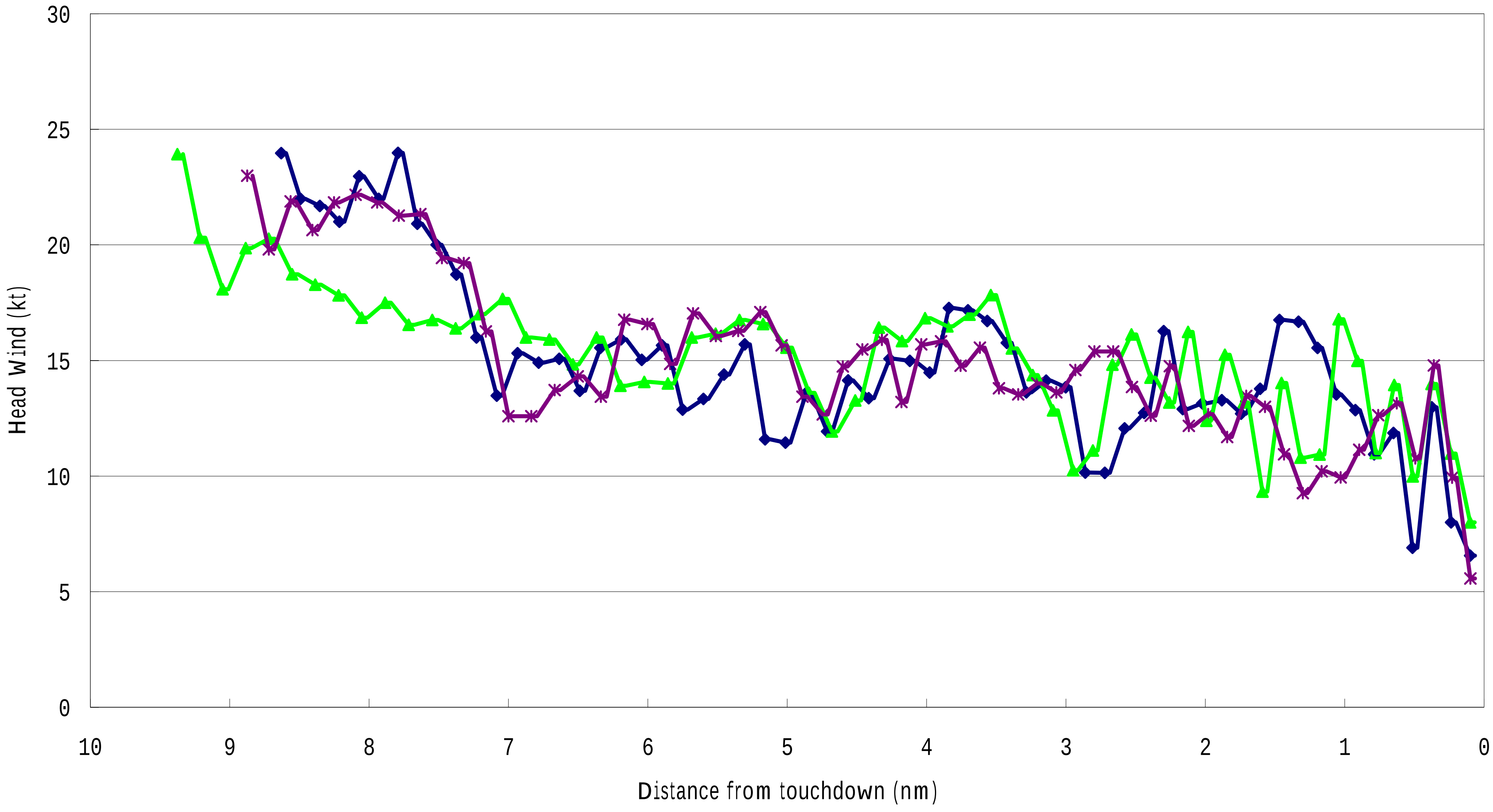

Figure 14. Geographical Situation Display as at 0742Z on 14 December 1998

