Utilization of weather-radar data to observe the Sea Breeze Front (SBF) over the North Coast of Banten-Jakarta (case study in 2018)

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Abstract. One of the important factors in weather and climate dynamics that can trigger precipitation on the coast and the surrounding area is a sea breeze. Sea breeze occurs because of differences in the surface temperature between land and sea due to solar heating which then forms a pressure gradient that leads to a land called the sea breeze circulation. An important part of sea breeze circulation is the Sea Breeze Front (SBF). SBF is a boundary area where wind from the sea direction meets the wind from the land direction, which is marked by significant changes in temperature, humidity, wind and can trigger convective activity. This study aims to determine the characteristics of the SBF on the north coast of Banten-Jakarta in 2018 which were identified using a Doppler weather radar Plan Position Indicator (PPI) product and convective activity using the Column Maximum (CMAX) product. Qualitative and quantitative methods are used to determine the SBF parameters such as frequency of occurrence, onset time, duration, length, column depth, and SBF penetration, and convective activity during the occurrence of SBF. The results showed that SBF was detected more in the rainy season January, February, and December 2018, and occur between 08:08 LT and 15:20 LT. SBF can trigger the occurrence of convective clouds and affect the temperature and humidity conditions around the SBF.

Keywords: sea breeze front, convective activity, Doppler-weather radar

1. Introduction
The contrasting temperature differences between land and oceans along the coast lead to atmospheric interactions in the form of land and sea breeze circulation [1,2]. Sea breeze circulation (SBC) in the sea develops when solar warming causes a difference in the surface temperature on land and oceans which creates a mesoscale pressure gradient that leads to the land [1]. The SBC is a local circulation that has an important role in weather and climate dynamics, one of which triggers convection causes precipitation on the coastal edge and surrounding areas [3–6].

Sea Breeze Front (SBF) is an important part of SBC, as the boundary area where the SBC meets the wind from the land, characterized by significant changes in temperature, humidity, and wind [7]. SBF is a mesoscale weather phenomenon that can intrude up to 100 km inland and last several hours until it eventually becomes extinct [1]. SBF triggers the formation of convective cloud cells when the mass of cold air-flows from the sea interacts with the mass of warm air-flows from the land, which finally causes rain and lightning on the land [4,8].

The identification of the SBF phenomenon has been carried out using remote sensing data, such as by [9] and [3] used a Doppler weather radar. Doppler radar can detect SBF clearly when the weather conditions in the observed area are not covered by clouds. Hadi et al [9] have identified the sea breezes in the Serpong area (~6.4°N, 106.7°E) using the satellite imagery data and Boundary Layer Radar (BLR),
showed that SBF developed well along the north coast of West Java, spread inland until the structure is damaged by the complex topography. SBC is more common in the dry season, from July to October.

Simpson et al [1] who identified the characteristics of SBF in Chennai using a Doppler-weather radar showed that the penetration of sea breezes to land can be identified by the thin-line echo with a reflectivity of 13-19 dBZ along the coastline. About 80% of the total rain events observed during the southwest monsoon in Chennai are directly related to convection caused by SBC. Suresh [3] continued the SBF study in Chennai using an S-band Doppler weather radar. Radar plan position indicator (PPI) or constant altitude PPI (CAPPI) products are used to determine the altitude of the SBC. It is known that the time of sea breeze onset in Chennai is between 08:00-10:00 UTC, spread inland at average speeds of 4-15 km/hr to 10-20 km/hr, and in some events can intrude up to 100 km inland. Besides, about 53% of observed SBF events associate with convective activity.

There is some research about the SBF in the Indonesian territory, such as by Novitasari [10] on the north coast of Jakarta and Meilusiani [11] in Makassar. The depth of the SBF affects the maximum reflectivity (Z) of the convective cloud radar and the extent of the convective cloud formed, where the convective cloud formed by SBF is a single cell type [10]. The higher the depth of the SBF column, the wider the diameter of the clouds formed [10,11]. The SBF that occurs in Makassar predominantly occurs at 14:32-15:54 LT with a duration ranging from 1.9-2.7 hours, has a face length of 21.5-25.5 km, the height of the column reaches 0.64-0.76 km and can intrude the mainland as far as 13.9-18.8 km [11].

