Circulation characteristics of two cases of Sea-entering Tibetan Plateau Vortices causing obvious differences in China precipitation

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Abstract. By using the NCEP FNL, historical synoptic charts and the year books of Tibetan plateau vortex and shear Line, based on synoptic and diagnosis methods, the observation facts of the sea-entering Tibetan Plateau vortices (STPVs) from 1998 to 2018, (STPVs) from 1998 to 2018, the two southeast-path STPVs that made great differences in precipitation are comparatively analyzed. The results show that: (1) The would bring precipitation to the eastern coast of China, and further affecting Korean Peninsula, Japan and Russia. (2) The different circulation characteristics of large- and small-scale precipitation STPVs are as follows: there are strong north and south branch jets at 200hPa and the north branch jet extends to eastward with the core moving to east, and the circulation is more stable at 500hPa to the north of 45º N in East Asia, and STPV induces low vortex in the lower atmosphere in large-scale precipitation STPV process. The opposite situation is true for small-scale precipitation STPV process. As a result, there are rising motion areas with large range and strong strength in and near the large-scale precipitation STPV area in the middle and lower troposphere, where larger water vapor flux and strong water vapor flux convergence also exist.

Keywords: Tibetan Plateau Vortex, Southeast Path, Precipitation Difference, Circulation characteristics, Sea-Entering, Frontal Zone

1. Introduction
The Tibetan Plateau vortex (TPV) is an important low-value weather system affecting China. Once the TPV moves eastward out of the main body of the Tibetan Plateau, it will lead to heavy rains in vast areas of China, causing disastrous weather [1-9]. Therefore, the study of eastward-moving TPV has become the focus of TPV research.

In the past ten years, the study of TPV eastward moving out of the plateau has attracted much attention. The average thickness of the air column in the central and eastern plateau can illustrate the movement of the TPV[10]. The vertical superposition of plateau vortex and Southwest China Vortex (SCV) would strengthen the TPV and the SCV simultaneously[11]. The common large-scale conditions for different types of TPV to move out of the plateau are: the weather system that affects TPV movement is strengthening; the TPV is baroclinic low vortex; and the north and south branch
The eastward transmission characteristics of positive vortices are obvious during the process of low vortex shifting toward east [13]. The vortex would move along the center of latent heat release [14]. The sensible heat heating of the mid-west plateau surface is the leading factor for the generation, development and eastward migration of the TPV [15]. The large-scale circulations and heating fields have a close relationship with the moving speed of the TPVs [16]. The heating centers of Q1 at 400 hPa mainly sourced from the condensation latent heat are beneficial to the eastward movement of the TPVs [17]. The atmospheric thermodynamic factors also show a remarkable effect on the eastward propagation distances of the TPVs moving off the plateau [18].

Some studies have shown that the eastward movement of the TPV will affect its structure. There are the significant differences in the structure characteristics of TPV between those having and not having moved out of the plateau [19]. The evolution of the TPVs is determined by the structures of TPVs themselves to some extent [20]. The TPV contains the structural features of both eddy Rossby waves and inertial gravity external waves [21]. The latent heat of condensation and water vapor play a key role in maintaining the low vortex and the evolution of structural characteristics [22]. The convections associated with the TPVs are elliptic and stretch from southwest to northeast [23]. Three forms of activity associated with plateau vortex and southwest vortex, which are TPV-induced SCV, coupling between TPV and SCV, and two vortices under the same weather system [24]. The effect of cold air make TPV maintenance [25], the latent heat on The plateau surface plays an important role in the generation of TPV, and has a much greater impact on the generation of removing TPV [26]. The convective activity on the plateau will strengthen the TPV, and the eastward movement of the TPV can promote the formation of the SCV [27].

Some studies have illustrated the influence of eastward-moving TPV on precipitation in China. The coupling activity of TPV and SCV will lead to torrential rainstorms [11]. The TPV can cause precipitation above moderate magnitude after it moves out of the plateau, in which 60% of the active vortex that lasts for ≥36 h after out of the plateau would create torrential rain or severe heavy rain [28]. The TPV swirls in the Hetao region, causing severe heavy rain in northern Shaanxi [29]. The TPV that is continuously active east of the plateau not only affects a wide range of China, but also affects the Korean Peninsula, Japan and Vietnam [6]. The TPV that has been active for a long time after out of the plateau has a strong impact on heavy precipitation in China and even East Asia [30]. TPV-associated precipitation can account for up to 40% of the total precipitation in parts of China in selected months, often due to individual TPVs [8]. The eastward-moving TPV category occurs mostly in May and June, but leastly in July and September. With consecutive enhancement of precipitation intensity and convection intensity, an increasing trend is found in the proportions of deep convection clouds and multiple layer clouds during the TPV category eastward movement [31]. The impact of TPVs is mainly found in the region to the west of 115° E between 30° N and 36° N, becoming weaker along with the longitude. Sichuan Basin is the area with the greatest influence from the TPVs [32]. So, what causes the eastward movement of the TPV to have such a large impact on precipitation in China is worth investigating. This is of great significance for further understanding the relationship between TPV activity and China’s heavy precipitation process, guiding the prediction of TPV and reducing the disasters caused by it. For this reason, this paper selects the cases of TPVs that had similar paths and caused precipitation across eastern and western China and that only caused precipitation in western China to carry out comparative analysis of the ambient fields and some physical quantity fields to reveal the reasons why the TPVs with similar paths could cause significant differences in precipitation.

2. Data and methodology

2.1. Data and NCEP - FNL of Reliability Analysis
The data used in this paper include: (1) historical synoptic charts for the period 1998-2018 at 08:00, 20:00 (Beijing time, same below) provided by the National Meteorological Center of the China
Meteorological Administration (CMA). (2) NCEP (National Center for Environmental Prediction)/NCAR (National Center for Atmosphere Research) - FNL (final analysis data available globally) reanalysis data in May 2017 with a time resolution of 6 h and a horizontal resolution of 1°×1°. (3) The 1998 Yearbook of Tibetan Plateau Low Vortex Shear Line [33] to The 2018 Yearbook [34].

Although the NCEP reanalysis data has been widely used in TPV research [13], [35-36], NCEP-FNL generally performs better than ERA-interim [37]. For the sake of prudence, the 500hPa situation field (abbreviated as observation) obtained from the analysis of conventional meteorological observation data for each time of the two TPV processes and the 500hPa situation field obtained from NCEP reanalysis data are compared. The intensity of TPV center is represented by the geopotential height. Table 1 shows the observed conditions at each important time of the TPV in the two processes as well as the location and intensity of the TPV center by NCEP data analysis. As can be seen from Table 1, the position and intensity of the TPV analyzed by the NCEP data are relatively close to the observation. The maximum deviation between east and west, north and south is within 1 latitude/longitude, and the maximum deviation of the low vortex center intensity does not exceed 2 dagpm. So, the NCEP data can better reflect these two TPV processes, and the grid analysis data provided by NCEP is credible.

Table 1. Comparison of changes in center position and intensity of plateau vortices between observations and NCEP data.

| Process | Key times | Center position (observed|NCEP) | Center intensity (observed|NCEP) (dagpm) |
|---------|-----------|-------------------------|--------------------------|
| C1717 vortex | Formed: 08:00 BT 15 | 38.6°N,96°E|38.5°N,96°E | 576|574.4 |
| | Moved out: 20:00 BT 17 | 34.8°N,104.8°E|35°N,105°E | 574|575.0 |
| | Strengthened: 08:00 BT 18 | 36.7°N,105.7°E|36.5°N,105.5°E | 573|572.1 |
| | About to sea: 20:00 BT 20 | 32.5°N,120.7°E|31.5°N,121°E | 577|575.7 |
| | About to dissipate: 08:00 BT 22 | 33.2°N,127.2°E|32.5°N,127.5°E | 578|577.4 |
| C1720 vortex | Formed: 08:00 BT 25 | 37.4°N,100.7°E|37.5°N,101°E | 579|578.8 |
| | Moved out: 08:00 BT 26 | 34.7°N,105.1°E|35.5°N,104.5°E | 577|577.0 |
| | Strengthened: 08:00 BT 27 | 31.1°N,113°E|31.5°N,113.5°E | 577|575.2 |
| | About to sea: 08:00 BT 28 | 29.4°N,118.5°E|28.5°N,117.5°E | 579|577.9 |
| | About to dissipate: 20:00 BT 28 | 29.7°N,123°E|30°N,123.5°E | 580|579.6 |

2.2. Cases selection
The principles for selecting individual cases are as follows: (1) The paths of sea-entering TPVs (STPVs) are similar; (2) To reduce the influence of different seasons on the out-moving and activity of the TPV, we selected the cases near the seasons when the TPV moves out of the plateau; (3) The STPV process in which the precipitation was caused by the southeast path across the east and west of China (referred to as large-scale precipitation vortex), i.e., the C1717 vortex process was selected (the Chengdu Institute of Plateau Meteorology, CMA, and the Plateau Meteorology Commission, CMS, 2019), and the onset and end time of the process was 08:00 BT 15 and 08:00 BT 22 May 2017 (Figure 1a). The southeast path only brought about the STPV precipitation in western China (referred to as small-scale precipitation vortex), i.e., the C1720 vortex process (the Chengdu Institute of Plateau Meteorology, CMA, and the Plateau Meteorology Committee, CMS, 2019), and this process started at 08:00 BT 25 and ended at 20:00 BT 28 May 2017 (Figure 1b).
2.3. Methods
The method is that, on the basis of analyzing the activities of the STPVs seen during 1998 - 2017, the comparative analyses are conducted about the geopotential height field, temperature field and the divergence, vertical velocity, moisture flux, moisture flux divergence field for the cases of STPVs which caused precipitation across the east and west of China along the southeast path and those that only caused precipitation in the west.

