Remote Sensing Observations of the Subsidence Zone Within the Eye of Typhoon Nuri in Hong Kong in 2008

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ABSTRACT

There are a number of ground-based remote sensing equipment operating at or near the Hong Kong International Airport (HKIA), including two wind profilers, a minisodar (sonic radar) and a multi-wavelength microwave radiometer. The wind profilers and minisodar are able to measure the three components of wind, whilst the microwave radiometer provides the temperature profile of the troposphere continuously. In August 2008, during the period when Typhoon Nuri made landfall in Hong Kong, these equipment provided continuous data for close monitoring of the variation of dynamic and thermodynamic parameters of the atmosphere. When the eye of Nuri approached HKIA, a subsidence zone with downward motion of up to 6 m/s within the eye was captured by the wind profiler and minisodar while rise of temperature of 6 deg C together with a temperature inversion at the lower atmosphere were revealed by the microwave radiometer. This paper analyses the remote sensing data mentioned above.

1. INTRODUCTION

There are a number of remote sensing equipment operating in Hong Kong, including the wind profiler, minisodar and multi-wavelength microwave radiometer. The wind profiler and minisodar measure the three components of wind, whilst the microwave radiometer provides the temperature profile of the troposphere continuously. In August 2008, during the period when Typhoon Nuri made landfall in Hong Kong, these equipment provided continuous data for close monitoring of the variation of dynamic and thermodynamic profiles of the atmosphere. Nuri was the fourth tropical cyclone that necessitated the issuance of tropical cyclone warning signals in Hong Kong in 2008. It also necessitated the issuance of the Increasing Gale or Storm Signal No. 9. This was the first No. 9 signal since the passage of Typhoon Dujuan in September 2003.

On 22 August 2008, Nuri made landfall in Hong Kong and its track within the territory is given in Figure 1. Typhoon Nuri was first located near the Hong Kong University of Science and Technology (H.K.U. of Sci & Tech) in Sai Kung area over the eastern part of Hong Kong at around 4:50 p.m. (08:50 UTC, local time = UTC + 8 hours) and weakened into a severe tropical storm. Under the effect of terrain, the circulation of Nuri re-organized itself. The original centre moved northwestwards and dissipated rapidly. A new centre formed near Tseung Kwan O and turned to move westwards, passing over the eastern part of Victoria Harbour and the southern part of Kowloon Peninsula within 1 km south of the Hong Kong Observatory (HKO) headquarters. The centre of Nuri then passed to the south of Tsing Yi Island, and turned northwards to cross the northeastern part of Lantau Island, Tuen Mun and Yuen Long that evening. Nuri then crossed Deep Bay, the western part of Shenzhen and the Pearl River Estuary that night and made a second landfall near Nansha of the Guangdong province subsequently.

Radar imagery in Figure 2 depicts that there was no intense precipitation at 7 p.m. on 22 August 2008 at Siu Ho Wan and near the centre of Nuri. Only a few millimeters of rainfall were estimated in the imagery. In fact, only a few millimeters of rainfall were recorded by the automatic weather stations nearby Nuri's eye.

2. REMOTE-SENSING EQUIPMENT

The radar wind profilers located at Siu Ho Wan and Sha Lo Wan (locations in Figure 1) continuously monitored the variation of vertical wind profiles when Nuri was over Hong Kong. Technical details of these profilers can be found in [1]. They belong to the boundary-layer type and operate at a frequency of 1299 MHz. Wind profiles, including the horizontal and vertical velocities, are available every 10 minutes.

The minisodar (co-located with Siu Ho Wan wind profiler) uses acoustic waves of 4500 kHz to disturb the atmosphere. The turbulent eddies in the atmosphere will cause the sound wave to become reflected. From the backscattered signal, the three-dimensional wind components of the lower atmosphere could be obtained. The detection height of the minisodar is 100 m and the height resolution is 5 m. Wind profiles are available every 5 minutes.

