FLY INTO TYPHOON HAIYAN WITH UAV AEROSONDE

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1. INTRODUCTION

During middle 1970s to the autumn 1987, typhoon reconnaissance flights around western Pacific Ocean was instituted continuously by Guam_based U.S. Air force C130 aircraft fleet. Now the U.S. national hurricane program only put focus of hurricane reconnaissance observation on the eastern Pacific and Atlantic Ocean by Air force and NOAA P3 aircrafts with dropsonde facility (OFCM, 2002; Hock and Franklin, 1999). Such aircraft measurement costs high and several programs have suggested other cheaper but also effective solution with unmanned aerial vehicle (UAV) (Longford and Emanuel, 1993; Bluth, et al, 1996).

A small robotic UAV (Figure 1) designed by the InSitu Corp. (McGill, 1994) and applied in several atmospheric field experiments (Holland et al., 2001; Lin et al., 2000) shows the possibility to take typhoon reconnaissance observation. The disaster mitigation program in the National Science Council started to support the Aerosonde project from 1998 in Taiwan. The Taiwan Aerosonde Team (TAT) got technical transfer from Melbourne Aerosonde Ltd. in 1999 and had seven trials of landfall typhoons through 200 to 2001. The most complete case it did is Typhoon Haiyan on October 16,2001. Section 2 will describes Aerosonde capability and its on-board meteorological sensor. The working process of TAT is also introduced. Then we diagnosed the data during Typhoon Haiyan reconnaissance flight in section 3 and section 4. More future of TAT research will be addressed in section 5.

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2. CHARACTERISTICS OF AEROSONDE AND THE RECONNAISSANCE ARRANGEMENT

Eight Mark-1 Aerosondes was purchased by Central Weather Bureau (CWB) and National Taiwan University in 1998 and then joined the South China Sea Monsoon Experiment (Lau et al, 2000). Table 1 gives the detail of Aerosonde characteristics. The most important feature is its 30-hour sustainable capability in the air. But the disadvantage of Aerosonde is its VHF radio communication range for 150~200km maximum. Although Aerosonde Ltd kept working on Iridium satellite communication function on their Mark-3 module, only few flights are successful until now. The on-board instrument, Vaisala RSS901 (Figure 2), is a new fast-response PTU sensor made by Finland Vaisala Company. Similar part is also used in balloon sounde and aircraft dropsonde (Finne, 2002). Table 2 lists the accuracy of parameters from the RSS901 sensor. Three RSS901 sensors are installed under the Aerosonde wings and its cabin. Ground calibration is needed before it is used on board.

TAT has different subgroups to operate Aerosonde together. The department of Atmospheric Sciences in National Taiwan University (NTU/DAS) leads the charge in scientific plan and the field observation. CWB works on the application of aviation space permission and supports facilities from weather stations. The Chung-Shang Institute of Scientific Technology takes the charge of Aerosonde maintenance. During the summertime of 2001, TAT stood-by when CWB announced Typhoon Warning on the sea. The authors in NTU/DAS surveyed weather predictions and decided the flight mission or not. The first author also led six crews to operate Aerosonde in one of the ground bases, I-Lan or Jo-Pan, which are located on the northeastern and southeastern coasts of Taiwan (Figure 3). After five failures of Typhoon trials, TAT debated Typhoon Haiyan (BWP#25 by Joint Typhoon Warning Center) well in the final trial of 2001 (Table 3). One Aerosonde was launched at 07:00LTC, October 16, 2001 at I-Lan, and had vertical soundings above the base first. Then it started the reconnaissance flight on 1600m at 08:30LTC, and crashed into the ocean at 11:21LTC where it has flied the coast 108km away. This location is 215km away from the typhoon eye. Figure 4 shows the aerosonde trajectory on the Radar rainfall reflectivity image.