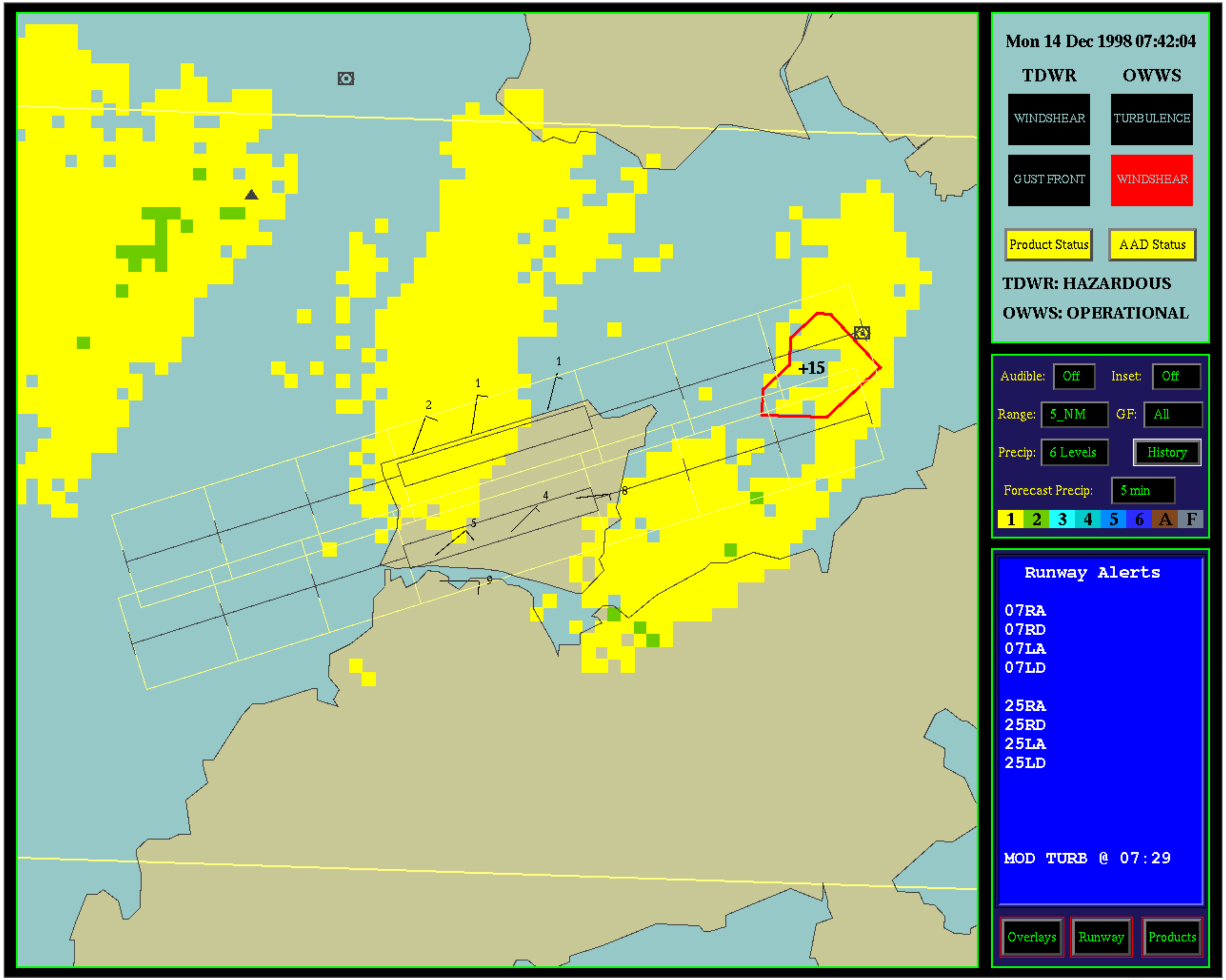

Figure 15. Geographical Situation Display as at 0748Z 14 December 1998