The microwave radiometer at the HKIA (location in Figure 1) is similar to that described in [2]. It retrieves the temperature and humidity profiles up to 10 km by measuring the radiation intensity at 14 channels in the microwave spectrum that are dominated by molecular oxygen emissions (51-59 GHz) and atmospheric water vapor (22-30 GHz) respectively. The microwave radiometer is able to make both zenith scans (for temperature and humidity profiles up to 10 km) and elevation scans (for temperature measurements within the boundary layer of the atmosphere, up to 2 km).

3. WIND PROFILER OBSERVATIONS

Figure 3 depicts that, at around 7 p.m. on 22 August 2008 when the eye of Nuri moved closer to the Siu Ho Wan profiler, changes in the vertical wind profile occurred at altitudes of 1800 m to 3000 m above Siu Ho Wan. Within this year, the wind speed reduced significantly, changing from fresh northwesterly to light westerlies, and finally picking up as strong southwesterlies. Similar variation of the wind profile occurred at altitudes of 3000 m to 4200 m later at about 8 p.m., and similar changes also occurred near the surface (between the ground and 600 m) at about the same time. The appearance of the tilting of the circulation centre with height within the eye of Nuri suggests that the intensity of Nuri had weakened.

If we consider the vertical motion measured by the Siu Ho Wan profiler, subsidence occurred from a height of 4200 m to near the surface at about 6:30 p.m. (Figure 4). The blue colour in the figure represents downward motion. Approaching 8 p.m., the subsidence was even stronger than before with vertical velocity (downward) reaching 5.8 m/s. Precipitation could also appear as downward motion in the data of boundary-layer wind profiler. However, the radar imagery in Figure 2 showed that there was no intense precipitation near Siu Ho Wan around the time. Therefore the downward motion in Figure 4 is believed to mainly arise from the subsidence within the eye of Nuri.

4. MINISODAR OBSERVATIONS

Figure 5 shows that when Nuri passed over Siu Ho Wan, there was an obvious change in the wind direction in the lower atmosphere as measured by the minisodar. The lower level wind changed from northwesterly to northeasterly at around 6 p.m. initially. After Nuri departed Siu Ho Wan, southwesterlies prevailed at the lower levels after 8 p.m.

Figure 6 depicts the distribution of the vertical velocities at the lower levels of Siu Ho Wan at around 7 p.m. It is observed that subsidence occurred at the lower levels of Siu Ho Wan with the maximum downward velocity of about 3.2 m/s. In between 7 p.m. and 8 p.m., the subsidence persisted (not shown) and the maximum downward velocity reached about 4.3 m/s. This value was close to that measured by the wind profiler in Section 3.

5. RADIOMETER OBSERVATIONS

Figure 7 shows the vertical temperature profiles above HKIA in the afternoon of 22 August 2008. In the Figure, from the ground up to 2000 m aloft, the isothermals appear to be "convex" upwards. The temperature differences at the same height could reach 4 to 6 degrees between the times with and without the warming up of the boundary layer. The rise of temperature is likely due to the subsidence within the eye of Nuri. This observation coincides with the timing of the subsidence (downward motion) as observed by the wind profiler and the minisodar (discussions in Sections 3 and 4). The vertical temperature profile at the time of maximum warming is given in Figure 8. There is a temperature inversion of 0.3 degree Celsius extending from 300 m to around 630 m.

Looking at the radar imagery in Figure 2, there was no intense precipitation in the vicinity of HKIA where the microwave radiometer was located. Moreover, the amount of rainfall recorded by the rain gauge at HKIA did not exceed 15 millimeters in an hour. According to the study in [2], the temperature profile obtained by the microwave radiometer would be more accurate when the rainfall rate is smaller than 15 millimeters per hour. Therefore the microwave radiometer data acquired during the passage of Nuri is considered to be reliable.