3. DATA COMPARISON BETWEEN AEROSONDE ANDDOPPLER RADAR

This session discusses the data comparison among Aerosonde RSS901 PTU data, Radar reflectivity and Doppler radial wind from CWB Wu-Fen-San (121.7725E, 25.0727N) NEXRAD-S Doppler Radar. Aerosonde PTU and wind information were transmitted back to the ground control station immediately in 10-second sampling rate. For the 1km grid-size Radar reflectivity and radial wind, the NCAR/ATD SOLO software was used to analyze. In this case, only the lowest angle (0.4 degree) volume scan was processed to match the Aerosonde flight level.

The specific humidity (q) measured by Aerosonde has the following relationship with Radar reflectivity (Z) around 850hPa layer:
$Z = 0.003^* q^{4.3285}$, with root mean square (RMS) 0.61 (Figure 5) and their correlation is up to 0.67, too. It shows that Aerosonde has potential to validate the Radar reflectivity to estimate the atmospheric volume water content over the lower marine boundary layer.

The correlation of radial wind field between Radar and Aerosonde has only 0.3 in this case study. Aerosonde measures single-point atmospheric wind speed from its pitot tube pressure and static pressure, and calculates wind direction through S-shaped motion in every constant spatial distance (McGill, 1994). In the other hand, the Radar wind field gets 1km^2 average wind structure only. We believe the radial wind comparison to each other has the scale mismatch problem. Because we found that the amount of the pitching and yawing rate and wind speed from Aerosonde increased significantly together when it hit to the rainband which reflectivity is over 37.5 dBz. Aerosonde gave response to the small-scale turbulent wind, but Radar beam processing gives the area-mean wind only.

4. THE OUTER CORE STRUCTURE OF TYPHOON HAIYAN

(1) Boundary layer near the coast and over the open ocean

Two vertical sounding profiles of virtual potential temperature (θ_v) and tangential wind speed (V_θ) near the coast and over the open ocean were diagnosed from 300m to the flight level. They both had maximum V_θ around the 1000m height, but the coastal profile had 5 m/s less the ocean profile (Figure 6a). Meanwhile, costal wind speed on 500m layer (the coastal hill altitude) was over 15 m/s which was used to define the outer core of typhoon by Weatherford and William (1988). We suggest the outer core of Typhoon Haiyan had touched the land (265km away from the core) and this radius is bigger than the CWB announcement (250km). The θ_v profiles were similar each other, but the air became less stable over the open ocean (Figure 6b). Although the soundings were taken in the outer core of typhoon, the stability of lower boundary layer were not so unstable as people expected.

(2) Structure of outer core

The environmental variables including tangential wind, pressure, air temperature and specific humidity, along the flight level were examined to outline the outer core structure of Typhoon Haiyan. Figure 7 demonstrated that the closer to the typhoon core, the higher variation of the tangential wind speed. We found the variation of tangential wind had 1.4 times larger in the region less than 230km radius. This phenomenon can be explained that the rainband penetrated by Aerosnde had stronger turbulence and gust wind. Beyond 230km radius, Aerosonde met one significant dry subsidence motion. Relative humidity dropped less than 70% and temperature rose 1.5 ℃(Figure 8). Two smaller subsidence motions existed at 230km and 255 km radius again. All of them were part of multi-cell convective systems in the outer core. During the 220 to 215km radius, Aerosonde made the vertical sounding again before it crashed.

5. CONCLUSION AND DISCUSSION

Due to the weightless and engine killed trouble of Aerosonde, we didn't finish a complete reconnaissance flight through Typhoon Haiyan at all, but only 50 km depth into the Typhoon outer core. Nevertheless, it's the first record of UAV application in typhoon reconnaissance. This case encourages TAT to devote time to plan the flight strategy more. Through data analysis of Aerosonde data in Typhoon Haiyan, we summarize several results as:

(1) In-situ humidity measurement has good relationship to the Radar reflectivity. But the wind field had scale-mismatch problem.