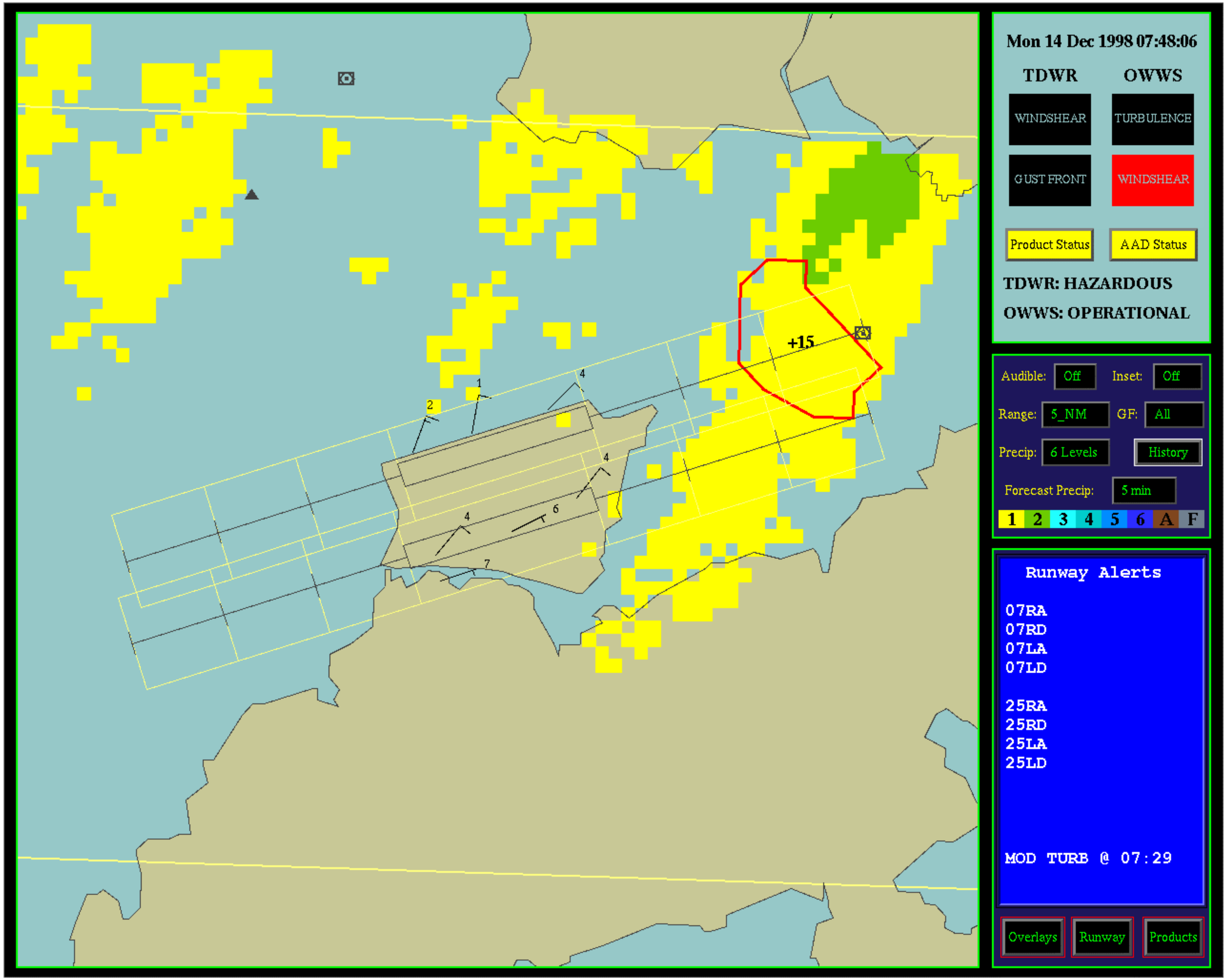

Figure 16. Windshear Gain Magnitude as analysed by WTWS

