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ENVIRONMENTAL PARAMETER ANALYSIS DURING THE EXTREME DAMAGING GALE THAT HIT THE EAST COAST OF THE SHANDONG PENINSULA

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Abstract

In this study, sounding data were used to investigate the environmental parameters of the eastern Shandong coast. June was the month with the most extreme thunderstorm winds, according to the results. Several parameters, which can be referenced in daily forecasts and early warnings, are indicative of extreme thunderstorms and gales. Strong convective storms are often the cause of extreme gales. Usually, there must be moderate to strong vertical wind shear conditions. The wet layer does not need to be excessively thick, but there is a very distinct dry layer with strong entrainment potential in the middle layer.

Key words: extremely damaging gale, environmental parameters

Introduction. Due to the rapid development of coastal cities and population growth, urban operations are becoming increasingly vulnerable to severe convective weatherdisasters. Extreme gales are characterized by high frequency

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and strong disaster in severe convective weather, which poses significant challenges to early warning. One of the key factors in weather research is the environmental conditions and proximity warning technology produced by thunderstorms and gales [1–8]. In recent years, the eastern coastal areas of Shandong Province have been frequently and severely impacted by extremely damaging gales.

For instance, on August 6, 2017, wind and hail successively hit some counties in Weifang, Qingdao, Yantai, and Weihai, and strong winds of F11 scale or above occurred at 8 stations. The direct economic loss was 240 million yuan, affecting 158 000 people. On June 13, 2018, it was hit by wind and hail in succession. Extremely damaging gales afflicted eight stations on the island's coast, all of which were rated on the F11 scale. The peak instantaneous wind speed at Qingdao Station reached 34.8 m/s (F12 scale), which is the highest recorded since June 1966. On the afternoon of August 16, 2019, a 34.6 m/s thunderstorm gale occurred in Rizhao Port, causing a relatively serious disaster and the capsize of a ship in the sea area.

Numerous researchers have summarized the most important environmental parameters of severe convective weather and identified environmental parameter indicators that are useful for operational forecasting [9–17]. However, there is a paucity of research on environmental parameters specifically targeting extreme gales in the coastal regions of the peninsula. The terrain along the eastern coast of Shandong is coastal, with gently undulating low mountains and hills in the north, the Bohai Sea in the north, and the Yellow Sea in the east and southeast. It has complex terrain conditions and a relatively disparate distribution of land and sea. What are the environmental conditions that lead to extreme thunderstorm gales? What distinguishes coastal areas from inland regions? The goal of this study is to strengthen the ability to predict extreme thunderstorm gales in the peninsula area by providing a simple foundation.

Data. According to the sounding data, the environmental parameters closely associated with severe convective weather are calculated. At 00:00 and 12:00 UTC every day, the most recent time before the occurrence of severe convective weather is selected from the Qingdao representative sounding station. The research period is 2014 to 2020, and the research area is the coastal area, which includes Qingdao, Yantai, Weihai, and Rizhao. The extremely strong wind is F11 scale or above (excluding systematic gales and typhoon gales). During this period, 15 cases were screened (Table 1).

Main influence system and monthly frequency characteristics. The physical process of the occurrence, development, and demise of the severe convective mesoscale synoptic system is limited by the evolution of the synoptic scale system and the configuration structure of the basic elements of the ambient atmosphere. This is due to the fact that the evolution of the synoptic scale system has significantly altered the instability of local thermal stratification, vertical shear, the potency of uplift movement, and the transport of water vapour [18].

Table 1

List of extreme thunderstorm gales

Main weather systems	Case time	Beaufort scale
Upper cold vortex	20140527	F11
	20160630	F12
	20160720	F11
	20170707	F11
	20170806	F12
	20180613	F13
	20200517	F11
	20200518	F11
Westerly trough	20160503	F11
	20170620	F11
	20180628	F13
	20190604	F11
	20200803	F11
Shear line	20140601	F12
	20150804	F11

Main influence system. Extreme thunderstorm gales are more likely to occur in the presence of an upper cold vortex circulation, according to an analysis of the weather conditions of 15 cases. There are 8 times when the upper cold vortex is present, and 5 times when the westerly trough is present. Extreme thunderstorm gale with a smaller range can also happen under the influence of the shear line at the edge of the subtropical high. Along the coast of the peninsula, the upper cold vortex is the most prevalent impact system.