6. COMPARISON WITH OTHER STUDIES

Because of the high temporal resolution, wind profilers become more important in daily meteorological operations. Reference [3] made use of wind profiler data from Macao and Hong Kong to analyze the tropical storm Kompasu. Their result showed that under the influence of a tropical storm, the change in wind direction could be very fast and there was an obvious change in the wind direction before and after a tropical storm made landfall. In the present study, besides the change in wind direction with the passage of Nuri, the subsidence associated with the cyclone is also examined from vertical velocity data of wind profiler.

There are very few studies to observe the warm core structure of tropical cyclones using ground-based microwave radiometers so far. There have been studies to observe the warm core using satellite-based microwave radiometer, e.g. [4]. At the warm core of a tropical cyclone, the temperature difference at the higher levels of the troposphere (at around 250 hPa) could reach 16 degrees Celsius. This paper gives a preliminary study on the warm core structure of a tropical cyclone in the boundary layer using a ground-based microwave radiometer.

7. CONCLUSIONS

The remote sensing equipment operating in Hong Kong, including the wind profiler, minisodar and multi-wavelength microwave radiometer, provide continuous data for the close monitoring of the variation of dynamic and thermodynamic profiles of the atmosphere. Their data are used in the present paper to document the eye structure of Typhoon Nuri when it made landfall over Hong Kong. The wind profiler and the minisodar capture the subsidence motion within the eye. The microwave radiometer measures the warming of the boundary layer associated with the subsidence. The remote-sensing equipment would be used to study the structures of other tropical cyclones moving close to Hong Kong, e.g. Tropical Storm Nangka in June 2009 to see if similar characteristics could be found.

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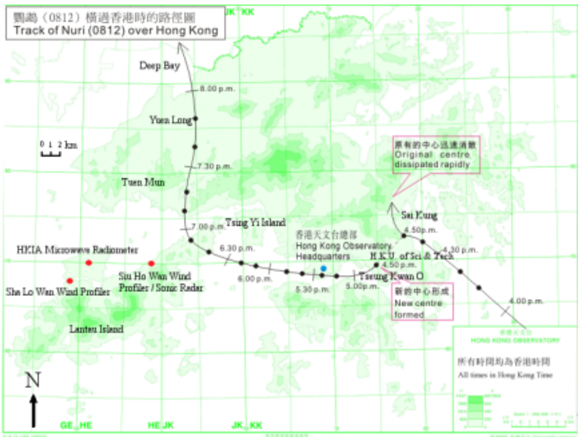


Figure 1 Track of Nuri over Hong Kong on 22 August 2008. The positions of the wind profiler, minisodar (sonic radar) and the microwave radiometer are marked in red.

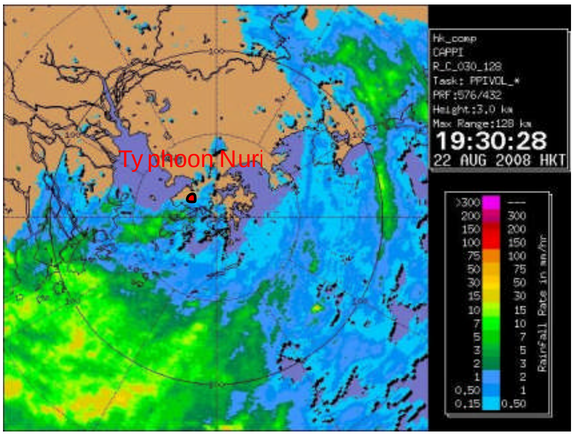


Figure 2 Radar imagery at 3 km above mean sea level at 7 p.m., 22 August 2008.

