Gust prediction
by a high density ground surface observation network (POTEKA)

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Abstract. POTEKA (POint TEEnki KAnsoku in Japanese) compact weather stations can observe seven meteorological variables, including temperature and pressure. In Gunma and Saitama prefectures, Japan, about 150 POTEKAs have been installed to create a high density ground surface observation network which has a resolution of approximately 2 km. This observation network has observed multiple downburst and damaging wind events, and has revealed the characteristics of downbursts, such as changes in the meteorological variables and phenomena proceeding these events (Iwashita et al. 2019). By analyzing the downburst event on Jun 15, 2015, which was the most damaging event observed by the network, we have succeeded in developing a downburst gust prediction system that utilizes the high density ground surface observation data. The high density ground surface observation network can be used to predict the occurrence of a downburst event several minutes in advance using temperature and pressure data. The cumulonimbus forward velocity can be calculated from the distance and time between the locations of temperature drops. Areas with a high probability of gust occurrence can be estimated based on the magnitude of the temperature drop. Thus, it may be possible to predict the occurrence times and locations of downburst gust events by utilizing high-resolution observations of the temperature and pressure.

Keywords: High density observation, Surface observation network, Downburst, Gust prediction

1. Introduction

In the previous paper (Iwashita et al. 2019), on the basis of a high density ground surface observation network POTEKA (POint TEEnki KAnsoku in Japanese) installed in Gunma and Saitama prefectures in Japan, several cases of the F1 downburst events that were accompanied by substantial damage (the downburst events of August 11, 2013, June 15, 2015 and July 14, 2016) were presented.

As a detection technique of downbursts (gust fronts), Bedard et al. (1977) installed a high density ground surface pressure observation network around the airport and reported that the travelling speed and direction of a gust front which might cause a downburst could have been indicated by the pressure jump detector array with 125...
locations and a resolution of about 1 km on the surrounding area of Dulles International Airport in Washington D.C. Also, a pressure jump of about 1 hPa over about 10 minutes was caused by a gust front passing.

In Gunma and Saitama prefectures in Japan, almost just below a severe downburst, the pressure jump by a gust front occurred at almost the same time as a steep temperature drop. Also, the steep temperature drop occurred at about 5 minutes before the steep pressure jump of about 3 to 4 hPa caused by downburst itself. Moreover, in contrast to pressure, which both increased and decreased complicatedly, temperature monotonically decreased (Iwashita et al. 2019). Temperature information is considered to be very useful in order to provide advanced warning as soon as possible and to realize the automated gust prediction system.

Here, we report downburst characteristics revealed by a high density ground surface observation network in Gunma and Saitama prefectures. We also present a gust prediction methodology developed by analyzing the most damaging downburst event, which occurred on Jun 15, 2015. Moreover, we describe the results of the verification of our prediction methodology.

2. Downburst characteristics

In Gunma and Saitama prefectures, a high density ground surface observation network has succeeded in observing 11 downburst and damaging wind events over about 5 years since 2013. The high density ground surface observation network in Gunma and Saitama prefectures is shown in Fig. 1.

A severe downburst, in the F1 category of the Fujita scale, was observed on Jun 15, 2015 and was the most damaging event among the 11 cases. The surface weather chart for this day is shown in Fig. 2. Because of colder air at higher altitudes, the atmosphere was unstable over eastern Japan on this day.

Figure 1. High density ground surface observation network in Gunma and Saitama (POTEKA network)
In Gunma prefecture, a cumulonimbus was developing over the mountains in the northwest. In the afternoon, the cumulonimbus that was located to the northwest of the network produced an F1 downburst resulting in damage while proceeding to the southeast. The observation network was able to record observations before and during the severe downburst. The observation data about 1 km from the most damaged area are shown in Fig. 3.

We have identified the four following characteristics before a downburst, according to the POTEKA data near F1 damage of downbursts.

- A steep pressure jump of about 3 to 4 hPa is observed at almost the same time as the
downburst gust occurrence.

- About 5 minutes before the steep pressure jump, a steep temperature drop is observed.
- A pressure jump of about 1 hPa is observed at almost the same time as the steep temperature drop.
- In contrast to temperature, which monotonically decreases, pressure both increases and decreases complicatedly.

Other severe downburst events, such as those occurring on Aug 11, 2013 and Jul 14, 2016, also had these characteristics (Iwashita et al. 2019).

This observation network could determine the direction that a cumulonimbus was proceeding in. It was observed that the area experiencing sudden changes in temperature and pressure was proceeding from the northwest to the southeast.

Figure 4. Contour plot of the conditions proceeding the downburst on Jun 15, 2015

Figure 5. Locations where a steep temperature drop was observed on Jun 15, 2015
contours showing the path of the cumulonimbus is shown in Fig. 4.

We have found that downburst events in the Gunma and Saitama areas have three main characteristics.
· A steep temperature drop is observed somewhere on the outer line surrounding the network.
· The area experiencing a temperature drop changes with time.
· The damage path follows the path of the area experiencing the temperature drop.
Other severe downburst events, such as those occurring on Aug 11, 2013 and Jul 14, 2016, also had these characteristics (Iwashita et al. 2019).