The TPV are generated on the Tibetan Plateau at an isobaric surface of 500hPa. All low pressures with closed contours or cyclonic circulations in wind direction at three stations are called low vortices [38]. The TPV area refers to the vortex center with a radius of 3 longitude/latitude [24]. The TPV’s going to sea depends on the center of the TPV. The TPV number begins with the “C” letter, plus the latter two digits of the year and the two digits of the low vortex sequence of the year [34].

2.4. Observations facts of Sea-Entering Tibetan plateau vortices
Seen from the summary table of the impact of the STPV during 1998-2018 (Table 2), the earliest process of sea vortex occurred in April and the latest was in August, of which the process tended to occur more frequently in May and June, a total of 14 times, accounting for 73% of all the STPVs that are found. Thus, the main period of STPVs activity is from May to June, which is different from the main period (June-August) of the continuous activities of the TPVs after their moving out of the plateau [6]. During the period from 1998 to 2018, there were 19 vortices going to sea, of which the vast majority (18/19) had a significant impact on precipitation in China, bringing rainfalls to the regions from the plateau to the eastern coast of China, and even causing rainstorm or severe rainstorm (16/19) in some areas. These vortices were mainly dominated by east paths. Comparatively, the C1720 vortex process that was only under the guide of the southeast path had a small impact range, only bringing about light rain to the northeast of the plateau and its surrounding areas, and the maximum precipitation amount in the process was 12.2mm.

From the path diagram of the 1998-2018 STPVs (Figure 2), we see that the source of the sea vortex by east path is mainly in the central part of the plateau, while the source of the STPVs along southeast path lies in the northeast of the plateau. Therefore, the STPVs that emerge in the central plateau but out of the plateau by the east path in May-June cannot be underestimated. Besides, we see that the STPV not only impacts China, including the northeastern and eastern China, the southeast coast of China as well as the areas of the Bohai Sea, Yellow Sea and East China Sea, but also affect the Korean Peninsula, Japan and Southeast Russia.
Table 2. Impact statistics of the sea plateau vortices during 1998-2018.

| No. | Ref. No. | yr. | Process time | Primary location | Paths | Range of precipitation | Intensity |
|-----|----------|-----|--------------|------------------|-------|------------------------|-----------|
| 1   | C0012    | 2000| 08:00 BT 1-20:00 BT 3 Jul. | 33.7°N 102.3°E | E     | Plateau to E-coast     | Severe Rainstorm |
| 2   | C0115    | 2001| 08:00 BT 1-20:00 BT 5 Jun. | 31.8°N 98.5°E | ENE   | Plateau to E-coast     | Severe Rainstorm |
| 3   | C0128    | 2001| 08:00 BT 29 Aug.-20:00 BT 3 Sep. | 34.0°N 95.6°E | NE    | Plateau to E-coast     | Severe Rainstorm |
| 4   | C0319    | 2003| 20:00 BT 12-20:00 BT 14 Jul. | 38.3°N 99.0°E | E     | Plateau to E-coast     | Severe Rainstorm |
| 5   | C0409    | 2004| 20:00 BT 7-20:00 BT 10 Apr. | 34.3°N 95.1°E | E     | Plateau to E-coast     | Rainstorm   |
| 6   | C0411    | 2004| 08:00 BT 15-08:00 BT 19 Apr. | 32.7°N 94.5°E | E     | Plateau to E-coast     | Severe Rainstorm |
| 7   | C0726    | 2007| 20:00 BT 6-20:00 BT 13 Jun. | 35.5°N 96.7°E | E     | Plateau to E-coast     | Severe Rainstorm |
| 8   | C0727    | 2007| 08:00 BT 10-08:00 BT 13 Jun. | 33.0°N 91.6°E | ENE   | Plateau to E-coast     | Rainstorm   |
| 9   | C0730    | 2007| 20:00 BT 19-20:00 BT 25 Jun. | 35.2°N 95.3°E | E     | Plateau to E-coast     | Severe Rainstorm |
| 10  | C0732    | 2007| 20:00 BT 24-20:00 BT 28 Jun. | 29.9°N 101.6°E | NE    | Plateau to E-coast     | Severe Rainstorm |
| 11  | C1321    | 2013| 08:00 BT 24-20:00 BT 27 May | 33.2°N 94.2°E | E     | Plateau to E-coast     | Severe Rainstorm |
| 12  | C1323    | 2013| 20:00 BT 4-08:00 BT 10 Jun. | 34.0°N 94.2°E | E     | Plateau to E-coast     | Severe Rainstorm |
| 13  | C1413    | 2014| 20:00 BT 6-08:00 BT 15 Jun. | 32.8°N 92.3°E | E     | Plateau to E-coast     | Rainstorm   |
| 14  | C1619    | 2016| 20:00 BT 17-20:00 BT 22 May | 34.0°N 91.2°E | E     | Plateau to E-coast     | Severe Rainstorm |
| 15  | C1714    | 2017| 20:00 BT 6-08:00 BT 10 May | 35.8°N 100.0°E | NE    | Plateau to E-coast     | Heavy rain  |
| 16  | C1717    | 2017| 08:00 BT 15-08:00 BT 22 May | 38.6°N 96.0°E | NE    | Plateau to E-coast     | Rainstorm   |
| 17  | C1720    | 2017| 08:00 BT 25-20:00 BT 28 May | 37.4°N 100.7°E | SE    | Plateau to around plateau | Moderate rain |
| 18  | C1820    | 2018| 20:00 BT 30 May-08:00 BT 3 Jun. | 33.5°N 92.5°E | E     | Plateau to E-coast     | Heavy rain  |
| 19  | C1823    | 2018| 20:00 BT 6-20:00 BT 11 Jun. | 33.5°N 92.5°E | NE    | Plateau to E-coast     | Rainstorm   |

Figure 2. Paths of the STPVs during 1998-2018 (The area over 3000 m above sea level is shown in black as Tibetan Plateau area. The numbers are the Serial numbers in Table 1. Solid circle represents the position of plateau vortex; black line is for the east path, red line for the northeast path, purple line for the east-northeast path and blue line for the southeast path).

3. Characteristics of circulations

3.1. Influence and evolution characteristics of the southeast-path Sea-Entering Tibetan Plateau Vortices

The C1717 vortex was generated in Dachaidan in the northeast of Tibetan Plateau at 8:00 BT 15 May 2017, with geopotential height of 576 dagpm; then the C1717 vortex moved southeastward and strengthened, and at 8:00 on the 17th the geopotential height was 574 dagpm. By 20:00 on the 17th the C1717 vortex stepped out of the plateau. When the C1717 vortex was active, it led to light to moderate rain in the northeastern, eastern, central and southern regions of the plateau; after it moved out of the
The C1717 vortex was born in Gangcha in the northeast of Tibetan Plateau at 8:00 BT 25 May 2017, with a geopotential height of 579 dagpm; later it moved southeastward and the low vortex strengthened. At 8:00 on the 26th, the geopotential height became 577 dagpm, and the C1720 vortex moved out of the plateau, causing light to moderate rain in the northeast region of the plateau, light
rain in southern Gansu and northeastern Sichuan, where only two stations collected the rainfall of ≥10mm and the maximum rainfall was 12.2mm in Xining, Qinghai Province. After moving out of the plateau, the C1720 vortex developed southeastward with the strength changing less first but then intensifying, and at 08:00 on the 27th the geopotential height of the low vortex was 575 dagpm. Afterwards, its southeastward movement weakened, and by 08:00 on the 28th, it arrived in the east of Zhejiang Province to go to sea with the geopotential height of 579 dagpm, causing only scattered light rain in some areas of Hubei, Anhui and Fujian provinces. At 20:00 on the 28th, the geopotential height of the C1720 vortex at the time of going to the sea was 580 dagpm, and then the C1720 vortex weakened and died out, resulting in no precipitation, but only gust winds of magnitude 7 at a few stations along the southeast coast.