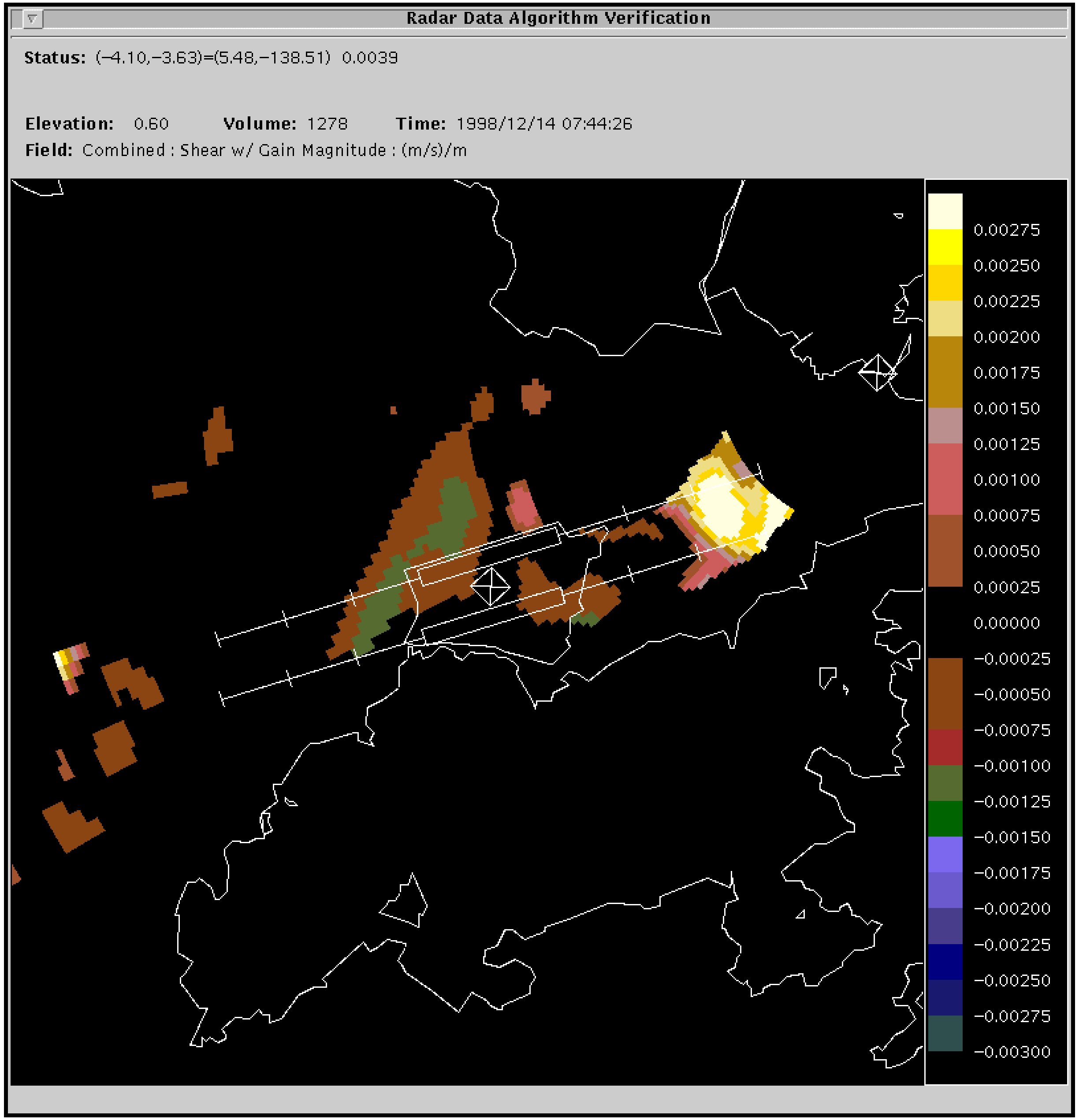

Figure 17(a). RSM Forecast Time Cross Section at HK grid

(9812 1318 – 9812 1418 UTC)