Moreover, we have found that a steep temperature drop (−2 °C or less per minute) was only observed under the center of the cumulonimbus which was proceeding. Figure 5 shows the northwest area of the observation network. The steep temperature drop was only observed at the eight stations in this area.

3. Gust prediction methodology

As shown in section 2, the high density ground surface observation network observed the path and velocity of the cumulonimbus that caused the downburst event. The path of the cumulonimbus is determined by the area with low temperatures. We observed that a steep temperature drop occurred about 5 minutes before the steep pressure jump and the temperature monotonically decreased. Moreover, we observed that the steep temperature drop occurred under the center of the cumulonimbus which was proceeding. Thus, to realize a downburst gust prediction system, we should utilize the temperature data.

We therefore conclude that it may be possible to predict downburst events from the path of the low-temperature area and from the location of the first point to experience

![Procedure of gust prediction methodology]

**<Step 1>**
The predicted gust area expands up to 10 km around the location at which the first steep temperature drop was first observed (−2 °C or less per minute).

**<Step 2>**
The cumulonimbus velocity is calculated from the distance and observation time between the first drop location and the second drop location at which a small temperature drop of -1 °C or less per minute is observed.
⇒ The predicted gust time is then calculated.

**<Step 3>**
Whenever a small temperature drop of -1 °C or less per minute is observed, the cumulonimbus velocity and predicted gust time are modified.

**<Step 4>**
By distinguishing between the steep temperature drop (−2 °C or less per minute) locations and moderate temperature drop (between −1 and −2 °C per minute) locations, the predicted gust area is narrowed.

Figure 6. Detailed gust prediction procedure
a steep temperature drop. We have developed a downburst gust prediction methodology by utilizing the high density ground surface observation data of the area experiencing the greatest damage from the downburst event on June 15, 2015.

The outline of the gust prediction methodology is as follows.

- The rate of the temperature drop at each observation point is determined assuming a uniform temperature drop caused by the observed cold air pool.
- It is determined whether there is a high or low probability of gust occurrence. (The threshold is a $-2\, ^\circ C$ per minute transition.)
- The predicted area is narrowed every time the probability of gust occurrence is determined.

The detailed gust prediction procedure is shown in Fig. 6. Above steps 1 to 4 and utilizing the observation data from Jun 15, 2015, we performed a gust prediction for the downburst event on Jun 15, 2015. The results of the prediction are shown in Figs. 7-1 to 7-7. The actual damage occurred between 16:05 and 16:15 in the purple area. The colors in Figs. 7-1 to 7-7 are as follows.

- Red indicates a predicted gust area (high-probability area).
- Grey indicates an area predicted to have no gusts (low-probability area).
- Purple indicates an area where damage from the downburst gust was observed.
- Yellow labels indicate the updated observation data.
- White labels indicate the past observation data.

1. **Step 1.** At observation point ①, a steep temperature drop ($-2.2\, ^\circ C$) is detected at 15:28 JST. The predicted gust area (high-probability area) expands up to 10 km of ①.

![Figure 7-1. Prediction result at 15:28 JST](attachment:image)
(2) **Step 2.** At observation point ②, a small temperature drop (−1.0 °C) is detected at 15:33 JST. The predicted gust area (high-probability area) expands across the observation area. The distance between ① and ② is 5 km. The difference in the observation times between ① and ② is 5 minutes. The cumulonimbus velocity is thus estimated as 1 km min⁻¹. The predicted gust time of each point is calculated.

![Figure 7-2. Prediction result at 15:33 JST](image)

(3) **Step 3.** At observation point ③, a small temperature drop (−1.3 °C) is detected at 15:42 JST. The distance between ① and ③ is 9 km. The difference in the observation times between ① and ③ is 14 minutes. The cumulonimbus velocity is now updated from 1 to 0.64 km min⁻¹. The predicted gust time of each point is modified accordingly.

![Figure 7-3. Prediction result at 15:42 JST](image)
(4) **Steps 3 and 4.** At observation points ② and ③, the temperature drop was moderate (more than −1.6 °C) at 15:47 JST. On the other hand, at observation point ④ a steep temperature drop (−2.1 °C) was detected at 15:47 JST. **The area between ② and ③ can be determined to have a low probability of gust occurrence. This area is thus removed from the predicted gust area. The cumulonimbus velocity and predicted gust time are modified as in (3).** From the above, the predicted time for the damage occurrence is from 15:57 to 16:13 JST, while the observed time was from 16:05 to 16:15 JST.

![Figure 7-4. Prediction result at 15:47 JST](image)

(5) **Step 3.** At observation point ⑤, a steep temperature drop (−3.2 °C) was detected at 15:53. **This entire area where the gust is predicted to occur has a high probability of gust occurrence and is not narrowed. The cumulonimbus velocity and predicted gust time are modified as in (3) and (4).**

![Figure 7-5. Prediction result at 15:53 JST](image)
(6) **Steps 3 and 4.** At observation point ⑥, a moderate temperature drop was detected (more than \(-1.4 \, ^\circ\text{C}\)) at 15:58. **The area south of ⑥ is determined to have a low probability of gust occurrence. This area is also removed from the predicted gust area.** The cumulonimbus velocity and predicted gust time are modified as in (3) to (5).