The above two cases of STPVs are seen to be responsible for the light to moderate rain on the Tibetan Plateau before their moving out of the plateau, and their significant difference in causing precipitation mainly appears during their activities after they move out of the plateau. The C1717 vortex induced extensive precipitation in the western and eastern parts of China. Gansu was caught by torrential rains, and Henan, Anhui and Zhejiang saw heavy rains while Zhoushan Islands experienced very strong winds of magnitude 6-7. However, the C1720 vortex only caused light to moderate rain in the northeast of the plateau and light rain of small range in the area around the plateau.

3.2. Circulation characteristics at 500hPa
The 500hPa circulation characteristics of large- and small-scale precipitation vortices are analyzed from the perspective of 500hPa geopotential height fields and temperature fields of the C1717 vortex (Figure 3) and the C1720 vortex (Figure 4). The two plateau vortices had similar circulation backgrounds, where the subtropical high was located to the south of 20°N and was active on the shear line when the plateau vortices formed and moved out of the plateau. Their differences are as follows:

1. The circulation situation north of 40°N in East Asia for the C1717 vortex maintained a two-trough and one-ridge pattern after it moved out of the plateau, and the circulation was stable. When the C1720 vortex was going to move out of the plateau, it had the one-trough and one-ridge circulation; when it strengthened, the situation changed into two-ridge and one-trough pattern; and when it was about to the sea, the situation turned into the pattern of two troughs and two ridges. So, this plateau vortex kept being active till entering the sea under the situation of changing circulation.

2. The airflow of C1717 vortex was relatively flat and the frontal zone was obvious. It developed southeastward, approaching the low vortex gradually. The split cold air was constantly invading the low vortex, which strengthened the activities of low vortex for several times (1 time before moving out of the plateau, 2 times above the mainland and 1 time after going to the sea). The frontal zone of the C1720 vortex was not obvious and short in length (less than 10 longitudes), and the cold air area accompanied by the C1720 vortex was weakening.

3. The influence systems after the two vortices moved out of the plateau are that, for the C1717 vortex, it was the south branch trough, while for the C1720 vortex was the shear line.

4. The subtropical high of the C1717 vortex extended westward after the vortex’s moving out of the plateau, but that of the C1720 vortex was retreating eastward. The obvious difference of the 500hPa circulation characteristics shows the stable circulation situation at 500hPa in the process of large-range precipitation vortex activities. The airflow is relatively flat and does not block the east-moving weather system. The frontal zone favorable for the cold air to move eastward and southward is obvious and the cold temperature trough behind the trough is obvious. The subtropical high extends westward, which is conducive to the strengthening of the southwest airflow in front of the trough, and the weather system that affects the activity of the low vortex is strong and strengthening, etc. All these are important circulation features of the large range precipitation caused by the slow moving of STPV. This is also different from the circulation characteristics of the TPV, which is spinning in Hetao region due to its eastward movement blocked by the tropical low vortex activity in the relatively weak shear environment field [36].
Figure 4. The 500 hPa geopotential height (solid black line, unit: dagpm), temperature (red dashed line, unit: °C) during the active process of C1720 vortex (red dot) in May 2017.
(a) 08:00 BT 25 (formation), (b) 08:00 BT 26 (out of the plateau), (c) 08:00 BT 27 (strengthening), (d) 08:00 BT 28 (about to sea), (e) 20:00 BT 28 (about to dissipate after out to sea) (Illustrations are the same as in Figure 3.)

3.3. Jet and divergence field at high-level
Large scale weather systems can affect the movement speed and intensity of weather systems, and can cause the interaction of different scale weather systems [39]. In the study of the activity of the TPV, many scholars have analyzed the characteristics of the upper jet and its influence on the TPV. The subtropical westerly jet axis of TPV moving out of the plateau passed over the main part of the plateau and was close to the vortex center [40]. The vortex moving out of the Tibetan Plateau is steered by the prevailing westerly wind in the upper layer, and has a stronger steering speed than the TPV not moving out of the plateau [41]. The TPV moving to the east by northeast always moved along with the jet center on the north side of the upper southwest jet [42]. The TPVs in the eastern Plateau are first strengthened by the latent heat release and the baroclinic forcing of the upper jet flow, and then continue to develop due to the tilt effect of the front - earth surface interaction [43]. The TPV affecting the flood in eastern China moved out of the plateau when the 200 hPa westerly jet strengthened and extended eastward, and the center of the westerly jet moved eastward [44]. The eastward movement and development of the TPV affecting the rainstorm in Gansu Province was caused by the high-altitude divergence on the right side of the entrance area of the high level northwest wind jet and the descend of the low-level air pressure [45]. Studies have pointed out that changes in the high-level fronts reflected by high-level jets have a significant impact on the continued
activity of low vortices after they move out of the Tibetan Plateau [24], [46]. The above studies are mainly aimed at the TPVs in the east route. What are the characteristics of the high level jet flow associated with the southeast route STPVs? What is the difference in the characteristics of the high level jet flow associated with the southeast route STPVs with large precipitation difference? For this reason, the 200hPa wind vector field and divergence field in the course of large-scale precipitation vortex and small-scale precipitation vortex activity are compared and analyzed.

Seen from the 200 hPa wind vector fields of the C1717 vortex (Figure 5a) and the C1720 vortex (Figure 5b), the characteristics of the 200 hPa high-level jets of the large- and small-scale precipitation vortices are similar during the process of vortex activity. Above the north of and near the low vortex, there are jet streams ≥28 m/s, respectively, referred to as the north and south branch jets. Moreover, the north branch jet gradually moves southward, but the south branch jet is stable relatively. The TPV lies under the right side of the core area of the north brance westerly jet.

Figures 5a and 5b also illustrate that the distributions of the high-level jets over the C1717 vortex and the C1720 vortex are distinct greatly. (1) The positions of the high-level jets are different. The north branch jet with axis at 53°-57°N over the C1717 vortex is norther than that jet axis is at 50°-56°N over the C1720 vortex. When and after the C1717 vortex moves out of the Tibetan Plateau, the north branch jet above it is souther than over the C1720 vortex, and the south branch jet over the C1717 vortex is 2-4 latitudes souther than over the C1720 vortex. (2) The intensities of the high-level jet are different. The north branch jet over the C1717 vortex is significantly stronger than over the C1720 vortex. When the C1717 vortex evolves from generation to strengthening, it has a jet core area of 44-48 m s⁻¹, which is shifting to the east. However, the jet core area of the C1720 vortex is only 36-40 m s⁻¹, and it is retreating to the west. After the two vortices are strengthened, although their north branch jet cores are strengthening, at the moment the low vortex is about to the sea and after out to sea when the C1717 vortex dissipates, the wind speed in the jet core area reaches 56-60 m s⁻¹, while the wind in the jet core area of the C1720 vortex is only at the speed of 44-48 m s⁻¹. (3) After the C1717 vortex is generated, the north and south branches of the jet stream above it are larger than those above the C1720 vortex in length and width. For the north branch jet above the C1717 vortex, the length and width increase as the C1717 vortex develops from formation to strengthening ,while those of the C1720 decrease. The south branch jet over the C1717 vortex is slightly stronger when the vortex evolves from formation to strengthening than that over the C1720 vortex. The C1717 vortex continues to have a jet core area of 56-60 m s⁻¹ and the jet core area for C1720 vortex is of 52-56 m s⁻¹. After the C1717 vortex strengthens, the south branch jet core over it weakens, but that over the C1720 vortex gets strengthened. (4) There is a large difference in the position of low vortex under the high-level jet. When the C1717 vortex is formed, moves out of the plateau, strengthens and goes to sea, the northwest airflow on the left edge of the south branch jet is over the low vortex. When the C1720 vortex is formed and moves out of the plateau, the westerly airflows on the left edge of the south branch jet is above the low vortex. When the C1720 vortex is strengthened, is about to sea, and is to dissipate after going to sea, there are northwesterly, westerly and southwesterly airflows of the south branch jet respectively lying over the low vortex. The distance between the low vortex of the C1717 vortex and the core area of the north branch jet is shorter than the distance between the low vortex of the C1720 vortex and the north branch jet core. When the C1717 vortex moves out of the plateau and is strengthened, the distance between the C1717 vortex and the north branch westerly jet core decreases, but that between the C1720 vortex and the north branch westerly jet core increases. These all reflect that the upper-air fronts reflected by the high-level jets have a significant impact on the low-vortex activity below them. Thus, the large-scale precipitation vortex activity is closely related to the strong high-level north and south branch jets and the eastward shift of the north branch jet core.
Figure 5. The 200hPa wind vector field during the strengthening of the plateau vortices C1717 (a) and C1720 (b), and the positions of 200hPa jet axis when the plateau vortices form (blue solid line), move out of the plateau (green solid line), strengthen (red solid line), are about to sea (solid purple line), and to dissipate after entering sea (solid black line). (Short vertical line on the jet axis shows the position of jet core, and number represents the wind speed in the jet core area.)