The geographical condition of the north coast of Banten-Jakarta, which is directly adjacent to the Java Sea, supports the occurrence of SBC in the northern region of Banten-Jakarta. The northern area of Banten-Jakarta, which is included in the effective area of the BMKG Tangerang Doppler-weather radar observation, allows us to carry out the SBF research in this area. This research was conducted to complete the identification of the characteristics of the SBF on the north coast of Banten-Jakarta and its effect on convective activity using the Doppler-weather radar data.

2. Methods

This research was conducted using quantitative and qualitative methods of experimental data based on pre-determined problem boundaries. Quantitative research was used to obtain the interval, frequency, and range of events for SBF. Qualitative research is used to analyze and describe the characteristics of the SBF parameters and the convective activity detected on the weather radar.

2.1. Research period and location

The period of this study is January-December 2018, divided into 3 periods, i.e. the rainy season (December-January-February or DJF), the dry season (June-July-August or JJA), and the transitional period (March-April-May or MAM and September-October-November or SON).

The area of this study is the north coast of Banten-Jakarta, which is directly adjacent to the Java Sea and within reach of the Tangerang weather radar (Figure 1), which the radar specifications are shown in Table 1.

| Table 1. Tangerang Doppler-weather radar specifications |
|--------------------------------------------------------|
| **Brand** | Gematronik |
| **Latitude** | -6.1669°N |
| **Longitude** | 106.6502°E |
| **Band type** | C-band |
| **Polarization** | single polarization (horizontal) |
| **Antenna height** | 20 MASL |
Figure 1. Map of the research area

2.2. Research data and tools
The data used in this study are data for the period January-December 2018, such as:
- Tangerang weather radar data in volumetric (.vol) format, including raw data reflectivity (Z).
- Surface observation data from the Soekarno-Hatta Meteorological Station, including data on temperature, humidity, wind direction and speed, and cloud conditions.

The tools used in this study are Rainbow Manager application to process radar raw data into radar products in the form of reflectivity, and spreadsheet application to perform mathematical calculations, graphs, tables, and quantitative analysis.

2.3. Research methods
The following is the flow of data processing carried out in this study:
- Processing the Z weather-radar data using the Rainbow Manager application to produce PPI (Z) products at the elevation of 0.5° to detect the presence of SBF, as well as Column Maximum (CMAX) (Z) products to detect convective activity. The SBF pattern is characterized by a low reflectivity value and was in the form of a thin line that has a pattern almost the same as the shoreline. Convective activity is characterized by a reflectivity value > 38 dBZ.
- Calculating the frequency of occurrence, onset time, and duration of detected SBF, and present it in tables and graphs. The frequency of events is the total SBF events during 2018. Onset time is the initial time when SBF events are detected by weather radar. The duration of the SBF is the period from its onset until the SBF pattern becomes extinct or was no longer detected by radar, the time format in UTC.
- Identify the length of the SBF frontage by calculating the length of the SBF pattern (in km unit) detected by weather radar using the distance measurement feature in the Rainbow Manager application. The length of the SBF frontage was then presented in graphical form.
- Identify the depth of the SBF column using the Vertical Cut (VCUT) feature, which is the vertical distance SBF (in meter unit) detected by weather radar. The measurement results are then presented in graphical form.
- Identify the farthest distance from SBF penetration to the mainland-based on the time-series data of the PPI (Z) product. The farthest distance from the SBF penetration is calculated from the coastline until the location of the SBF begins to decay on the mainland (in km unit) using the distance measurement feature. The measurement results are then presented in graphical form.
- Identifying the convective activity parameters, i.e. the maximum reflectivity value and the distance of the convective cloud to the SBF. The maximum reflectivity value is known using the CMAX (Z) product, while the distance of the convective cloud appearance from the SBF is expressed in km unit and determined using the distance measurement feature.
- Identify the weather conditions during the appearance of the SBF based on analysis of the observational data.

The results of data processing the analyzed descriptive to analyze and present the data in form of tables, graphs, and diagrams. The following are the descriptive analysis carried out in this study.

