Special edition paper

Research on a Gust Detection System Using Doppler Radar



Chusei Fujiwara* Taro Kitamura** Hiroto Suzuki*

JR East set up a Doppler weather radar on the roof of Amarume Station in March 2007 with the aim of developing a gust detection and prediction method and assessing applicability of that to train operation decisions. This report covers characteristics of gusts in the Shonai area based on observations. Furthermore, the results of a study on specifications and location of a new Doppler radar for improvement of gust detection accuracy are also shown.

●Keywords: Doppler radar, Gust, Tornado, Gust detection, Weather observation

1 Introduction

Gusts sometimes bring about railway accidents with their destructive force. Therefore, establishing a gust warning method is an important issue in terms of railway accident prevention.

On December 25, 2005, a derailment occurred near the Daini-Mogamigawa Bridge between Kita-Amarume and Sagoshi stations on the Uetsu Line. Regarding the accident, the investigation results report of the Aircraft and Railway Accidents Investigation Commission (current Japan Transport Safety Board) stated that serious efforts needed to be made on effective countermeasures against gusts by conducing broad-ranging research while focusing on advancements in meteorological observation technologies, information processing technologies, and the like.[1)]

Gusts such as tornados and downbursts (strong downdrafts from cumulonimbus clouds) form in a small space in a short span of time. For that reason, it is difficult to detect those with existing anemometers placed at discrete points. Even if we could issue a warning when a gust is detected with anemometers along the track and control train operation, the gust would have already passed the track by the time train operation control is implemented. Thus, for effective prevention of railway accidents by gusts, a method needs to be developed to observe by Doppler radar gust in a wide area continuously at a short interval and stop trains before a gust passes the track.

We set up a Doppler weather radar on the roof of Amarume Station on the Uetsu Line and started observation in March 2007 with an aim of developing a gust detection method and assessing applicability of that to train operation decisions. And in July 2007, we started observation of ground level wind speed, atmospheric pressure, and the like in the Shonai area of Yamagata Prefecture (details in 2.1) with the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA).

This report first covers findings on gust characteristics gained from observations and findings on a gust detection method. It then covers results of a study on the specifications and location for a new radar to be set up in order to improve accuracy of detecting gusts.

2 Findings on Gust Characteristics Obtained from Observations

2.1 Gust Observation in the Shonai Area

In order to develop a system of detecting, tracking, and issuing warnings of gusts and implement train operation control, it is important to identify actual gusts we have known little about. Observation of gusts such as tornados and downbursts and the weather phenomena that cause them is difficult to do by anemometers and the like as those occur in a small scale in a short span of time. We therefore constructed a weather observation network in the Shonai area of Yamagata Prefecture (Fig. 1). Elements of that network are as follows.

(1) Doppler radar at two locations (JR East radar (Amarume Station), MRI radar (Shonai Airport)

(2) Ground-level weather observation points at 26 locations* (wind direction and speed: 1 second sampling cycle / temperature, humidity, atmospheric pressure: 10 second sampling cycle)

* 12 locations from 2015

(3) Multipoint observation system at one location (12 anemometers, 25 barometers: 0.1 second sampling cycle)

(4) Thunderstorm observation points at five locations

(5) High altitude sonde observation

2.2 Major Findings on Characteristics of Guests in the Shonai Area

2.2.1 Features of Radar Images when Gusts Are Observed at Ground Level

In order to identify features of radar images when gusts are observed at ground level, we conducted case example analysis and statistical surveys. First are the results of case example analysis for December 5, 2007. Fig. 2 shows change over time of ground-level wind speed when guests were observed. In this case, sudden increase in wind speed, a feature of gusts, was observed. We investigated the radar images where these ground-level guests were observed (Fig. 3). As a result, hook-shaped rainfall distribution patterns characteristic of when vortices are present were observed (Fig. 3 (a)) and a pair of winds approaching and receding was present in Doppler velocity profiles (Fig. 3 (b)). From these results, we found that vortex-shaped patterns are present in the atmosphere when gusts are observed at ground level in this case.[2)]

*Disaster Prevention Laboratory, Research and Development Center of JR East Group
**Planning Sect., Facilities Dept., Tokyo Branch Office, JR East (previously at head office Safety Planning Dept.)