The activities and changes of the north branch jet at 200hPa of the C1717 vortex and C1720 vortex (Figures 5a and 5b), combined with the 500hPa circulation situation (Figures 3 and 4), illustrate that during the active process of the C1717 vortex, the 500hPa frontal zone is obvious, and as the front moves eastward and southward, it constantly splits the cold air which intrudes into the C1717 vortex. This is matched with the strong 200hPa north branch jet accompanied with it and the southward extension and southward movement. During the C1720 vortex activity, the 500hPa frontal zone is not obvious, which agrees with the weak 200hPa north branch jet accompanying the frontal zone.
The 200 hPa divergence field (figure omitted) denotes that the central area of the divergence zone is situated above the low vortex area when the C1717 vortex and C1720 vortex are formed, move out of the Tibetan Plateau and are strengthened, but is over the southeast of the low vortex when they are about to sea and about to dissipate after out to sea. However, differences can be seen clearly. When the C1717 vortex moves out of the plateau and strengthens, it has a center of a strong divergence zone $\geq 7 \times 10^{-5} \text{ s}^{-1}$, while the divergence center of the C1720 vortex is weaker than that of the C1717 vortex by 2-3 times (Figures 6a and 6b). When the C1717 vortex is formed and develops to about to dissipate after going to sea, the divergence zone over the vortex area is larger than that of the C1720 vortex. Therefore, the average value of the divergence over the vortex area of the C1717 vortex is larger than that of the C1720 vortex during the active process of the C1717 vortex (Figures 6a and 6b). Especially
when the low vortex is strengthened, the “pumping effect” over the C1717 vortex is stronger than that of the C1720 vortex, that is, the C1717 vortex has more favorable high-level conditions for the strengthening of the low vortex than the C1720 vortex. Comparing the activities and changes of the 200hPa south branch jets (Figures 5a and 5b), we can see easily that the strong divergence zone which is closest to the low vortex is linked to the activity of the accompanied south branch jet above the nearby low vortex.

Therefore, both the large- and small-scale precipitation vortices of the southeast route STPVs with large precipitation difference are accompanied by the north and south branch jets, and the north branch jet gradually shifts southward while the south branch jet remains stable relatively. The STPVs, affected by the north branch jet, makes the mid-troposphere frontal zone continuously go to east and south under the situation that the upper-air front zone moves eastward and southward. Influenced by the south branch jet, the STPVs have a divergence zone at 200hPa above it, thereby providing favorable upper-air conditions for the STPVs to stay there for a long time. However, the changes and impacts of the north and south jets accompanied by the two STPVs are different. The north branch jet accompanied by the large-scale precipitation vortex is stronger than that of small-scale precipitation vortex, and the eastward extension of jet and the eastward movement of the jet core area are more obvious than those of the small-range precipitation. The south branch jet accompanied by the large-scale precipitation vortex is longer than that of the small-scale precipitation vortex, which makes the large-scale precipitation vortex more conducive to the formation of upper-air divergence conditions for low-vortex strengthening.

The southeast route STPVs with the large- and small-scale precipitation rain area are accompanied by high level air jet flow, same as the east route STPVs, both accompanied by north and south side air flow jet. This demonstrates that the long time TPV over the Chinese mainland is accompanied by two high level jets in the north and south. The difference is that the STPV of southeast route is connected with the north air jet flow moving to the south, and the STPV of east route is connected with stabilized north jet air flow. The situation of the STPV of southeast route with high level jet flow is also different from that of the STPV of northeast route. The latter (the TPV of east northeast route) moves with the jet flow center on the north side of the high level southwest jet stream [42]. In the process of large- and small-scale precipitation of TPV activity, there is a relatively divergent central area over the vortex area affected by air jet flow, which is consistent with the conclusion [47].

4. Water vapor transport and vertical velocity
Among all kinds of rainstorms in China, such as China Yangtze river and Huaihe rainstorms [48], China North-west heavy rainstorms [45], and China south rainstorms [49], etc. All fully reflected that the heavy rainfall is generated under the ondition of strong ascending motion and sufficient water vapour. What are the precipitation conditions of large and small region precipitation caused by STPVs with the southeast route? What is the reason for the big difference in precipitation? To this end, the water vapor field and the vertical velocity field during the large-scale precipitation vortex and small-scale precipitation vortex activities are to be compared and analyzed below.

4.1. The 500hPa water vapor transport and vertical velocity field
The vortex area and the rising motion around the vortex area for the large and small ranges of precipitation vortices are analyzed by the 500hPa vertical velocity field (Figure omitted). While the STPVs moves out of the plateau, strengthens, and are about to the sea, the strongest rising motion area around the vortex area are all the southeast part of the low vortex, but there are great differences, which include: (1) the ranges of the rising motion are different. There is a rising motion part in the west and southwest of the low vortex area when the C1717 vortex is formed. When the C1717 vortex moves out of the Tibetan Plateau and strengthens (Figure 7a), the rising motion part is expanded to most of vortex area. For C1720 vortex, however, most part of the low vortex area is upwelling when it is formed. When C1720 vortex moves out of the plateau, the rising motion part of the low vortex is
narrowed down to the northeast and southeast of the vortex area, and, further to the east and southeast of the vortex area when it strengthens (Figure 7b). So, it can be seen that the rising motion part gradually decreases when the C1717 vortex is going to sea and dissipates after out to sea whilst the range of the rising motion during the evolution process of the C1720 vortex expands to most of the vortex area. (2) The intensities of rising motion are different. The rising motion strength of the C1717 vortex is stronger than that of the C1720 vortex. When the two vortices live in different stages, i.e., forming, moving out of the plateau, strengthening, going to sea and dissipating after out to sea, the C1717 vortex has rising motion centers of \(-2.73\times Pa\cdot s^{-1}\), \(-2.51\times Pa\cdot s^{-1}\), \(-2.53\times Pa\cdot s^{-1}\), \(-1.5\times Pa\cdot s^{-1}\) and \(-0.32\times Pa\cdot s^{-1}\) in its vortex area and vicinity, but the rising motion centers of the C1720 vortex are \(-2.07\times Pa\cdot s^{-1}\), \(-1.56\times Pa\cdot s^{-1}\), \(-1.07\times Pa\cdot s^{-1}\), \(-0.89\times Pa\cdot s^{-1}\) and \(-0.18\times Pa\cdot s^{-1}\), respectively. The changes of C1717 vortex in rising motion intensity are not so big when it forms, moves out of the plateau and strengthens (Figure 7a), which means it has stronger upward movement all the time. However, the upward motion of the C1720 vortex is weakening (Figure 7b). This reflects that the large range of heavy precipitation caused by the plateau vortex is closely related to the upwelling motions around the plateau vortex, especially the upwelling motion strength.

Analyze the characteristics of water vapor transport and water vapor convergence near the vortex area and its vicinity in large- and small-scale precipitation vortices from the 500hPa water vapor flux and the divergence field of water vapor flux (Figure omitted). The similarity is found to be that there is a quasi-east-west water vapor flux large-value conveyor belt from south of the plateau through the eastern part of China to Japan when the two vortices are formed, and also the water vapor flux value and water vapor flux convergence are increasing as they vortices are strengthened.