- Assessing the characteristics of SBF, including the frequency of onset time, duration, face length, penetration, and depth of the SBF column which is classified into several class intervals. The class interval determination was based on the method of Sturges [12], which was then presented in diagrams and graphs.
- Assessing the convective activity parameters to determine the frequency of convective cloud growth and its distance to the SBF.
- Assessing the weather parameters, i.e. the temperature, humidity, wind direction, and speed, also cloud conditions during the SBF occurrence.

The following are the equations of the Sturges method used in this study.

\[ R = X_{\text{max}} - X_{\text{min}} \]  \hspace{1cm} (1)

\[ K = 1 + 3.31 \log n \]  \hspace{1cm} (2)

\[ P = \frac{R}{K} \]  \hspace{1cm} (3)

where \( R \) is the data range, \( X_{\text{max}} \) is the highest data value, \( X_{\text{min}} \) is the lowest data value, \( K \) is the number of the class, \( n \) is the number of the data, and \( P \) is the class interval.

3. Results and Discussions

3.1. Identification of SBF events

Based on the results of Tangerang weather radar observations, there were 24 SBF occurrences during 2018. The results of the identification of SBF occurrence on the north coast of Banten-Jakarta which was observed on January-December 2018 shown in Table 2 below.

| Month (2018) | Total days | Number of days processed | Number of identified SBF |
|-------------|------------|--------------------------|--------------------------|
| January     | 31         | 31                       | 2                        |
| February    | 28         | 28                       | 1                        |
| March       | 31         | 31                       | 4                        |
| April       | 30         | 29                       | 0                        |
| May         | 31         | 31                       | 1                        |
| June        | 30         | 30                       | 1                        |
| July        | 31         | 31                       | 3                        |
| August      | 31         | 30                       | 2                        |
| September   | 30         | 30                       | 1                        |
| October     | 31         | 31                       | 3                        |
| November    | 30         | 29                       | 1                        |
| December    | 31         | 31                       | 5                        |
| **Total**   | **365**    | **362**                  | **24**                   |

Due to the limited availability of weather radar data, radar limitations such as clutter and radar coverage, the amount of data analyzed during 2018 was 362 days and 24 identified SBF events.
The identified SBF events have a reflectivity value range of 5-20 dBZ. The radar image on the SBF event on 2 March 2018 (Figure 2) shows the SBF pattern began to form at 04:00 UTC (11:00 LT), identified by the echo formed parallel to the coastline and starting to enter the land. The SBF was visible at 05:04 UTC, then continued to move inland until 06:16 UTC the SBF was still very clearly on the radar. The SBF line pattern started to break and then the SBF echo went extinct at 07:44 UTC.

3.2. Characteristics of SBF parameters
Following are the values of the parameters of the 24 identified SBF events on the north coast of Banten-Jakarta during 2018 (Table 3).

| No | Date/Month/Year | Onset time (LT) | Duration (hour) | SBF length (km) | SBF column depth (km) | SBF penetration (km) |
|----|-----------------|-----------------|-----------------|-----------------|-----------------------|----------------------|
| 1  | 02/01/2018      | 11:32           | 1.7             | 36.92           | 0.80                  | 12.8                 |
| 2  | 03/01/2018      | 09:56           | 4.3             | 62.56           | 1.03                  | 34.8                 |
| 3  | 16/02/2018      | 10:28           | 3.9             | 69.98           | 1.07                  | 28.4                 |
| 4  | 02/03/2018      | 11:00           | 3.7             | 59.61           | 1.00                  | 34.4                 |
| 5  | 15/03/2018      | 10:36           | 4.5             | 63.72           | 0.80                  | 13.6                 |
Of the 24 SBF events, 14 SBF events occurred consecutively on the following day or 2 days after the SBF event, i.e. on 2 and 3 January, 15 and 16 March, 3, 4, and 6 July, 5 and 6 August, 18, 19, and 20 October, also 17 and 19 December. This indicates a tendency for SBF to reoccur in the following days or occur continuously.

3.2.1 Frequency of onset time and duration of the SBF

Of the 24 events of SBF, 6 onset time class intervals were determined, i.e. 08:05-09:17 LT, 09:18-10:30 LT, 10:31-11:43 LT, 11:44-12:56 LT, 12:57-14:09 LT, and 14:10-15:22 LT, which then presented in graphical form shown in Figure 3 below. The time of SBF onset on the north coast of Banten-Jakarta was dominant at 10:31-11:43 LT, with a frequency of around 37.5%.