(2) The in-situ variables in the outer core reconnaissance flight gave a consistent status of multi-cell systems that Aerosonde penetrated. Wind field and the aircraft attitude parameters can respond to the small-scale turbulence well. For well-planed flight strategy, Aerosonde can be a good platform in the study of marine atmospheric boundary layer.

(3) The radius of Typhoon Haiyan announced by CWB is smaller than the Aerosonde measurement.

From the spring of 2002, TAT starts to survey the possibility of building bigger UAV in Taiwan. Our first target is to build a UAV under manual control mode with 5kg payload capability. Air sampler and aerosol sampler are the additional instruments besides the meteorological radiosonde. Second target is the autopilot mode like Aerosonde has. The performance of this UAV will be limited for marine boundary studies, because typhoon is a big challenge to people, not only for the small aircraft. However, TAT will keep the typhoon reconnaissance observation with the residual four Aerosondes to collect more cases for study.

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Table 1：The specification of Aerosonde MARK-I

Wing length	2.9m
Weight	13 kg (airframe: 8kg, fuel: 5kg)
Engine	20 cc Petrol
Operation	Manual mode during takeoff and landing, and remote mode for out of vision
Cruise speed	20 m/s
Navigation	GPS
Range of navigation	150 km
Altitude	300m~4000m
Max. flight time	30 hours
Radio freq.	400~406MHz
Variables recorded	Pressure, air temperature, humidity, wind speed and direction, altitude, latitude/longitude, flight status, air speed, engine temperature and RPM.

Table 2：Specification of Vaisala RSS901 PTU sensor

	Pressure	Temperature	Humidity
Measurement range	1060~3hPa	-40~80℃	0~100%
Accuracy	0.1hPa	±0.15℃	±2%(1~90RH) ±3%(90~100RH)

Table 3: The records of Aerosonde flights during landfalling typhoons.

Typhoon Flight	Date	Hour	Typhoon Name
1	10/25-10/26, 2000	10	Yagi
2	6/23,2001	5	Chebi
3	7/4,2001	1	Utor
4	7/11,2001	1	Trima
5	9/25,2001	5	Lekima
6	10/16,2001	7	Haiyan