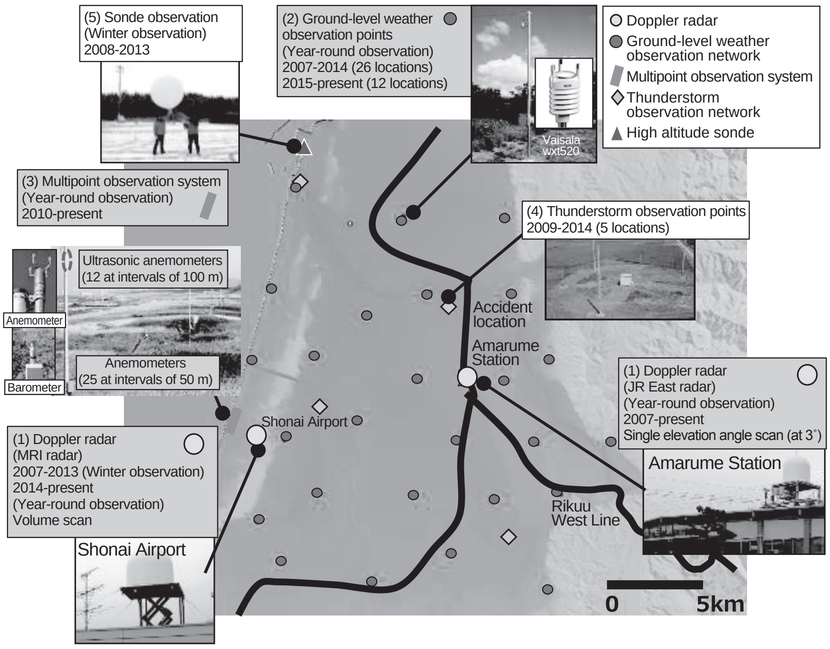

Fig. 1 High Density Weather Observation Network Built in Shonai Area

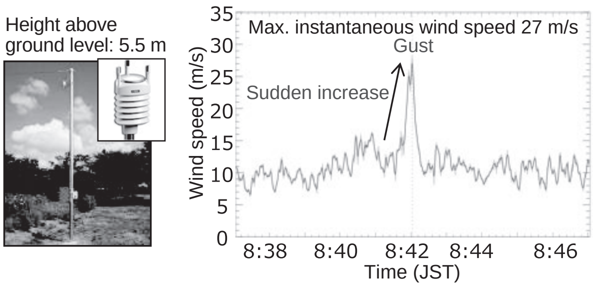

Fig. 2 Wind Speed Change Over Time when Gusts Observed by Ground-level Anemometers

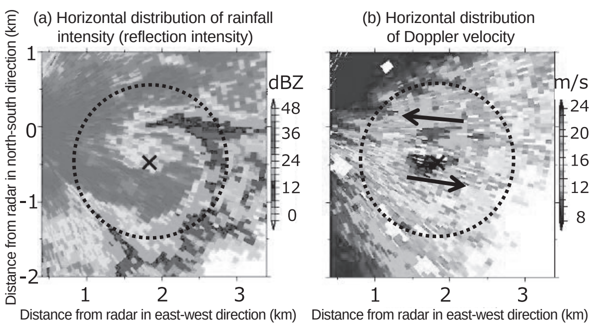

Fig. 3 Radar Images when Gusts Observed by Ground-level Anemometers (x: Location of Ground-level anemometer)

In order to verify whether or not results obtained in case analysis have generality, we conducted statistical surveys on features of radar images for examples where gusts were observed by ground-level anemometers. As a result, we found that vortex-shaped radar patterns accompanied precipitation in approx. 90% of the 44 examples of gusts observed in the seven winters (October to March) from 2007 to 2013.