![Figure 3. The frequency of SBF onset time on the north coast of Banten-Jakarta in 2018](image-url)
The determination of SBF duration is calculated based on the difference between onset time and the extinction time of the SBF. The SBF duration is classified into 6 class intervals, i.e. 0.4-1.0 hours, 1.1-1.7 hours, 1.8-2.4 hours, 2.5-3.1 hours, 3.2-3.8 hours, and 3.9-4.5 hours, which are then presented in graphical form shown in Figure 4 below. The highest SBF duration frequency occurred at the interval of 3.9-4.5 hours, which was also the longest duration of SBF events, the frequency of around 25.0%.

![Figure 4. The frequency of SBF duration on the north coast of Banten-Jakarta in 2018](image)

Generally, the SBF on the north coast of Banten-Jakarta in 2018 occurred at 10:31-11:43 LT, which is the earliest time for SBF to occur at 08:08 LT and the last at 15:20 LT. The SBF can last for 3.9-4.5 hours, which has the longest duration of about 4.4 hours. A total of 15 SBF events occurred when the surface air temperature reached its maximum value. It indicates that the occurrence of the SBF is very dependent on the surface air temperature conditions in the coastal area. The SBF can occur when there is a temperature contrast of 5°C or more between the surface of warmer land and a cooler ocean, which generally occurs when the maximum surface air temperature occurs [13].

### 3.2.2 Frequency of SBF length

The SBF length is the distance between the two side borders of the SBF that enter the land, measured using the distance measurement feature in the Rainbow Manager application. The SBF observed by weather radar is not always in a straight line because it follows the shoreline pattern on the north coast of Banten-Jakarta. This is a consideration so that in measuring the length of the SBF, several measurements need to be made, as shown in Figure 5.

The distance measurement feature is shown by a black arrow, while the value is shown in the red box. The measurement values were then summed up to get the actual value of the SBF length. The results of the SBF length measurement are grouped into 6 class intervals, i.e. 19.0-27.7 km, 27.8-36.5 km, 36.6-45.3 km, 45.4-54.1 km, 54.2-62.9 km, and 63.0-71.7 km, and then presented in graphical form as in Figure 6.

The highest frequency of SBF length is 35.6-45.3 km, around 29.2%. The longest SBF phenomenon identified on the north coast of Banten-Jakarta in 2018 reached 71.4 km, while the shortest was only 19.2 km. The length of the SBF is influenced by the shape and length of the coastline [7] so that it will vary from location to location. Besides, the limited radar coverage also affects the detected length measurement of the SBF.
3.2.3 Frequency of SBF column depth

The depth of the SBF column is the vertical height of the SBF observed by radar. The SBF column depth is measured using the VCUT feature, by determining the cut point that corresponds to the length of the SBF echo (Figure 7), so that a perpendicular slice of the SBF echo is obtained (Figure 8).

The results of measuring the depth of the SBF column classified into 6 class intervals, i.e. 0.45-0.57 km, 0.58-0.70 km, 0.71-0.84 km, 0.85-0.97 km, 0.98-1.10 km, and 1.11-1.23 km, and then presented in graphical form as in Figure 9. The highest frequency of the SBF column depth on the north coast of Banten-Jakarta in 2018 is in the interval of 0.58-0.70 km, with a frequency of around 29.2%. The maximum observed depth of the SBF column during 2018 was 1.20 km, while the lowest was 0.47 km. The depth of the SBF column is influenced by topographic conditions, such as the shape and size of the coastline of the area [7].
3.2.4 Frequency of SBF penetration

Sea breeze penetration is the farthest distance the SBF can reach inland. The SBF penetration was measured using the distance management feature on PPI (Z) products, by measuring the distance between the shoreline to the farthest location of the SBF extinction on land, as shown in Figure 10 below. The SBF penetration into the mainland is classified into 6 class intervals, i.e. 8.2-14.6 km, 14.7-21.1 km, 21.2-27.6 km, 27.7-34.1 km, 34.2-40.6 km, 40.7-47.1 km, and then presented in graphical form as in Figure 11.