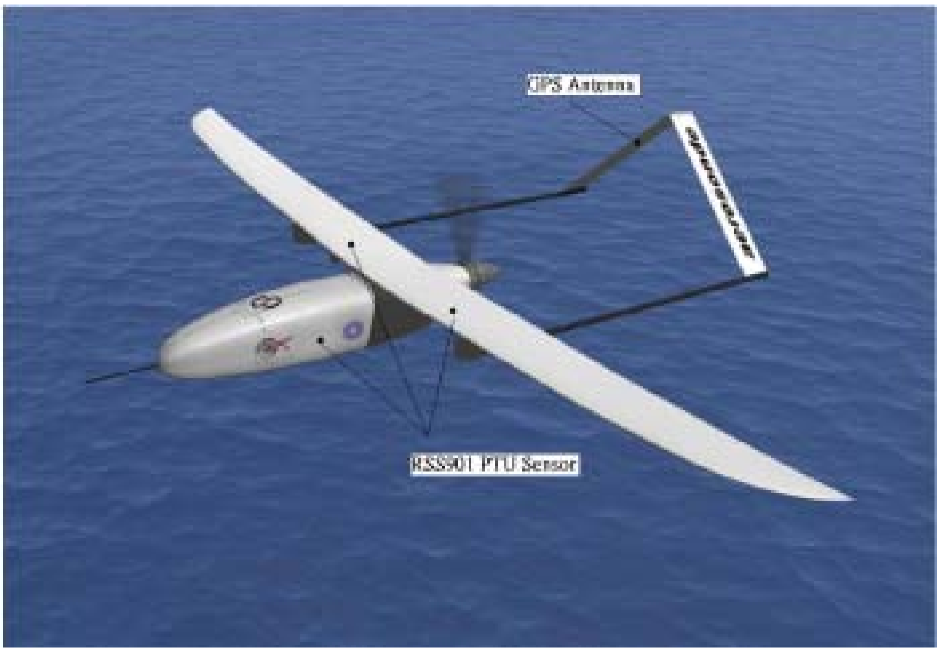


Figure 1: Aerosonde and its sensors' location

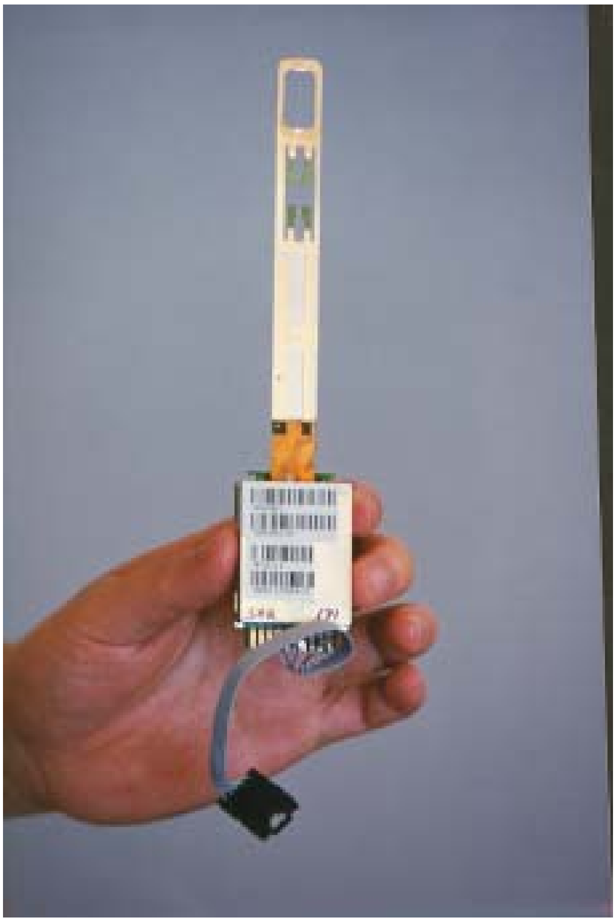


Figure 2: Vaisala RSS901 PTU sensor mounting on Aerosonde

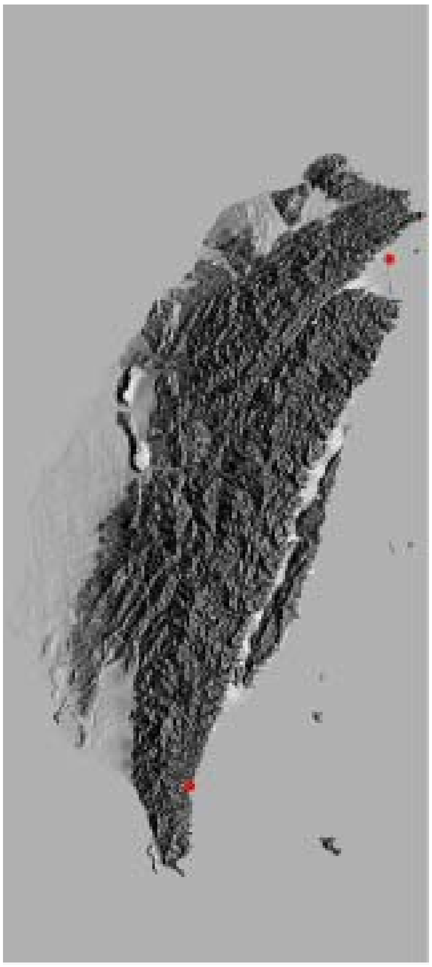


Figure 3: Ground bases (red points) of Aerosonde in Taiwan