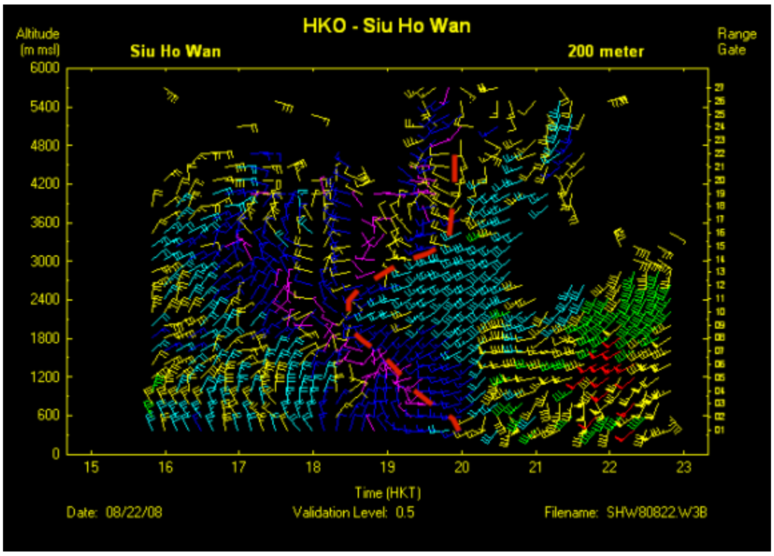


Figure 3 Vertical profile of horizontal wind from Siu Ho Wan wind profiler in the afternoon of 22 August 2008. Red dotted line represents the axis of the eye of Nuri.

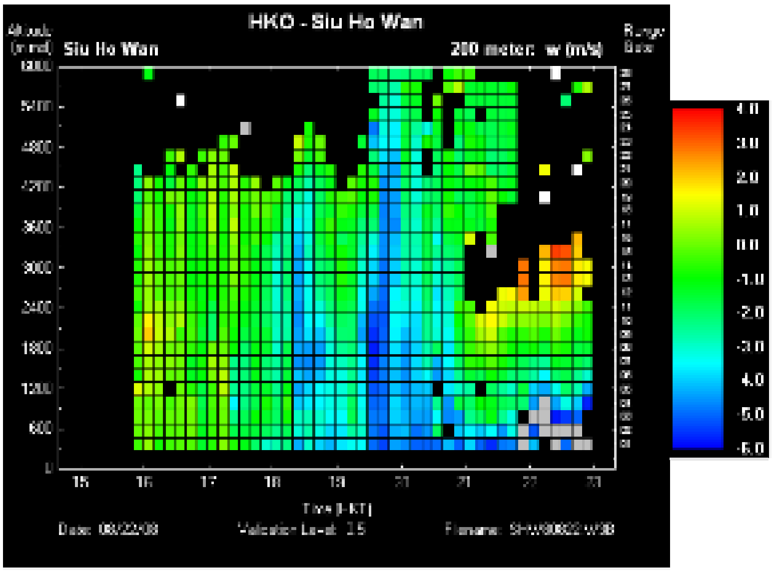
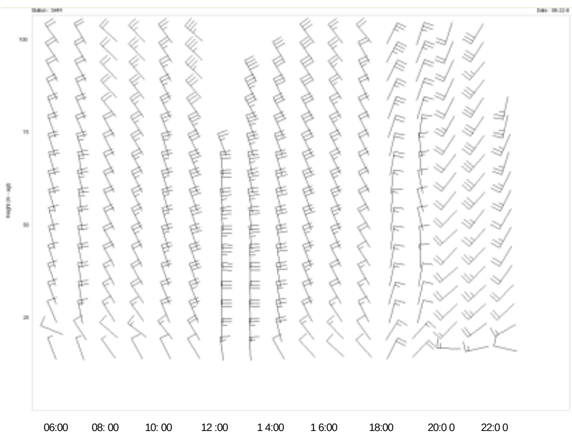


Figure 4 Time-height plot of vertical velocity measured by Siu Ho Wan wind profiler in the afternoon of 22 August 2008.