From those results, we concluded that the method of detecting vortices by Doppler radar is effective in detecting ground-level gusts.

2.2.2 Characteristics of Movement of Gusts

In order to identify characteristics of movement of gusts (vortices) generated in the Shonai area, we investigated cases observed in the seven winters (October to March) from 2007 to 2013. Routes of movement of vortices observed by the JR East radar are shown in Fig. 4. In that figure, 96 examples are shown where maximum wind speed of vortices was 25 m/s or greater. As a result, we found that vortex movement can be classified into the following two patterns, that they moved mostly in a straight line from west to east, that they form over the Sea of Japan, and that they move inland.

(1) Many vortices that form when winter pressure patterns are present move from northwest to southeast (approx. 80%, Fig. 4 (a)).

(2) Many vortices accompanying cold fronts move from southwest to northeast (approx. 20%, Fig. 4 (b)).

From these results, we concluded that prediction of the direction of vortices is possible by tracking vortices.

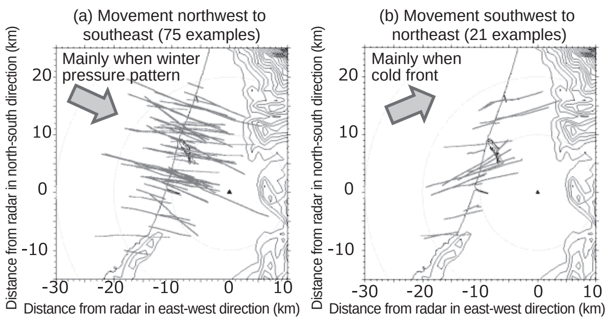

Fig. 4 Routes of Movement of Vortices

2.2.3 Formation and Evolution Mechanism of Vortices that Cause Gusts

In order to identify the formation and evolution mechanism of vortices that accompany cold fronts in the Shonai area in winter, we conducted high-resolution numerical simulations[3]. As a result of the numerical simulations, we found that vortices grow from low altitudes to high altitudes[3]. Therefore, we found that a detection method by frequent observation by radar at low altitudes would be appropriate for early detection of vortices.

3 Findings on Methods of Gust Detection: Cause Analysis Related to Misidentification of Vortices

Based on findings of observations, we built a prototype gust detection system that can display the location and intensity of vortices that cause gusts.[2] While vortices could be detected at a certain level with the prototype gust detection system, we found that misdetection occurs due to misidentification of vortices.[4] In this section, we present results of analysis of causes of that.

Weather radar is used to find distribution of precipitation from signals reflected from precipitation particles such as rain droplets (precipitation echo). On the other hand, reflection from surrounding buildings and terrain (terrain echo) also is sometimes observed in addition to precipitation echo. The current radar observes from the roof of Amarume Station (8 m above ground), so there are obstacles (buildings, radio towers, etc.) to radar observation. And the surrounding area features undulating terrain that includes Mt. Chokaisan. Due to the impact of such surrounding terrain with obstacles, terrain echo is generated in a broad part of the observation range (Fig. 5). This causes failure of "Doppler velocity unfolding"*, and it is recognized as apparent vortices (pairs of winds approaching radar and receding), causing misidentification of vortices in the area circles in Fig. 6.

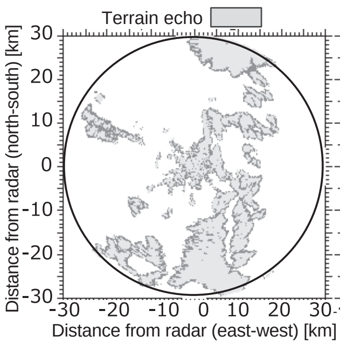

Fig. 5 Terrain Echo Distribution Diagram

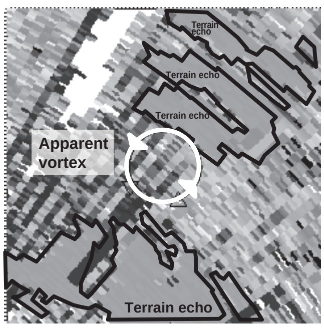

Fig. 6 Example of "Unfolding" Failure around Terrain Echo

* Doppler velocity unfolding:: With Doppler radar, the measurement range where Doppler velocity can be measured is principle fixed. For that reason, "unfolding" occurs at speeds exceeding that range, resulting in a value different from true Doppler velocity. Thus, in the process of data processing, "unfolding" is corrected from the continuity of surrounding data.