The features of water vapor transport and water vapor convergence of the C1717 vortex are significantly different from those of the C1720 vortex: (1) The locations of the water vapor transport are different. After the formation of the C1717 vortex, there is another water vapor transport belt from the central to the eastern part of the plateau. When the C1717 vortex moves out of the Tibetan Plateau till 6 hours before the low vortex dissipates, the water vapor transport belt in the central to eastern part of the plateau moves eastward and gets linked with the quasi-east-west water vapor transport belt to the south of the plateau, so the water vapor flux area in the vortex area is always connected to the quasi-east-west large-value water vapor transport belt, and the water vapor flux area of the vortex area and its vicinity shows up a circular distribution pattern around the center of the vortex. In contrast, the C1720 vortex keeps being located north of the quasi-east-west water vapor conveyor belt to the south of the plateau. (2) The water vapor flux intensities in the vortex area and its vicinity are different. When the C1717 vortex is formed and dissipates after entering the sea, the water vapor flux area in the southeast of the vortex area is weaker than that of the C1720 vortex; from the time when the C1717 vortex moves out of the plateau to the time when it is going out to sea, the water vapor flux value of the vortex area is greater than that of the C1720 vortex. When the C1717 moves out of the plateau and strengthens (Figure 7a), and is about to sea, the water vapor flux values in most parts of the vortex area are \(2.51\times g\cdot hPa^{-1}\cdot cm^{-1}\cdot s^{-1}\), \(2.5.8\times g\cdot hPa^{-1}\cdot cm^{-1}\cdot s^{-1}\) and \(1.5\times g\cdot hPa^{-1}\cdot cm^{-1}\cdot s^{-1}\), respectively, while those values of the C1720 vortex (Figure 7b) are the small parts of the vortex area, i.e., \(1.23\times g\cdot hPa^{-1}\cdot cm^{-1}\cdot s^{-1}\), \(1.3\times g\cdot hPa^{-1}\cdot cm^{-1}\cdot s^{-1}\) and \(1.45\times g\cdot hPa^{-1}\cdot cm^{-1}\cdot s^{-1}\), respectively.

(3) The range and intensity of the water vapor flux convergence zone of the vortex area and its vicinity are different. When the C1717 vortex is formed, the water vapor flux convergence zone and intensity of the vortex area and its vicinity are smaller than those of the C1720 vortex. The C1717 vortex has a water vapor flux convergence zone \(\geq 26\times 10^{7}\ g\cdot hPa^{-1}\cdot cm^{-2}\cdot s^{-1}\) in the northwest, north, and northeast of the vortex area. The C1720 vortex has water vapor flux convergence zone \(\geq 81\times 10^{7}\ g\cdot hPa^{-1}\cdot cm^{-2}\cdot s^{-1}\) in most parts of the vortex area. From the time when the C1717 vortex moves out of the plateau to the time for low vortex is to dissipate, the water vapor flux convergence zone and intensity in the vortex area and its vicinity are larger than those of the C1720 vortex. When the C1717 vortex moves out of the plateau and strengthens (Figure 7a), most of the vortex area has water vapor flux convergence zone \(\geq 198\times 10^{7}\ g\cdot hPa^{-1}\cdot cm^{-2}\cdot s^{-1}\) and \(\geq 246\times 10^{7}\ g\cdot hPa^{-1}\cdot cm^{-2}\cdot s^{-1}\). The water vapor flux convergence zone in most parts of the C1720 vortex area (Figure 7b) is over 3 times
weaker than and near 3 times those of the C1717 vortex. When the C1717 vortex is going to sea and is about to dissipate after entering the sea, there exists water vapor flux convergence zone $\geq 95 \times 10^{-7} \text{g hPa}^{-1} \text{cm}^2 \text{s}^{-1}$ and $112 \times 10^{-7} \text{g hPa}^{-1} \text{cm}^2 \text{s}^{-1}$ in half of the vortex area. The water vapor flux convergence in a small part of the vortex area of the C1720 vortex is 28% and 4 times weaker than that of the C1717 vortex, respectively. These reflect the large range of severe precipitation caused by the STPV and the transport of water vapor northward to near the STPV are closely correlated to the larger water vapor flux values and the larger water vapor convergence values in the vortex area and its vicinity.

Figure 7. The 500hPa water vapor flux (vector, unit: $\text{g hPa}^{-1} \text{cm}^2 \text{s}^{-1}$), water vapor flux divergence (shaded, unit: $10^{-7} \text{g hPa}^{-1} \text{cm}^2 \text{s}^{-1}$), vertical velocity (solid red line, unit: Pa s$^{-1}$) with the strengthening of C1717 vortex (a, red dot) and C1720 vortex (b, red dot) (Thick red solid line indicates the range of the plateau vortex area.).

4.2. The 700hPa water vapor transport and vertical velocity field
The synoptic system in the middle troposphere has a certain influence on the lower troposphere [50], [24]. Since water vapor in the atmosphere is mainly concentrated in the lower troposphere, water vapor transport, water vapor convergence and upward motion of air are indispensable factors for
generating precipitation. For this reason, the wind vector field, vertical velocity, water vapor flux and water vapor flux divergence at 700hPa are to be analyzed below.

The 700hPa wind vector field (Figure omitted) suggests that when the C1717 vortex moves out of the plateau, a low vortex is generated at 700hPa under the vortex area in the south of Gansu Province with the center near Lanzhou, referred to as the Lanzhou vortex for short. When the C1717 vortex strengthens, the Lanzhou vortex under it strengthens (Figure 8a). Afterwards, the Lanzhou vortex persists until it is gone at 08:00 BT 19th. This Lanzhou vortex is induced by the C1717 vortex. In comparison, after the C1720 vortex moves out of the plateau, no low vortex is generated at 700 hPa below the vortex area(Figure 8b).

The 700hPa vertical velocity field (Figure omitted) indicates that the similar features of the upwelling motion under the vortex area and its vicinity of the large- and small-scale precipitation vortices lie in that when the C1717 and C1720 vortices move out of the plateau and strengthens, the strongest upwelling motion area in the lower atmosphere around the vortex area is in the southwest of the low vortex, and the upwelling motion strength increases as the low vortex strengthens. When the vortices are going to sea and dissipating after entering the sea, the upwelling motion area near the vortex area and its vicinity shrinks, and the strength weakens. Their difference is mainly in the range and intensity of the rising motion area. When the C1717 vortex moves out of the plateau, the range and intensity of the rising motion area in the southwest and south of the vortex area are slightly larger than that of the C1720 vortex, and the two vortices have the rising motion centers of -2.26 Pa•s⁻¹ and -2.15 Pa•s⁻¹, respectively. When the C1717 vortex is strengthened (Figure 8a), the rising motion area is enlarged more noticeably than that of the C1720 vortex, and the intensities of the upward motion centers associated with the C1717 vortex and the C1720 vortex (Figure 8b) are respectively increased to -3.00Pa•s⁻¹ and -2.93 Pa•s⁻¹. When they are going to sea and dissipate after entering the sea, the associated upward motion area is clearly reduced, with strength obviously weakened, but the C1720 vortex rising motion area is slightly larger than that of the C1717 vortex. The intensities of the rising motion centers associated with the C1717 vortex are -1.26 Pa•s⁻¹ and -1.34 Pa•s⁻¹, and those with the C1720 vortex are -1.05 Pa•s⁻¹ and -0.88 Pa•s⁻¹, respectively. Combined with the analysis of the 700hPa wind vector field, it is not difficult to see that the rising motion area of the C1717 vortex in the lower troposphere increases significantly when it is strengthened, which is related to the existence of low vortex there. This reflects that the large range heavy precipitation caused by STPV is also closely related to the range and strength of the rising motions under the STPV, especially the rising motion strength.