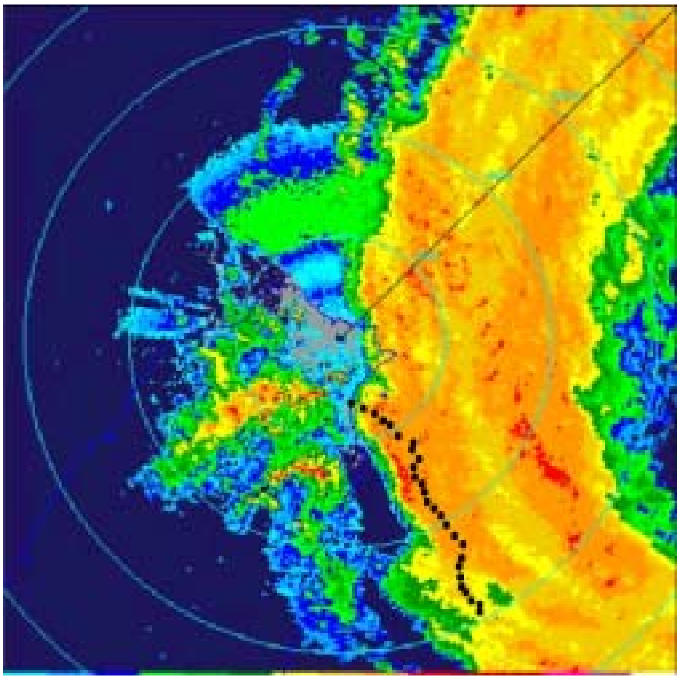


Figure 4: Aerosonde trajectory during Typhoon Haiyan. The rainfall echo image comes from the 03:19Z reflectivity product of Wu-Fen-San Radar station.

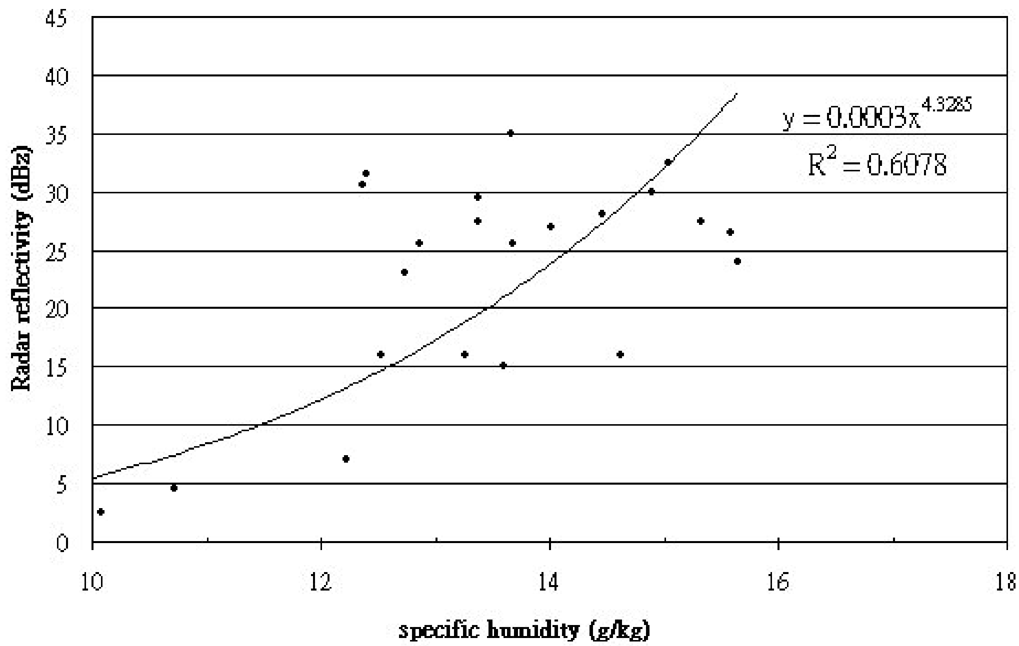
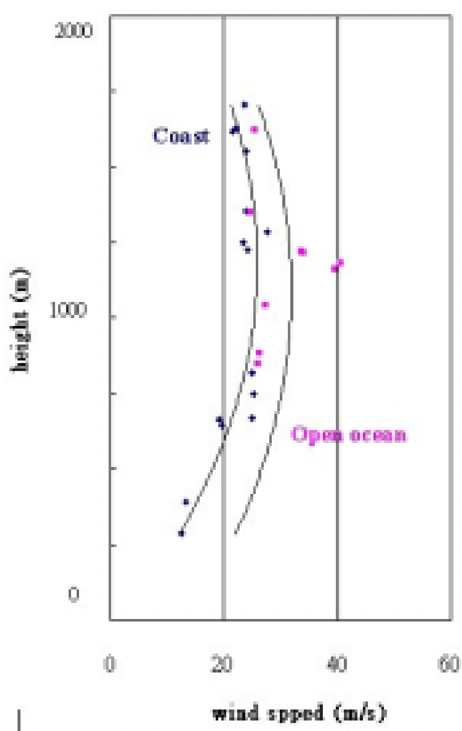