The frequency of SBF penetration on the north coast of Banten-Jakarta in 2018 most often occurred in the 8.2-14.6 km interval, the frequency value of around 33.3% or as many as 8 SBF events. In general, the SBF can intrude as far as 20-60 km inland but can be reduced if blocked by the topography obstacles or barriers on land, such as mountains or highlands, as well as the synoptic-scale winds in the opposite direction to the direction of SBF movement [13].
Figure 10. The technique of measuring the farthest SBF penetration distance using the distance management feature (SBF is shown in a red box, the broken SBF pattern indicating the extinction of the SBF)

Figure 11. The frequency of SBF penetration on the north coast of Banten-Jakarta in 2018

3.3. Convective activity associated with the SBF

The convective activity is identified by the growth of convective clouds around the SBF location, as shown in Figure 12, both after and before the SBF occurrence. The convective cloud was identified using the CMAX product with a reflectivity value greater than 38 dBZ [14].

Figure 12. The technique of distance measurement between the convective cloud and the SBF using the distance measurement features
The convective activity parameters were identified using the maximum reflectivity value, the difference between the appearance time of the convective cloud and the SBF (ΔT), and the distance between the convective cloud and the SBF. The maximum reflectivity value was determined based on the CMAX product, while the convective cloud distance to SBF was measured using the distance measurement feature (Figure 12).

Following is the result of the convective activity parameters identification based on 24 SBF events on the north coast of Banten-Jakarta in 2018 (Table 4).

Table 4. The results of the convective activity parameters identification based on the SBF events on the north coast of Banten-Jakarta in 2018

| No. | Date/Month/Year | Maximum Reflectivity (dBZ) | ΔT (minute) | Distance (km) |
|-----|----------------|-----------------------------|-------------|---------------|
| 1   | 02/01/2018     | 54.0                        | -56         | 2.9           |
| 2   | 03/01/2018     | 58.0                        | -8          | 0.0           |
| 3   | 16/02/2018     | 52.5                        | -96         | 0.0           |
| 4   | 02/03/2018     | 58.5                        | -48         | 0.0           |
| 5   | 15/03/2018     | 51.5                        | -16         | 11.9          |
| 6   | 16/03/2018     | 57.5                        | -72         | 13.9          |
| 7   | 20/03/2018     | 60.0                        | -16         | 6.0           |
| 8   | 31/05/2018     | 53.5                        | 24          | 3.3           |
| 9   | 16/06/2018     | -                           | -           | -             |
| 10  | 03/07/2018     | 52.5                        | 80          | 21.5          |
| 11  | 04/07/2018     | 50.5                        | 64          | 15.1          |
| 12  | 06/07/2018     | -                           | -           | -             |
| 13  | 05/08/2018     | -                           | -           | -             |
| 14  | 06/08/2018     | -                           | -           | -             |
| 15  | 12/09/2018     | -                           | -           | -             |
| 16  | 18/10/2018     | 59.5                        | 40          | 2.0           |
| 17  | 19/10/2018     | 56.5                        | 24          | 1.3           |
| 18  | 20/10/2018     | 56.5                        | 16          | 0.0           |
| 19  | 17/11/2018     | 57.0                        | 16          | 0.0           |
| 20  | 02/12/2018     | 58.0                        | 8           | 3.4           |
| 21  | 13/12/2018     | 58.5                        | 40          | 15.3          |
| 22  | 17/12/2018     | 57.0                        | 8           | 0.0           |
| 23  | 19/12/2018     | 58.5                        | 16          | 0.0           |
| 24  | 28/12/2018     | 53.5                        | -56         | 11.3          |

Among the 24 SBF events on the north coast of Banten-Jakarta in 2018, there were 19 events of convective activity. Most of the convective cloud forming time occurred after the SBF became extinct, several 11 out of 19 events. Meanwhile, in 8 other events, convective clouds formed before the SBF became extinct. The fastest convective cloud formed was about 1 hour 36 minutes before the SBF became extinct, and the last was about 1 hour after the SBF became extinct. Generally, the distance between the cloud-formation area and the SBF extinction was around 0-5 km. Meanwhile, in some SBF events, clouds formed at a distance of more than 10 km, such as on 3 July 2018 where convective clouds formed at a distance of 21.5 km from the SBF and about 80 minutes after the extinction of the SBF.