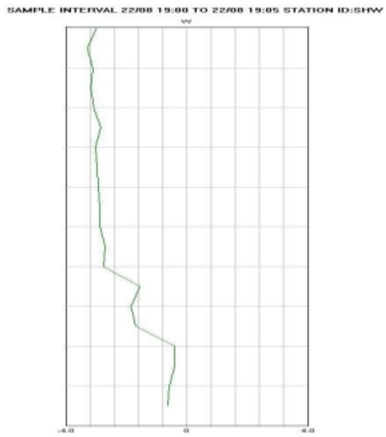


Figure 5 The hourly vertical profiles of horizontal winds from the minisodar at Siu Ho Wan on 22 August 2008 (between 6 a.m. and 10 p.m.).

Figure 6 Vertical velocity profile from the minisodar at Siu Ho Wan at 7 p.m., 22 August 2008. The horizontal axis has a range of -4 m/s to +4 m/s (negative means downward motion).

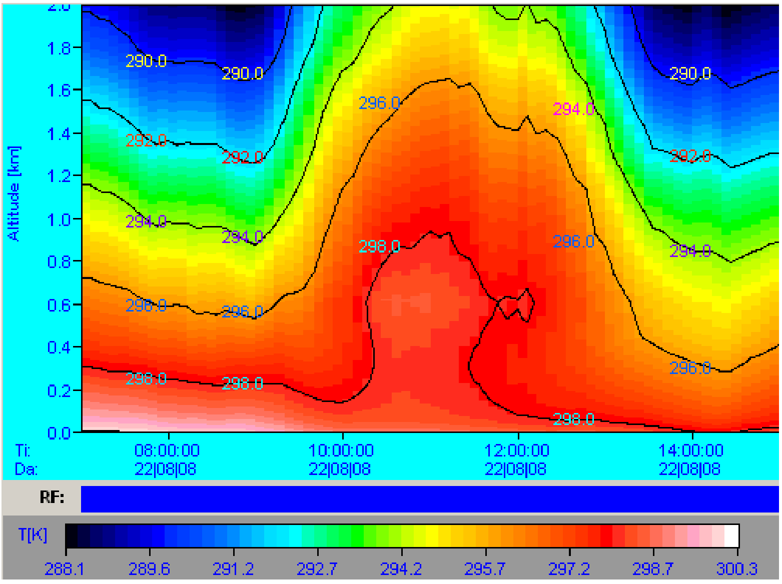


Figure 7 Time-height plot of boundary-layer temperatures as measured by the microwave radiometer in the afternoon of 22 August 2008. The time shown is in UTC (Hong Kong time = UTC + 8 hours).

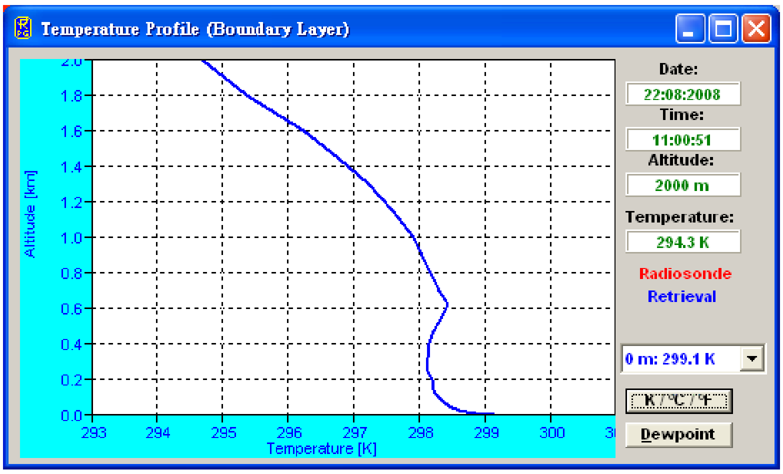


Figure 8 Variation of the temperature with height within the boundary layer as recorded by the microwave radiometer at 7 p.m., 22 August 2008.