Figure 5: The relationship between Aerosonde in-situ specific humidity (g/kg) and Radar reflectivity (dBz).



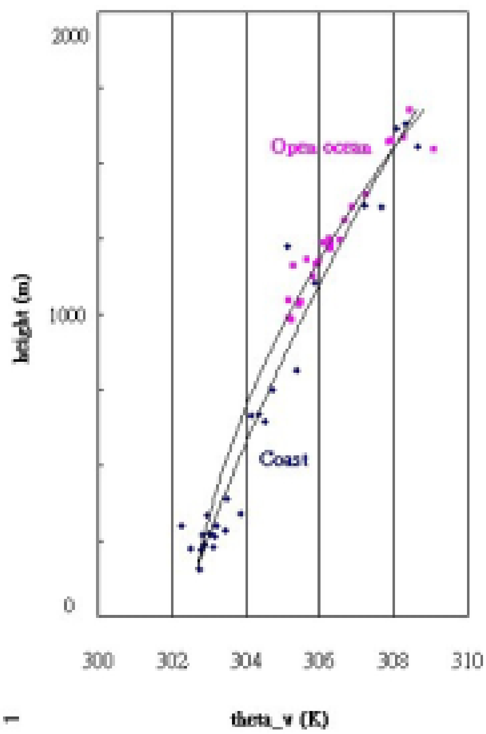


Figure 6a: Profiles of in-situ tangential wind speed measured by Aerosonde at coast and open ocean.

Figure 6b: Same as Figure 2a, but for the virtual potential temperature.