Monthly frequency characteristic. Statistics show that there were the most severe thunderstorm gales in June (6 times), followed by May (4 times), August (3 times), and July (2 times). The frequency of thunderstorm gales is highest in June, which differs from the double peak in April and June observed by Gao et al. [19] in inland regions, and the peninsula region exhibits a clear delay. This could be directly related to the fact that the coastal regions are subject to ocean regulation before June and that the temperature is typically low, which makes it difficult for strong convective weather to develop.

Characteristics of environmental parameters. Regarding the selection of key environmental parameters for severe convective weather, the key concept is to refer to the forecast method (Ingredients-based Methodology) that is based on ingredients. Deep wet convection typically requires three factors: static instability, water vapour, and an uplift triggering, whereas thunderstorm gales must also consider the vertical shear of deep wind and whether a dry layer exists in the middle troposphere. The selected parameters mainly include: K index, 850 and 500 hPa temperature difference (ΔT) , lifted index (LI), storm relative helicity (SRH), 0–3 km vertical wind shear (Wsr 0–3 km), 0–6 km vertical wind shear

(Wsr 0–6 km), dry layer intensity, sinking convective effective potential energy (DCAPE), etc. The violin chart is utilized to illustrate the distribution characteristics of environmental parameters.

K index and 850–500 hPa ΔT. The K index reflects the influence of temperature and humidity distribution in the middle and lower troposphere on the stability, taking into account both the vertical temperature gradient and the water vapour in the lower troposphere. $K = (T_{850} - T_{500}) + T_{d850} - (T - T_d)_{700}$. Figure 1 shows the K index and ΔT. The median K index is 25.5 °C, and 25% is 19.2 °C. The median ΔT index is 26 °C and 25% is 24 °C. When the extremely damaging gale occurs, ΔT is relatively large, with 1/4 cases exceeds 29 °C, and the maximum temperature of individual cases can reach 39 °C. K index and ΔT is slightly smaller than the inland area which is about 26–28 °C. Since the middle layer is typically dry in extreme gale cases and the difference in the K index is relatively large, it is important to note that the K index is frequently displayed as having a small value.

Storms Severity Index (SSI) and Energy Helicity Index (EHI). SSI = 100 represents the boundary between strong and non-strong thunderstorms, while EHI comprehensively reflects the combined effect of convective effective potential energy and storm relative helicity. The SSI and EHI diagrams for strong winds are shown in Fig. 1. The relative intensity of storms causing strong thunderstorms and strong winds is high, as indicated by the median SSI of 270 and the 25% percentage of 257.9. The 75% percentile was 1.48, the 25% percentile was 0.1, and the median SRH was 0.65. When extreme thunderstorm gales occur, the distribution of these two environmental parameters is relatively concentrated, so it has a strong guiding significance and requires additional consideration.

Water vapour integral of the whole layer (IQ) and wet layer thickness (HWET). The median IQ was 3265.0 (Fig. 2), with 75% accounting for 4297.62. The median HWET is 1401.5, and the 75% percentage is 3303.5. The very large difference between the maximum and minimum values reflects the two different types of thunderstorm gales. The thickness of the wet layer accompa-