4 Study on Specifications and Location of a New Radar for Improvement of Gust Detection Accuracy

Analysis of the causes of misidentification of vortices revealed that there is a limit to improvement of accuracy at the location of the current radar at Amarume Station. We thus conducted a study on specifications and location of a new radar in order to improve accuracy of detecting gusts.

4.1 Specifications of the New Radar

Table. 1 shows a comparison between specifications for the new radar, the current radar at Amarume Station, and the XRAIN set up by the Ministry of Land, Infrastructure and Transport (MLIT). XRAIN is an X-band multi parameter radar network that can observe localized rainfall almost in real time in order to enhance torrential rain monitoring.[5] It was put in operation in 2010, and has been set up in 39 locations across Japan as of March 31, 2015.

The new radar is based on XRAIN specifications, but it has sampling resolution improved over that of XRAIN in both azimuth angle direction and range direction in order to improve gust detection accuracy.

Using a larger antenna that of the current radar, the new radar has narrower beam width and improved resolution in the azimuth angle direction important for vortex detection. Moreover, maximum detection distance is increased over that of the current radar in order to be able to detect gusts with good accuracy over a broader range.

By using solid-state devices instead of magnetrons for the transmission system with the new radar, stable operation is expected due to greatly increased lifespan of the transmission part.

Table 1 Comparison of Radar Specifications

Specification	MLIT XRAIN	New radar	Current radar
Range direction sampling	150 m	75 m	75 m
Azimuthal direction sampling	1.2°	0.7°	0.7°
Antenna diameter	2 m	2 m	1.2m
Beam width	1.2°	1.2°	2°
Max. detection distance	80 km	60 km	30 km
Transmission system	Solid-state device klystron	Solid-state device	Magnetron

4.2 Study on Location of the New Radar

We studied a location to set up the new radar from findings on characteristics of gusts. Vortices form over the Sea of Japan; so with a radar closer to the coastline, more time can be secured between detection of a vortex to controlling train operation (lead time) (see 2.2.2). And vortices grow from low attitudes; so a method of frequent observation with low angle of elevation, close to horizontal, is suitable (see 2.2.3).

We next studied where to set up the new radar taking into account the observation environment of the current radar at Amarume Station. The current radar observes from 8 m above ground on the roof of the station, which is not a very high altitude. For that reason, there are obstacles to radar observation in the surrounding area, such as buildings. We found that due to the shadow of buildings and the like near the radar, areas are generated where Doppler velocity cannot be observed (Fig. 7). Moreover, misidentification of vortices may occur due to failure in return correction due to terrain echo (see section 3). Therefore, data quality needs to be assured by setting up the radar on a hill, tower, or other location higher than surrounding buildings and structures as is as done with radars such as those of JMA and MLIT.

From the study above, we summarized the ideal location conditions and observation mode for the new radar as follows.

(1) Location near the coastline
(2) Frequent observation with low angle of elevation from location where radar is set up
(3) High altitude not obstructed by surrounding buildings and terrain

As a result of studying the location for the new radar from the above conditions, we decided to set up the new radar at Shonai sand dunes (altitude of approx. 50 m) approx. 2 km from the shoreline (Fig. 8, 9). As there is a pine tree forest with tree heights of about 20 m near the radar location, we are putting the radar on a 30 m high tower (Fig. 10). That will decrease the influence of surrounding obstacles and allow frequent observation of the lower atmosphere with a low angle of elevation close to horizontal, which is expected to increase accuracy of detecting vortices.