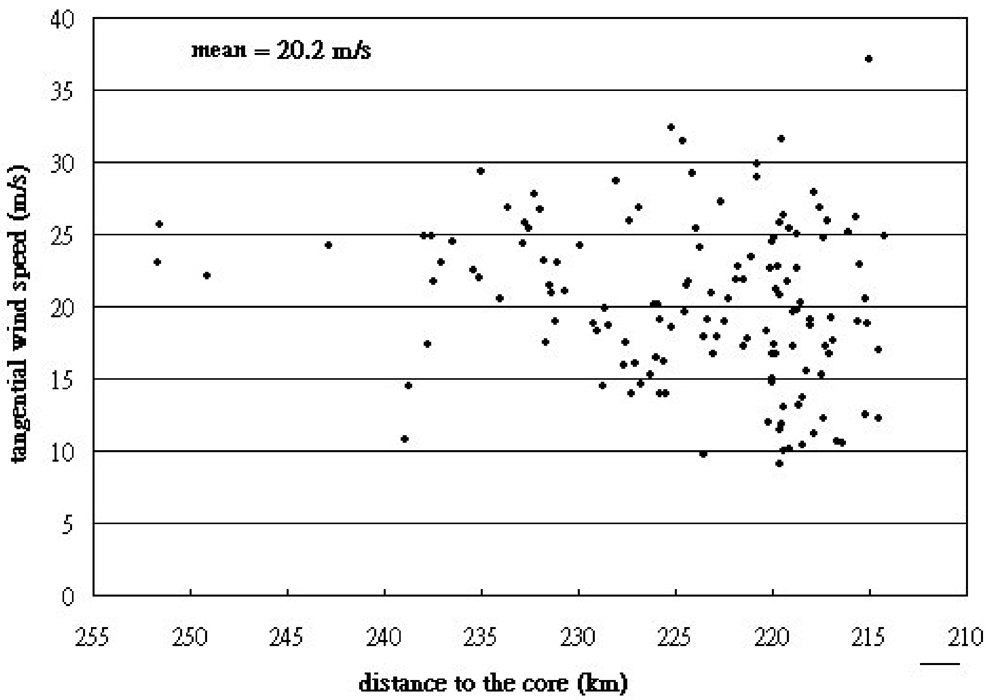


Figure 7: The distance distribution of the in-situ tangential wind speed measured by Aerosonde to the core of Typhoon Haiyan.

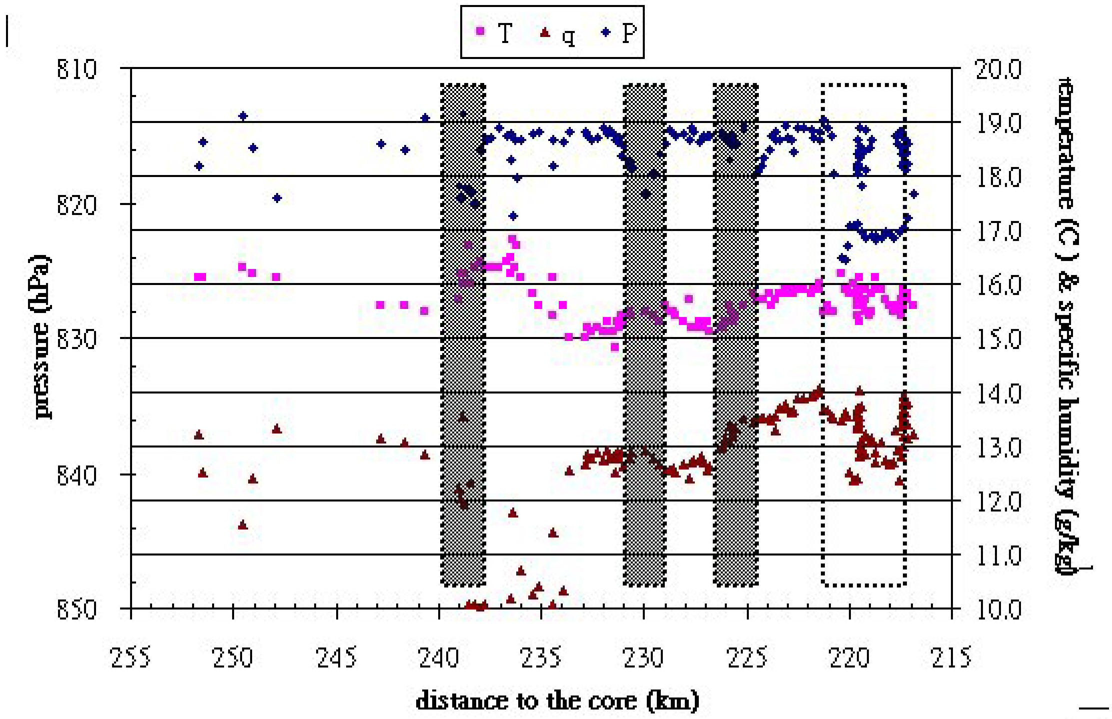


Figure 8: The distance distribution of the in-situ pressure, air temperature and specific humidity measured by Aerosonde to the core of Typhoon Haiyan. The grey boxes give mark of the subsidence motions, and the blank box represent the sounding flight at the open ocean.