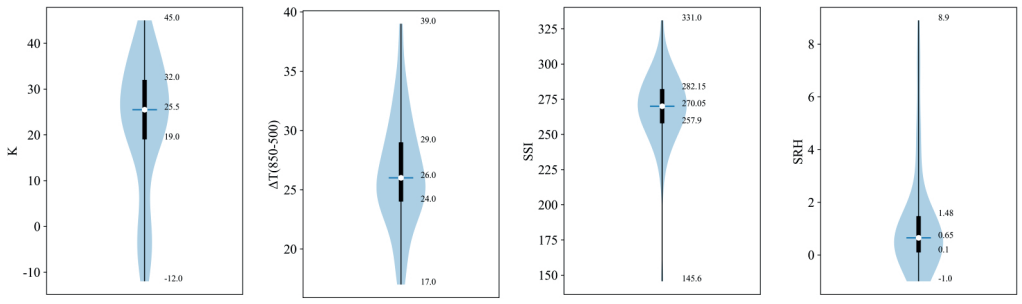


Fig. 1. The violin chart of K index, ΔT, SSI and SRH

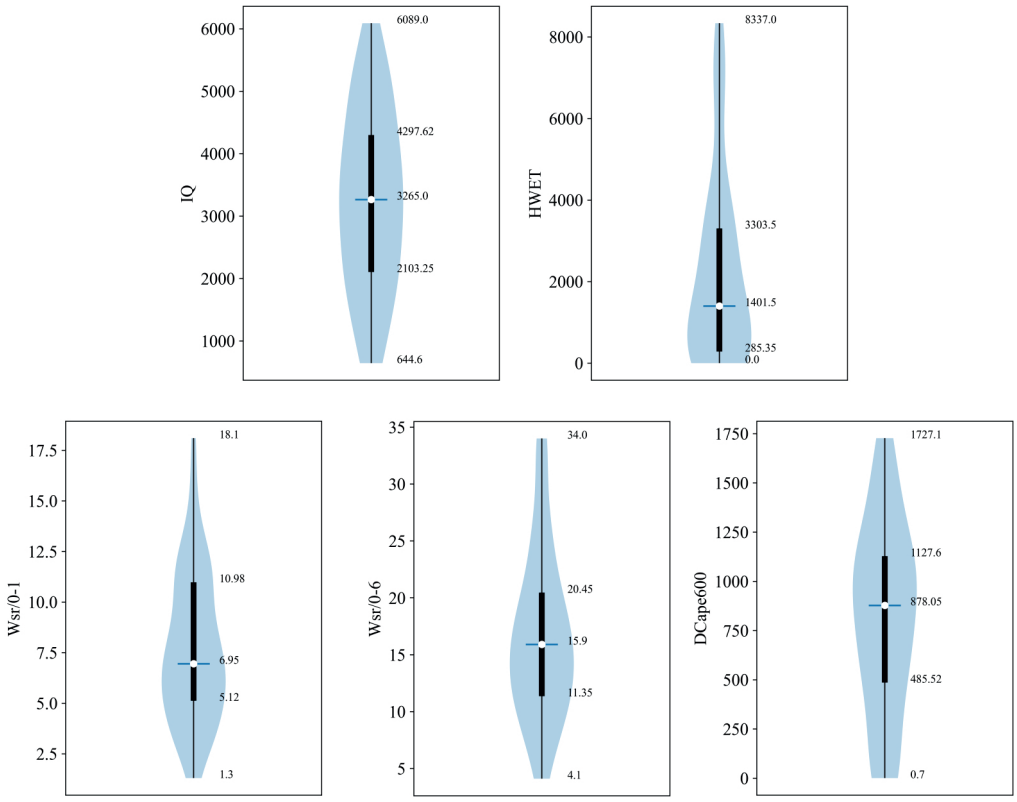


Fig. 2. The violin chart of water vapour integral of the whole layer (IQ), wet layer thickness (HWET), shear 0–3 km, shear 0–6 km and DCAPE_{600}

nying short-term heavy rainfall is relatively thick, whereas the thickness of the wet layer accompanying dry thunderstorm gales is relatively thin, and there is no discernible dry layer. Nevertheless, IQ and HWET are generally not large when a strong thunderstorm gale occurs, and there is a significant difference between IQ values of 4000 and above when a short-term heavy rainfall occurs.

Wsr 0–3 km and Wsr 0–6 km. The difference between the wind vectors from the ground to a height of 6 km represents the vertical shear of deep layer wind. In general, 0–6 km wind vertical shear < 12 m/s is weak deep wind vertical shear, 12–20 m/s is moderate deep wind vertical shear, and ≥ 20 m/s is strong. The median of extreme gale Wsr 0–3 km index is 9.9 m/s, and the percentage of 25% and 75% is 6.18 and 13.2 m/s. The median of Wsr 0–6 km is 15.9 m/s, and the percentage of 25% and 75% is 11.35 and 20.45 m/s. In 1/4 cases, the 0–6 km wind shear reaches the level of strong vertical wind shear, and the maximum 0–6 km vertical wind shear reaches 34 m/s. A few thunderstorm gales are still present in the case of weak vertical wind shear. Extreme thunderstorm gales are difficult to distinguish through 0–6 km vertical wind shear. However, in most cases, medium to strong conditions of vertical wind shear are required for extreme wind to occur.