The water vapor transport and the water vapor convergence characteristics under the large- and small-scale precipitation vortices are analyzed on the basis of the 700hPa water vapor flux and water vapor flux divergence field (Figure omitted), and their similarities are found to be that during the active stages of the two vortices, they both have a quasi-east-west water vapor flux conveyor belt at 700hPa with position souther than at 500hPa, and with their strengthening, the water vapor flux and the water vapor flux convergence are increasing. However, the water vapor transport and convergence characteristics of the C1717 vortex are significantly different from those of the C1720 vortex, which are reflected by: (1) the positions of the water vapor transport at 700hPa are different. When the C1717 vortex moves out of the Tibetan Plateau, there is another north-south water vapor conveyor belt from Yungui Plateau through eastern Sichuan to Ningxia. When the C1717 vortex strengthens (Figure 8a), the north-south water vapor conveyor belt is linked together with the quasi-east-west water vapor conveyor belt, and it lasts until 08:00 on the 19th. When the C1717 vortex is about to sea, the quasi-east-west water vapor conveyor belt is lifted to the north, and under it the C1717 vortex is at the edge of the quasi-east-west water vapor conveyor belt. When the C1717 vortex dissipates after entering the sea, the lower part of the C1717 vortex is to the north of the quasi-east-west water vapor conveyor belt, far away from the high-value water vapor conveyor belt. Comparatively, the C1720 vortex (Figure 8b) is always located north of the quasi-east-west water vapor conveyor belt, far away from this large-value water vapor belt, and there is only 4-6 g•hPa⁻¹•cm⁻¹•s⁻¹ water vapor transport in the east path when the C1720 vortex is to dissipate after entering the sea. (2) The intensities of water
vapor flux in the plateau vortex area and its vicinity are different. When the C1717 moves out of the Tibetan Plateau and is strengthened (Figure 8a), the water vapor flux intensity is significantly stronger than that of C1720 vortex and most part under the vortex area has water vapor flux area of 2-5.9 g•hPa⁻¹•cm⁻¹•s⁻¹ and 3-8.7 g•hPa⁻¹•cm⁻¹•s⁻¹, respectively. For the C1720 vortex (Figure 8b), in comparison, the water vapor flux area in the air under less than half of the vortex area is 1-2.5 g•hPa⁻¹•cm⁻¹•s⁻¹, and the center value (2.497 g•hPa⁻¹•cm⁻¹•s⁻¹) is reduced when the C1720 vortex shifts out of the plateau and strengthens (Figure 8b, 1.846 g•hPa⁻¹•cm⁻¹•s⁻¹). When the C1717 vortex is going to sea and is to dissipate after entering the sea, the water vapor flux intensity is obviously weaker than that of the C1720 vortex. Although the water vapor flux intensity of the C1717 vortex is weaker when it is going to sea than the time when it strengthens, still there is the water vapor flux area of 1-3.45 g•hPa⁻¹•cm⁻¹•s⁻¹ under most of the vortex zone. When the C1717 vortex is about to dissipate after entering the sea, the water vapor flux intensity continuously weakens, and only a small part of the vortex area has the water vapor flux area of 1-3.96 g•hPa⁻¹•cm⁻¹•s⁻¹ under it. In contrast, the water vapor flux intensity of under the C1720 vortex is more enhanced when the vortex is about to sea and to dissipate after entering the sea than when it strengthens, and most part of the vortex area has the water vapor flux area of ≥1.5 g•hPa⁻¹•cm⁻¹•s⁻¹ below it. (3) The range and intensity of the water vapor flux convergence zone in and around the vortex area are different. The water vapor flux intensity of C1717 vortex is significantly stronger than that of the C1720 vortex when it moves out of the plateau, strengthens (Figure 8a), and goes out to sea. The water vapor flux converging zone ≤1.0×10⁻⁷ g•hPa⁻¹•cm⁻²•s⁻¹ below the C1717 vortex area occupies the half, most and a small part of the vortex area, respectively, and the central intensity of water vapor flux convergence is -241×10⁻⁷ g•hPa⁻¹•cm⁻²•s⁻¹, -292×10⁻⁷ g•hPa⁻¹•cm⁻²•s⁻¹ and -257×10⁻⁷ g•hPa⁻¹•cm⁻²•s⁻¹, respectively. For the C1720 vortex, however, when it moves out of the Tibetan Plateau, strengthens (Figure 8b) and is about to sea, the central intensity of the water vapor flux convergence zone is half less than that of the C1717 vortex or more. The water vapor flux convergence zone is smaller than that of the C1717 vortex only when it moves out of the plateau. When the two vortices are to dissipate after entering the sea, the water vapor flux convergence zones ≤1.0×10⁻⁷ g•hPa⁻¹•cm⁻²•s⁻¹ account for most of the vortex area, but the central intensity of water vapor flux convergence of C1720 vortex, which is -121×10⁻⁷ g•hPa⁻¹•cm⁻²•s⁻¹, is stronger than that of C1717 vortex. To sum up, a large area of heavy precipitation caused by the STPV is related to the transport of water vapor northward to below the vortex area, and also related to the strong water vapor flux convergence under the vortex area.

It can be seen from the above that the similar part of ascending motion of TPV with south-east route causing large- and small-scale precipitation area are as follows: Both in the TPVs area and nearing region, the TPV on 500hPa and in the lower 700hPa are accompanied by ascending motion. When the two types of TPV move out of the plateau and strengthen, the intensity of the lower air ascending in southwest of it increases, and then obviously weakens. The different part are as follows: In the process of the two TPVs, the intensity of TPV on 500hPa and 700 hPa ascending motion centers accompanied by large-scale precipitation type is stronger than that of small-scale precipitation type, especially on the 500 hPa during the time when they are strengthened. The ascending motion region on 500hPa and 700hPa accompanied by the large-scale precipitation vortex is expanding from formation to strengthening phase, and then shrinking, while the small-scale precipitation vortex is on the converse side on 500hPa. The ascending motion region on 700hPa accompanied by the large-scale precipitation vortex is bigger than that of the small-scale precipitation vortex. This demonstrate that the deep upwelling air flow in TPV and closed area is closed related with the large scale precipitation caused by TPV. This is similar to the ascending motion of 700hpa-500hpa over the torrential rain area [51]. China south rainstorm with low vortex and shear lines [52]. However, the intensity of the ascending motion is far less than that of the torrential rain caused by the shear line and the low vortex in the west of south China and the torrential rain in the south of China caused by the SCV. This is because the torrential rain caused by the shear line and the low vortex in the west of south China and the torrential rain caused by the SCV are far more rainfall instense than that of the STPV. It is also
similar to the strong upwelling of monsoon low-pressure rainstorm at 700hPa [53], but different from the upwelling of monsoon low-pressure rainstorm reached to 300hPa level.

![Figure 8](image.png)

**Figure 8.** Water vapor flux (vector, unit: g·hPa⁻¹·cm⁻¹·s⁻¹), water vapor flux divergence (shaded, unit: \(10^7\) g·hPa⁻¹·cm⁻²·s⁻¹), vertical velocity (solid red line, unit: Pa·s⁻¹) at 700hPa during the strengthening of the C1717 vortex (a, pink dot) and the C1720 vortex (b, pink dot). (Thick pink solid line indicates the range of the plateau vortex region, and red dot indicates the 700hPa low vortex).

The water vapour convergence and water vapour transportation characteristics on 500hPa and 700hPa of large- and small-scale precipitation vortex of south-east route have similar features as follows: There is a large value water vapour transport belt of quasi east-west from the south of the Tibetan Plateau through the east of China to Japan when the two vortices are formed, and the position on 700hPa is southern than on that on 500hPa. When the two vortices are strengthened, the convergence of water vapour flux value and water vapour flux in the middle and lower troposphere are enhanced.

The difference features are as follows: From the time when the large-scale precipitation vortex moves out of the plateau to the time when it goes to the Sea, the vortex area and its vicinity on 500hPa and 700hPa, there is a water vapour transport connected with a large value water vapour transport belt in quasi east-west direction, while small-scale precipitation vortex, it is far away from the large value
water vapour transport belt, which makes most of the large-scale precipitation vortex have large water vapour flux and strong water vapour flux convergence, and the convergence of water vapour flux in the lower troposphere is stronger than that in the middle troposphere, while small-scale precipitation vortex, only a small part of the vortex area has small water vapour flux and the weak water vapour flux converges. This revealed that the activity of TPV with large-scale precipitation region is closely related to the deep water vapour transportation and the convergence of water vapor flux, and this is similar to the conclusion [54] that the heavy rainfall process during the 1998 flood period in the Yangtze River valley is closely related to the large supply of water vapor to the Yangtze River valley and large value of water vapour convergence, just that they’re referring to water vapor as a result of the vertical integration of the entire atmosphere column. This is different with the analysis of severe rainstorm caused by low vortex and shear line in the west of south China [51], and SCV rainstorm [55]. The two cases of water vapor transportation and water vapor flux convergence are in the lower troposphere level, which may be caused by the different activities of only the vortex in the lower troposphere and the large-scale precipitation vortex in the middle and lower troposphere.