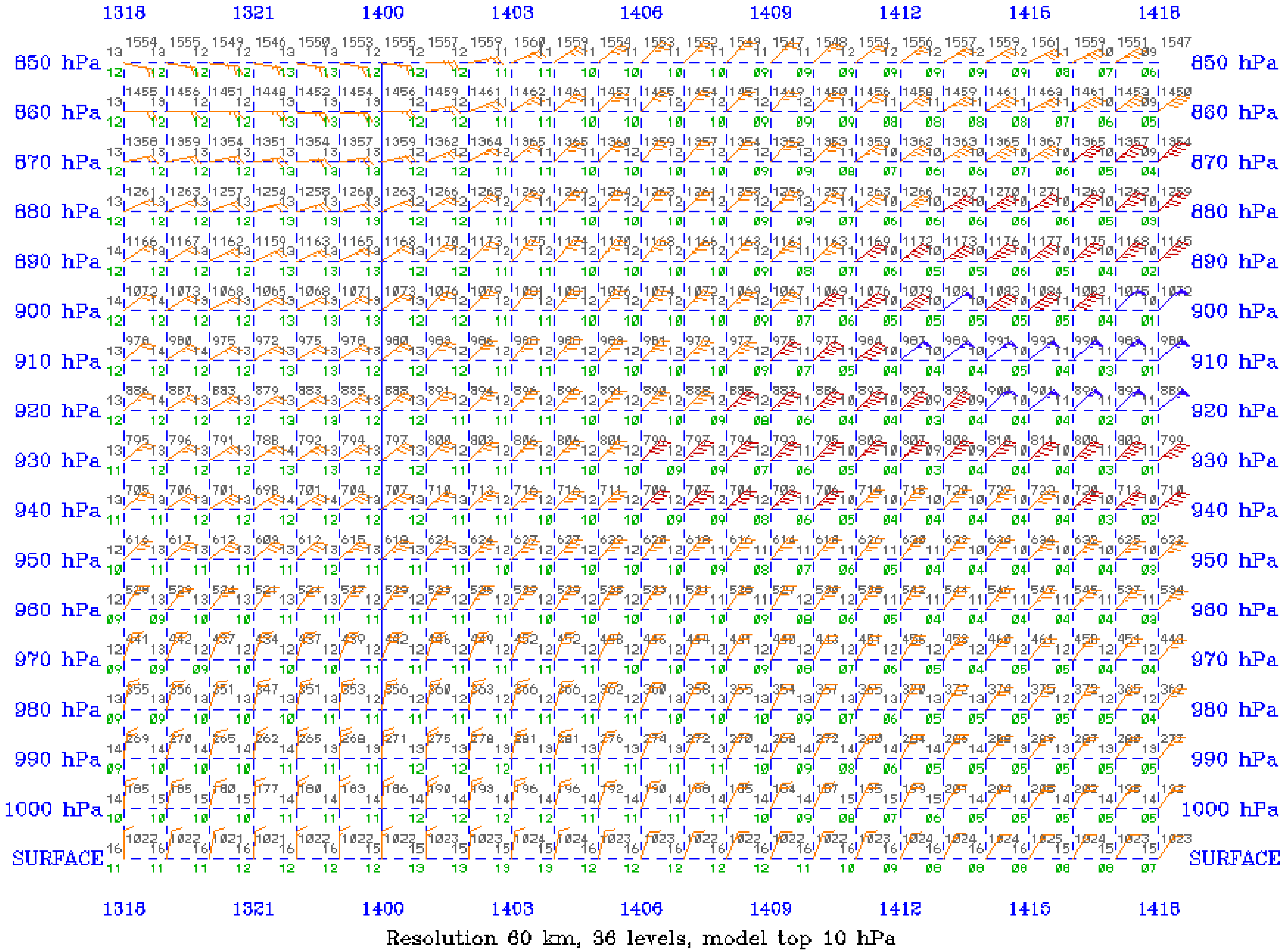

Figure 17(b). RSM Forecast Time Cross Section at HK grid

(9812 1318 – 9812 1418 UTC)