When the SBF intrudes the land, the convergence occurrence in front of the SBF, along with the addition of water vapour from the sea, triggers a convection process. This convergence causes convective clouds formation [3–5]. Based on the analysis of convective activity parameters using Doppler-weather radar, know that most of the convective activity triggered by SBF can be identified by the growth of single-cell type convective clouds around the SBF extension area, by the research of
Meilusiani [11]. The convective clouds induced by the SBF can be observed in CMAX radar products with the maximum reflectivity range of 50.5–60.0 dBZ.

Convective activity associated with the SBF events occurred mostly during the rainy season (DJF), about 8 SBF events. This shows the influence of the monsoon winds on the convective cloud formation process on the north coast of Banten-Jakarta. The DJF period was the active period of the north-western monsoon, where the wind blows from Asia towards Australia, following the direction of movement of the SBF on the north coast of Banten-Jakarta. The result was the sea breeze bringing a lot of water vapour supply so that it will more likely to have a convective process than during the dry season [8]

![Figure 13. Example of the SBF incident on 20 March 2018, which was accompanied by a decrease in temperature and an increase in air humidity (station locations are marked with a red dot)](image)

![Figure 14. Graph of temperature (a) and humidity (b) during the SBF incident on 20 March 2018 on the north coast of Banten-Jakarta](image)

The SBF events affect the weather conditions around the area where the SBF was formed [15]. In general, the SBF penetration is characterized by the decreased temperature, especially when the SBF location is observed on radar around Soekarno-Hatta Meteorological Station, which is accompanied by the increased humidity, as shown in Figure 13 and Figure 14 above.

It can be seen that the temperature increases at the onset time of the SBF event, i.e. during 07:00-11:00 LT. Then the temperature decreased and the humidity increased around 12:00 LT, on time when the SBF detected by radar was around the Soekarno-Hatta Meteorological Station. The temperature then increased again as the SBF moved away from the Soekarno-Hatta Meteorological Station. There were 11 events of SBF that showed the decreased temperature during the SBF events, which generally occurred between 12:00-13:00 LT before the temperature increased again. The decreasing temperature caused by the cold air mass from the oceans brings water vapour into the land [7,8]. A total of 15 SBF events occurred at maximum air temperature, i.e. when the surface air temperature was greater than 30°C. The SBF occurrence when the air temperature was high indicates the high-temperature gradient
between the surface of the land and the ocean. An increase in air temperature will be followed by a decrease in air humidity.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure15}
\caption{The surface wind direction during the SBF events on the DJF and MAM periods}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure16}
\caption{The surface wind direction during the SBF events on the JJA and SON periods}
\end{figure}

Based on the wind-rose in Figure 15 and Figure 16 above, it is known that the dominant wind direction and speed on the days of the SBF events in the DJF period was from the west and the speed was about 2.1-3.6 m/s. The MAM period was from the west-southwest and the speed was about 2.1-3.6 m/s. Meanwhile, during the JJA and SON periods, the dominant wind direction was from the south and the speed was about 0.5-2.1 m/s. In 12 of the 24 days of the SBF event, the convective clouds formed were Cumulonimbus clouds, with a cloud cover of 3-5 octas. There was a correspondence between the weather radar image and the observation data at the Soekarno-Hatta Meteorological Station.

4. Conclusions
The SBF events on the north coast of Banten-Jakarta in 2018 can be detected using a Doppler weather radar. The SBF was mostly detected during the rainy season, the DJF period. The SBF characteristics on the north coast of Banten-Jakarta i.e. occurred at 03:31-04:43 UTC (10:31-11:43 LT), the range of duration was 3.9-4.5 hours, the length between 36.6-45.3 km, column height reaching 0.58-0.70 km, and intrude to the mainland as far as 8.2-14.6 km. The SBF phenomenon caused the convective cloud formation around the SBF area, both before and after the SBF extinction. In general, the onset of SBF was when the air temperature reached the maximum value. The SBF intrusion on land was identified by the decreased temperature and increased humidity. The appearance of a single-cell type of convective cloud was a sign of convective activity caused by the SBF. The existence of radar limitations, such as clutter and limited radar coverage from the surface, have a significant effect on the identification of SBF events. Therefore, quality control data is needed to minimize clutter around the radar, and also a
combination of analysis using weather satellite and numerical weather model to complement the limited availability of observational data.

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