5. Summary and discussion
The TPV departure the Tibetan Plateau can cause heavy rainfall in southwest and east China land. Some of the vortices can also affect the Korean Peninsula, Japan and Vietnam. However, previous studies mainly focused on the effects of TPV on precipitation over the Tibetan Plateau and the eastward moving path departure the Tibetan Plateau. And the circulation characteristics of the long lasting TPV moving southeast after departure the Plateau are not clear. In this work, based on the analysis of the activities of the Plateau Vortices entering the sea from 1998 to 2017, a comparative analysis of various physical fields for the TPVs southeast path departure the Plateau with large region precipitation across the east and west of China and the TPVs with small region precipitation vortices which only caused precipitation in the west of China is carried out, which is in order to study the circulation characteristics of large- region precipitation vortices in the upper and middle troposphere, and the environmental conditions in the lower troposphere. The results show that the stable circulation on 500hPa, the relatively straight air flow, no block high to block the eastward moving weather systems, conducive to the cold air moving eastward, and also the front area is obvious; The circulation characteristics of the north branch westerly jet on 200hPa is strong, and the jet core area moves eastward, which are suitable for the TPV activities in different paths affecting east Asia departure the Plateau; The large- region precipitation caused by the plateau vortex activity is related to the deep ascending motion airflow in the vortex area and its vicinity, the deep water vapor transport and the convergence of water vapor flux, which are suitable for the precipitation analysis of low vortex weather system. The main results are shown as follows.

The vast majority of the STPVs, mainly by east paths, would bring precipitation to the eastern coast of China, causing heavy rains and severe or torrential rains in some areas, and also affecting the Korean Peninsula, Japan, and Russia. The precipitation caused by the STPVs along southeast path is less than the rainfall by east-path plateau vortex. In both given cases, the southeast-path sea plateau vortex would produce light to moderate rain on the plateau before moving out of the plateau, and the significant difference in precipitation mainly occurred during the activities after moving out of the plateau.

The common circulation features of large- and small-scale precipitation vortices that can last till going to sea are that the upper troposphere is accompanied by the north and south branch jets. The north branch jet shifts gradually southward, while the south branch jet is relatively stable, which makes the low vortex affected by the south-moving of the north branch jet, and upper-air front goes to eastward and southward, which makes the frontal zone in the middle troposphere sustained. The low vortex is affected by the 200 hPa south branch jet and there exists a strong divergence zone above the low vortex, causing obvious “pumping effect”. Besides, there are obvious low-value weather systems in the middle troposphere that significantly affect the activities of low vortex.
The characteristics of the different circulations in the upper troposphere after large- and small-scale precipitation vortices move out of the plateau are that the north and south branch jets with large-scale precipitation vortices are stronger, and the north branch jet extends to the east; the jet core area moves to the east and the south branch jet spans east Asia, but the situation of the small-scale precipitation vortices is opposite. As a result, the 500hPa frontal zone accompanied by a large-scale precipitation vortex is obvious. During the east-moving of the frontal zone to the south, the cold air is split into the low vortex continuously. The 500hPa frontal zone with the small-scale precipitation vortex is not obvious. Also, the central intensity of the 200hPa strong divergence zone over the vortex area is caused to be significantly stronger than that of the small-scale precipitation vortex.

The characteristics of different circulations in the middle troposphere after large- and small-scale precipitation vortices move out of the plateau are that the large-scale precipitation vortex is relatively stable to the north of 45ºN in East Asia, and the airflow is relatively flat. To the north of the vortices, the mid-latitude baroclinic frontal zone tends to approach the low vortex gradually in the southeast, moving southeastward with the south branch trough. The situation of small-scale precipitation vortex circulation varies a lot, and there is no obvious baroclinic frontal zone to the north, which shifts southeast with the shear line. As a consequence, when the large-range precipitation vortex moves out of the plateau and intensifies, the vortex area is accompanied by a larger range and stronger rising motion zone, and has larger water vapor flux and strong water vapor flux convergence, which is superior to the capability of the small-scale precipitation vortex.

The different ambient conditions in the lower troposphere after large- and small-scale precipitation vortices move out of the plateau are that large-scale precipitation vortex induces low vortex below it, and this low vortex lasts for a period of time. For the small-scale precipitation vortex, no such low vortex is generated. So, under the large-scale precipitation vortex and its adjacent area there is a rising motion zone with large range and powerful strength, and larger water vapor flux and very strong water vapor flux convergence, which is beyond the scope of a small-scale precipitation vortex.

It is worth noting that the circulation characteristics of TPV on 500hPa are high pressure in the east and west of the Plateau, and Indian monsoon low pressure in the south of the Plateau, and straight westerly or high ridge on the north side of the Plateau[56]. The TPV moves eastward along the shear line departure the Plateau[57]. The circulation characteristics of the southeast path TPV with large-scale precipitation on 500 hPa is different. Although the selected TPV is only case, in 1998-2017, there were only two cases of southeast path Plateau Vortices entering the sea with precipitation across the east and west of China. And they were active for more than 60 hours after moving out of the Plateau. Therefore, it is necessary to further analyze the southeast path TPVs which cause precipitation to cross the east and west of China in the coming years. As for those southeast path TPVs with short activity time after moving out of the Tibetan Plateau, further investigation should be carried out in the future. In addition, the circulation characteristics of the selected southeast path TPVs entering the sea with precipitation across the east and west of China are analyzed. And the research work on the development and strengthening mechanism of them is worthy of further study.

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References
[1] Tao S Y and Ding Y H 1981 Observational evidence of the influence of the Qinghai–Xizang (Tibet) Plateau on the occurrence of heavy rain and severe convective storms in China J. Bull. Amer. Meteor. Soc. 62 23–30
[2] Wang B and Orlanski I 1987 Study of a heavy rain vortex formed over the eastern flank of the
Tibetan Plateau *J. Mon Wea Rev.* **115** 1370-93

[3] Zhang S L, Tao S y, Zhang Q y and Zhang X L 2001 Meteorological and hydrological characteristics of severe flooding in China during the summer of 1998 *Quarterly J. Appl. Meteorol.* **12** 442–57

[4] Kuo Y H and Bao J W 1988 Numerical simulation of the 1981 Sichuan flood, part1: Evolution of a mesoscale southwest vortex *J. Mon Wea Rev.* **116**, 2481-504

[5] Liu X C and Chen Y R 2014 Comparative analysis of two heavy rainfall processes under interaction of Plateau Vortex and Southwest Vortex *J. Plateau and Mountain Meteorol. Res.* **34** 1–7

[6] Yu S H, Gao W L, Peng J and Xiao Y H 2014 Observational facts of sustained departure plateau vortexes *J. Meteor. Res.* **28** 296–307

[7] Chen B and Gao W L 2015 The causing storm rain in Southwest Sichuan basin characteristic analysis of Tibetan Plateau vortex *J. Plateau and Mountain Meteorol. Res.* **35** 9–15

[8] Curio J, Schiemann R, Hodges K I and Turner A G 2019 Climatology of Tibetan Plateau Vortices in Reanalysis Data and a High-Resolution Global Climate Model *J. Journal of Climate* **32** 1933-50

[9] Li L, Zhang R H, Wu P L, Wen M and Duan J P 2020 Roles of Tibetan Plateau vortices in the heavy rainfall over southwestern China in early July 2018 *J. Atmospheric Res.* **245** 105059

[10] Song M H and Qian Z A 2002 Impact of plateau and cold air on SHWP and rain belt summer in 1998 and 1991 *J. Plateau Meteor.* **21** 556–64

[11] Chen Z M, Min W B and Miao Q and He G B 2004 A case study on coupling interaction between plateau and southwest vortexes *J. Plateau Meteor.* **23** 75–80

[12] Yu S H, Gao W L 2008 The Large Scale Conditions of the Vortex Moving Out of Qinghai-Xizang Plateau *J. Plateau Meteor.* **27**(6) 1276-87

[13] He G B, Gao W L and Tu N N 2009 The dynamic diagnosis on eastwards moving characteristics and developing mechanism of two Tibetan Plateau vortex processes *J. Acta Meteor. Sinica.* **67** 599–612

[14] Xiang S Y, Li Y Q, Li D and Yang S 2013 An analysis of heavy precipitation caused by a retracing plateau vortex based on TRMM data *J. Meteor. Atmos. Phys.* **122** 33–45

[15] Tian S R, Duan A M, Wang Z Q and Gong Y F 2015 Interaction of surface heating, the Tibetan Plateau vortex, and a convective system: A case study *J. Chinese J. Atmos. Sci.* **39** 125–36

[16] Li L, Zhang R H and Wen M 2019 Large-scale backgrounds and crucial factors modulating the eastward moving speed of vortices moving off the Tibetan Plateau *J. Climate Dynamics.* **53** 1711–22

[17] Li L, Zhang R H, Wen M and Duan J P 2019 Development and eastward movement mechanisms of the Tibetan Plateau vortices moving off the Tibetan Plateau *J. Climate Dynamics.* **52** 4849–59