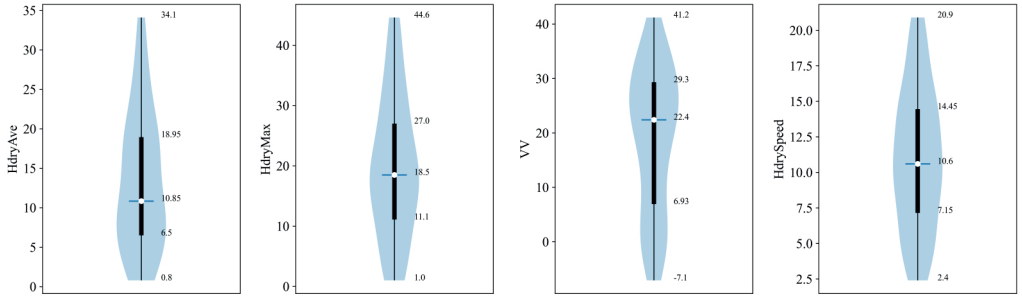


Fig. 3. The violin chart of HdryAve, HdryMax,VV index, and HdrySpeed

***DCAPE*$_{600}$.** The effective potential energy DCAPE of sinking convection will generate downdraft when there is precipitation evaporation in unsaturated air or precipitation melting on the frozen layer in the storm body, and the sinking potential energy is the energy size of these downdrafts. For hail and gales, DCAPE is a very powerful index parameter. DCAPE$_{600}$ refers to the effective potential energy of sinking convection starting from 600 hPa.

Figure 2 shows the DCAPE$_{600}$ corresponding to extreme wind. The median was 878.05 J/kg, and the 75% percentage was 1127 J/kg. It can be seen that DCAPE$_{600}$ is relatively high when extreme thunderstorms and gales occur, and it remains at a relatively high value. The extreme gales have very good indication significance.

***Average dry layer height* (*HdryAve*) *and Maximum dry layer height* (*HdryMax*).** Thunderstorm gales are most common when the middle troposphere has a dry layer. When relatively dry ambient air is entrained into the downdraft of a thunderstorm initiated by precipitation particles, raindrops or hail particles will produce severe evaporation or sublimation, resulting in a severe temperature drop, density increase, downward movement acceleration increase, and strong divergent gales when approaching the ground.

Figure 3 shows the corresponding dry layer intensity map (HdryAve and HdryMax), which is used to demonstrate the dry air layer intensity in the middle troposphere. Higher values indicate deeper or drier dry layers, which are more conducive to the development of strong downdrafts in thunderstorms. The median of extreme thunderstorm gales HdryAve and HdryMax are 10.85 °C and 18.5 °C, with 25% of them accounting for 6.5 °C and 11.1 °C, and 75% of them accounting for 18.95 °C and 27 °C.

***VV gale index* (*VV*) *and dry layer entrainment momentum downward transmission potential* (*HdrySpeed*).** The momentum downward transmission will substantially contribute to the ground gale when the wind speed in the entrainment layer is high. The magnitude of the downward potential of the momentum is expressed as the downward potential of the entrainment momentum in the dry layer. The corresponding VV and HdrySpeed diagrams are shown in

Fig. 3. The median VV was 22.4 m/s, and the 75% percentage was 29.3 m/s. The median of HdrySpeed is 10.6 m/s, and the percentage of 75% is 14.45 m/s. When gales hit the peninsula area, the median of the VV gale index and the HdrySpeed dry layer entrainment momentum downward transmission potential both have high values.

Discussion and conclusion. In contrast to the double peak in April and June in inland areas, the extreme thunderstorm gale in June was the highest, and the peninsula area has a clear delay. These weather systems influence severe convective weather: upper cold vortex, westerly trough, shear line, etc.

Extreme thunderstorm and gale indicators include a number of factors that can be used in daily forecasting and early warning systems. Extreme gales typically develop as a result of potent convective storms (the median of SSI is 270). Usually, there must be moderate to strong vertical wind shear conditions. The wet layer generally does not need to be very thick, but the middle layer has a very clear dry layer with a strong potential for entrainment. The middle value of dry layer thickness can reach 10.85, the gale index is 22.4 m/s, and the downward transmission potential of entrainment momentum is 10.6 m/s. K index and ΔT is slightly smaller than the inland area which is about 26–28 °C. The median of DCAPE_{600} was 878.05 J/kg which has a very good indication significance.

In general, the classification and statistics of key parameters of severe convective weather use seven years of cases in the eastern portion of the peninsula, but the number of samples of extreme gale events is still insufficient, so individual parameters occasionally show large differences, making it difficult to make a clear identification based on indicators, and most importantly, they provide a useful reference value or warning value.

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