![Figure 7-6. Prediction result at 15:58 JST](image)

(7) **Steps 3 and 4.** At observation point ⑦, a moderate temperature drop was detected (more than \(-1.7 \, ^\circ\text{C}\)) at 16:03. **The area north of ⑦ is determined to have a low probability of gust occurrence. This area is also removed from the predicted gust area.** The cumulonimbus velocity and predicted gust time are modified as in (3) to (6).

![Figure 7-7. Prediction result at 16:03 JST](image)

As shown in Fig. 7-2, about 30 minutes before (15:33 JST) the actual damage occurrence (16:05 JST), the downburst gust prediction methodology could provide advanced warning to actual damage area’s people. As shown in Fig. 7-4, about 20 minutes before (15:47 JST) the actual damage occurrence (16:05 JST), the predicted gust time (15:57 to 16:13 JST) was within 10 minutes from the actual damage time (16:05 to 16:15 JST).
JST). As shown in Fig. 7-7, the final predicted gust area (red) included the actual damage area (purple).

4. Verification for the other downburst events

4.1. Prediction result for downburst on August 11, 2013 (F1)

During the severe downburst (F1) on Aug 11, 2013, the affected area experienced a sudden temperature drop and pressure jump, proceeding from the west of the high density ground surface observation network to the east-northeast (Iwashita et al. 2019). Contours showing the direction of the cumulonimbus are shown in Fig. 8.

According to the gust prediction procedures in section 3, we tried to predict the downburst on Aug 11, 2013. The result is shown in Fig. 9.

Figure 8. Contour plot of the conditions proceeding the downburst on Aug 11, 2013

Figure 9. Final prediction result for the downburst on Aug 11, 2013
4.2. Prediction result for downburst on July 14, 2016 (JEF1)

During the severe downburst (JEF1) on Jul 14, 2016, the affected area experienced a sudden temperature drop and pressure jump, proceeding from the southwest of the high-density ground surface observation network to the north-northeast (Iwashita et al. 2019). Contours showing the direction of the cumulonimbus are shown in Fig. 10.

According to the gust prediction procedures in section 3, we tried to predict the downburst on Jul 14, 2016. The result is shown in Fig. 11.

Figure 10. Contour plot of the conditions proceeding the downburst on Jul 14, 2016

Figure 11. Final prediction result for the downburst on Jul 14, 2016

5. Conclusion

POTEKA compact weather stations can observe seven meteorological variables, including temperature and pressure. In Gunma and Saitama prefectures, Japan, about 150 POTEKAs have been installed to create a high density ground surface observation
network which has a resolution of approximately 2 km. This observation network has observed multiple cases of downbursts and damaging wind events, and has recorded detailed observations of the changes proceeding a downburst such as changes in the temperature and pressure.

The following features were observed before a downburst occurrence.

・ A steep pressure jump of about 3 to 4 hPa is observed at almost the same time as the downburst gust occurrence.
・ About 5 minutes before the steep pressure jump, a steep temperature drop is observed.
・ A pressure jump of about 1 hPa is observed at almost the same time as the steep temperature drop.
・ In contrast to the temperature which monotonically decreases, pressure both increases and decreases complicatedly.

The area beneath the cumulonimbus was characterized by the following features.

・ A steep temperature drop is observed somewhere on the outer line surrounding the network.
・ The area experiencing a temperature drop changes with time.
・ The damage path follows the path of the area experiencing the temperature drop.

Moreover, a steep temperature drop (−2 °C or less per minute) was only observed under the center of the cumulonimbus.

We considered the potential predictability of downburst events by tracing the location of steep temperature drops from the first observation of a steep temperature drop. We have developed a downburst gust prediction methodology by utilizing high-density ground surface observation network data. The detailed gust prediction procedure is as follows.

・ The predicted gust area expands up to 10 km around the location at which the steep temperature drop was first observed (−2 °C or less per minute).
・ The cumulonimbus velocity is calculated from the distance and observation time between the first drop location and the second drop location at which a small temperature drop of −1 °C or less per minute is observed.

⇒ The predicted gust time is then calculated

・ Whenever a small temperature drop of −1 °C or less per minute is observed, the cumulonimbus velocity and predicted gust time are modified.

・ By distinguishing between the steep temperature drop (−2 °C or less per minute) locations and moderate temperature drop (between −1 and −2 °C per minute) locations, the predicted gust area is narrowed.

For severe downbursts in the Gunma and Saitama area, this gust prediction methodology could help to provide advanced warning about the damage time and area. The predicted gust time was within about 10 minutes of the actual damage time. The predicted gust area included the actual damage area.

If we utilize high density ground surface observation data, we may be able to realize a downburst gust prediction system and predict the occurrence of extreme weather events which threaten human life and property.
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