[18] Li L, Zhang R H, Wen M, Duan J P and Qi Y J 2019 Effects of the atmospheric dynamic and thermodynamic fields on the eastward propagation of Tibetan Plateau vortices *J. Tellus A: Dynamic Meteorology and Oceanography* **71** 1647088

[19] Yu S H and W L Gao 2010 Comparison of structure characteristics between two Tibetan Plateau Vortices in summer, 1998 *J. Plateau Meteor.* **29** 1357-68

[20] Li L, Zhan R H and Wen M 2020 Structure characteristics of the vortices moving off the Tibetan Plateau *J. Meteorology and Atmospheric Physics.* **132**, 19-34

[21] Li G P, Lu X P, Chen T and Chen G 2011 Preliminary theoretical study of waves in the Tibetan Plateau vortex *J. Plateau Meteor.* **30** 553–8

[22] Song W W, Li G P and Tang Q K 2012 Numerical simulation of the effect of heating and water vapor on two cases of plateau vortex *J. Chinese J. Atmos. Sci.* **36** 117–29

[23] Li L, Zhang R H, Wu P L, Wen M and Li B 2019 Characteristics of convections associated with the Tibetan Plateau vortices based on geostationary satellite data *Int. J. Climatology.* **40** 4876-87
[24] Yu S H and Gao W L 2017 Analysis of environmental background and potential vorticity of different accompanied moving cases of Tibetan Plateau vortex and Southwest China vortex J. Chinese J. Atmos. Sci. 41 831-56
[25] Yu S.H and Gao W L 2018 A comparative analysis of cold air influences on short- and long-time maintenance of the Tibetan Plateau vortex after it moves out of the plateau J. Chinese J. Atmos. Sci. 42 1297-326
[26] Yu S.H and Gao W L 2019 Characteristics of surface land heating in the Qinghai-Tibetan Plateau vortex source regions along with the departure plateau vortex and non departure plateau vortex J. Plateau Meteor. 38 299-313
[27] Fu S M, Mai Z, Sun J H, Li W L, Ding Y and Wang Y Q 2019 Impacts of convective activity over the Tibetan Plateau on Plateau Vortex, Southwest Vortex, and downstream precipitation J. Atmos Sci. 76 3803-30
[28] Yu S H and Gao W L 2006 Observational analysis on the movement of vortices before/after moving out the Tibetan Plateau J. Acta Meteor. Sinica. 64 392–9
[29] Zhang H, Chen W D and Sun W 2006 Analysis of the influence of a Typhoon and mesoscale vortex in inner-mougolia irrigation area of Yellow river on rainstorm in north Shaanxi J. Plateau Meteor. 25 52-9
[30] Yu S H, Gao W L, Xiao D X and Peng Jun 2016 Observational Facts Regarding the Joint Activities of the Southwest Vortex and Plateau Vortex after Its Departure from the Tibetan Plateau J. Adv. Atmos. Sci. 33 34–46
[31] Chao Li , Wang X F , Zhou L L, Cui C H G, Jiang X W and Xu G R 2019Cloud Features of Tibetan Plateau Vortex Category Cloud Cluster over Different Regions along the Eastward-Moving Path in Summer J. Hindawi Advances in Meteorol. 2019 1-15
[32] Li L, Zhang R H, Wen M, Duan J P and Qi Y J 2019 Characteristics of the Tibetan Plateau vortices and the related large-scale circulations causing different precipitation intensity J. Theoretical and Applied Climatology 138 849–60
[33] Li Y Q, Yu S H, Peng J, Zhang H J, Xu W M, Xiao D X, Tu N N, Gao W L and Gu Q Y 2010 Tibetan Plateau Vortex and Shear Line Yearbook 1998 (Beijing: China Scientific Press) p 234
[34] Institute of Plateau Meteorology, China Meteorological Administration, Chengdu, and Plateau Meteorology Committee of Chinese Meteorological Society 2020 Tibetan Plateau Vortex and Shear Line Yearbook 2018 (Beijing: China Scientific Press) p 301
[35] Li G P, Lu H G , Huang C H, Fan Y Y, and Zhang B 2016 A climatology of the surface heat source on the Tibetan Plateau in summer and its impacts on the formation of the Tibetan Plateau J. Chinese J. Atmos. Sci. 40 132-41
[36] Yu S H , Tu N N and Gao W L 2018 Environmental fields analysis of a kind of Qinghai-Tibetan Plateau Vortex abnormal tracks J. Plateau Meteor. 37 686-701
[37] Li L , Zhang R H and Wu P L 2019 Evaluation of NCEP-FNL and ERA-Interim Data Sets in Detecting Tibetan Plateau Vortices in May–August of 2000–2015 J. Earth and Space Science. 7 e2019EA000907
[38] The Lhasa Focus Group on Tibetan Plateau Meteorology Research 1981 The Research of Vortex and Shear Line on 500 hPa of Tibetan Plateau in Summer Half Year (Beijing :China Meteorological Press) p 122
[39] Tao S Y 1980 Havery Rain of China (Beijing: Science Press) pp 25-34
[40] Qiao Q M 1987 The environement analysis on 500hPa vortexes moving out of Tibet Plateau in summer J. Plateau Meteor. 6 45-55
[41] Wang B 1987 The development mechanism for Tibetan Plateau warm vortices J. Amos. Sci. 44 2978-94
[42] San G W and Chen B D 1988 Dynamic processes of the moving and development LOWs on the Qinghai-Xizang plateau during the early summer J. Academy of Meteorol. Sci. 3 56-63
[43] Chang C.-P., Yi L and Chen G 2000 A Numerical Simulation of Vortex Development during
the 1992 East Asian Summer Monsoon Onset Using Navy’s Regional Model. *J. Mon Wea Rev.* **128** 1604-31

[44] Yu S H, Gao W L and Gu Q Y 2007 The Middle-Upper Circulation Analyses of the Plateau Vortex Moving Out of Plateau and Influencing Flood in East China in Recent Years. *J. Plateau Meteor.* **26** 466-75

[45] LIU L M, Deqing C M and Meng L X 2009 Analysis on a regional Heavy Rain Process in East of Gan su Province. *J. Arid Meteorology.* **27** 271-5

[46] Yu S H and Gao W L 2017 Circulation features of sustained departure Qinghai-Xizang Plateau vortex at upper tropospheric level. *J. Plateau Meteor.* **35** 1441-55

[47] Li C, Wang X F, Zhou L L, Cui C G, Jiang X W and Xu G R 2019 Cloud Features of Tibetan Plateau Vortex Category Cloud Cluster over Different Regions along the Eastward-Moving Path in Summer. *Adv. Meteorol., 2019* 1-15

[48] Lu E, Ding Y H, Murakami M and Takahashi K 1997 Nature of precipitation and activity of cumulus convection During the 1991 MeiYu season. *J. Acta Meteor. Sinica.* **55** 318-33

[49] Liu Y J, Ding Y H and Zhao N 2005 A study on the meso- scale convection systems During summer monsoon onset over the South China Seain 1998:1 Analysis of large- scale field for occurrence and development of meso- scale convection systems. *J. Acta Meteor. Sinica.* **63** 431-42

[50] Lu J H 1986 Introduction to the Southwest Vortex (Beijing :China Meteorological Pres) p 276

[51] Huang M C, Li J N, Nong M S and Huang J H 2010 An analysis of the mesoscale features of an excessive rainfall triggered low-shear line in the western part of South China. *J. Acta Meteor. Sinica.* **68** 748-62

[52] Chen Y R, Li Y Q, and Zhao T L 2015 Cause Analysis on Eastward Movement of Southwest China Vortex and Its Induced Heavy Rainfall in South China. *Adv. Meteorol.* **2015** 1-22

[53] Jiang J Y, Jiang J X, Bu Y L and Liu N Q 2007 Heavy rainfall associated with monsoon depression In South China:structure analysis. *J. Acta Meteor. Sinica.* **65** 537-49

[54] Ding Y H and Hu G Q 2003 A study on water vapor budget over China during the 1998 severe flood periods. *J. Acta Meteor. Sinica.* **61** 129-45

[55] Cheng X L, Li Y Q and Li X 2016 An analysis of an extreme rainstorm caused by the interaction of the Tibetan Plateau vortex and the Southwest China vortex from an intensive observation. *J. Meteorol Atmos Phys.* **128** 373–99

[56] Luo S W 1992 Study on some kinds of weather systems and around the Qinghai-Xizang Plateau (Beijing :China Meteorological Press) p 205

[57] Yu S H, Gao W L and Peng J 2015 Circulation features of sustained departure plateau vortex at middle tropospheric level. *J. Plateau Meteor.* **34** 1540–55