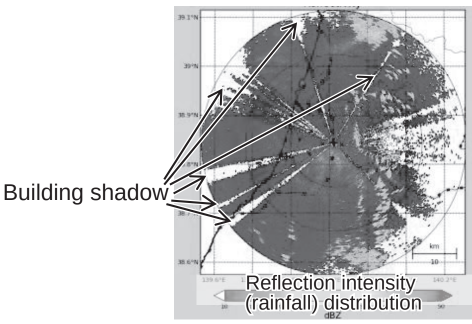

Fig. 7 Impact of Buildings Near Radar

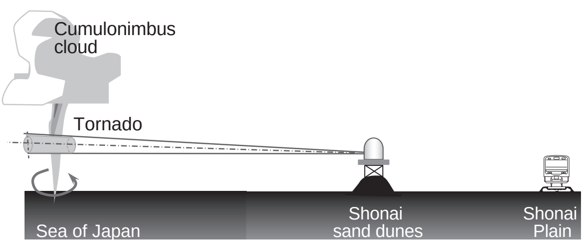

Fig. 8 Relationship between Radar Location and Gusts

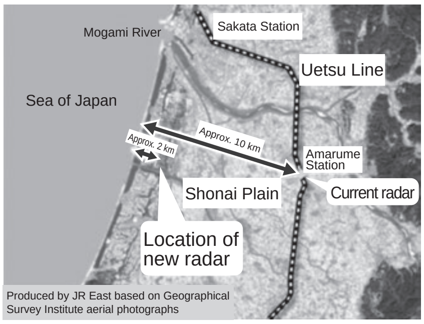

Fig. 9 Location of New Radar

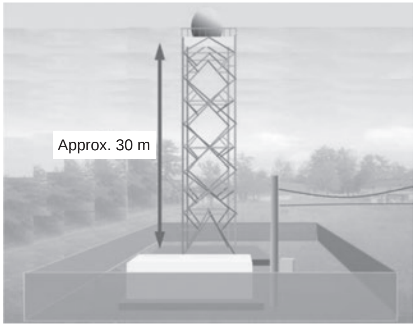

Fig. 10 Image of Setup of New Radar

5 Conclusion

This report covered findings related to characteristics of gusts obtained from the observation network deployed in the Shonai area of Yamagata Prefecture and findings related to gust detection methods. It has also covered a study on specifications and location of a new Doppler radar for improvement of gust detection accuracy.

Based on the results of the study, we are setting up a higher performance Doppler radar in a location suited for observation, with completion of construction scheduled by the end of March 2017. Moreover, we plan to conduct further studies with an aim of putting into practical use train operation control using a system for detecting gusts based on the data observed by the new radar.

Reference:

1) Aircraft and Railway Accidents Investigation Commission: Railway Accident and Incident Report, No. RA2008–4 [in Japanese] (April 2, 2008)
2) Kenichi Kusunoki et al. "Kogata Doppler Weather Radar ni yoru Tetsudo Anzen Unko no tameno Toppu Tanchi System no Kisoteki Kenkyu [in Japanese]", *Fiscal 2007 Report of Program for Promoting Fundamental Transport Technology Research*, the Japan Railway Construction, Transport and Technology Agency (2010)
3) Kenichi Shimnose et al., "2008 nen 12 gatsu 11 nichi Shonai Heiya ni Toppu wo Motrashita Kishou Jouran — Koukaizoudo Simulation" (A407) [in Japanese], *Proceedings of the 2010 Spring Meeting of the Meteorological Society of Japan* (2010)
4) Kenichiro Arai, Keiji Adachi, Hiroyuki Morishima, "Research on the Use of Doppler Radar in Railways", *JR East Technical Review*, No. 19 (2011): 37 - 40
5) Shuichi Tsuchiya, Hideyuki Yamaji, Masaki Kawasaki, "Technical documentation on practical application of XRAIN (X-band polarimetric (multi-parameter) radar information network) rainfall observation", *Technical Note of NILIM* No. 909 (2016)