The multi-layer feature of atmospheric boundary layer surrounding a subtropical monsoon island

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Abstract

In this study, six isochronal radiosondes' observation with different vegetation patterns (urban cities, airport, harbor and remote islands) surrounding steep terrain of Taiwan island were collected to diagnose the vertical virtual potential temperature (θ_v) profiles and wind flow below 4000 m of atmospheric boundary layer (ABL). The sounding data from 2010 to 2011 was re-processed from original raw data and analyzed by monthly. The results show that multi-layer feature of ABL is more obvious in summer, and is less in spring. It is also evident in nighttime (12:00UTC+08:00) than daytime (00:00UTC+08:00), except the flat island site. This flat island site has more concentrated feature of ABL layers in spring and winter season with strong winter monsoon flow. The highest diversity of ABL layers happens at the southern plain of Taiwan and CMR mountain foot in summer. Local thermal convective effect of land and vertical structure of wind field under winter-summer-reversed synoptic monsoon system play the important roles on multi-layers feature of ABL.

1. Introduction

The seasonal and daily evolution of atmospheric boundary over land and ocean is one of the main validation issues on numerical weather modeling. The depth of ABL is also one of the key factors on local wind circulation phenomenon and plant pollutant dispersion. Development of ABL is affected by topography, thunderstorms (Schafer et al.,2001), ground/sea surface temperature (Tanimoto et al.,2009) and so on. Radiosonde measurement is the major tool to detect the vertical profile of ABL worldwide for a long time. New devices, like Lidar and aircraft, were also studied to detect ABL (Hennemuth and Lammert, 2006; Matthews et al.,2007). Seidel et al. (2010) reviewed 10-year, 505-station radiosonde data and discussed seven methods for the boundary height estimation. They found ABL height is sensitive to vertical resolution of radiosonde data and high resolution of radiosonde derive lower ABL height.

Taiwan, located at western Pacific coast region, is a mountainous island bisected by the Tropic of Cancer and has 300-km north-south stretch of the Central Mountain Range (CMR) with more than 50 peaks above 3,000 m (Figure 1). The weather and climate of Taiwan are strongly affected by the circulation of the Eastern Asia winter and summer monsoon. These prevailing monsoon systems provide unique background environment for ABL developing surrounding this north-south stretching and steep terrain of island. The radiosonde network operated by different governmental agencies and universities in Taiwan had different types of radiosonde system before 2010. The geo-location of these radiosonde sites is shown in Figure 1. Two field campaign of radiosonde inter-comparison at Banchiao, Taipei, Taiwan were organized by first author in 2008 (Lin et al.,2008). They found the deviation among these different radiosondes' measurement, on wind vector and humidity, is significant. Fortunately, all the radiosonde systems in Taiwan come to the same manufacturer after August of 2010 and same type of radiosonde, is launched for meteorological and environmental monitor. This situation skips the error induced by different types of radiosonde sensor and encourages us to explore the vertical profiles of atmosphere surrounding this steep island.

The goal of this study is to analyze the highest resolution of radiosonde profiles from the surface to 4000m height around Taiwan Island. We expect more feature of ABL phenomena at this subtropical monsoon island could be presented for reference.

2. Data source and collation

These upper-air sounding observations operated by Central Weather Bureau of Taiwan, Air Force weather stations and the project-oriented field campaigns have distance less than 150 km to each other. All the radiosondes are the same type (Vaisala RS92-SGP) with in 1~2 seconds sampling rate from surface up to ~20 km height, and were processed into 25-m interval for sites' comparison. These balloon radisonde sounding sites surrounding Taiwan are marked in Figure 1 and Table 1. Banchiao site (code 46692) locates in the Taipei basin (Capital of Taiwan) which is the north end of CMR. Hualien site (code 46699) locates besides the eastern foot of CMR and closes to Pacific coast. Pingtong site (code 46750) locates in Ping-nan Air Force airport, south-eastern plain side of CMR. Another two small island sites are in Penghu airport (code 46734, central of Taiwan Strait, flat island), and at a hill top of Green Island (code, 46780, south-eastern side of CMR). Some radisondes were launched for project-oriented at Taichung Harbor (code 46777) and Taichung city center (code 46749), located on the western plain of CMR. Due to the humid climate feature in Taiwan (e.x., the annual precipitation in 2012 is near 3000 mm at Taipei), we decided to use virtual potential temperature (θv) profile, one of the seven methods discussed by Seidel et al. (2010), to identify the ABL layers by temperature and humidity factors together. The vertical gradient and curvature of θv are used together to detected the height of ABL layers. Wind vector will be analyzed to identify the patterns of synoptic weather systems.

3. Results and discussion

Under winter monsoon season, north-eastern (NE) cold flow hits Taiwan below 700hPa level (~3000m). Above 700hPa, the western wind of north hemispheric circulation is the major synoptic character over Taiwan. CMR blocks NE monsoon flow and produces wet stratus cloud at north and eastern side of CMR (46692, 46699). Dry and weak air appears at western and south-western plain of CMR (46999 and 46750). But the weather over Taiwan Strait (46734) and the western coast (46780) of Pacific Ocean is still windy and wet. Figure 2 shows the wind vectors in January from 500m to 4000m above these sites. The transition layer between ABL and free atmospheric layer could be identified clearly from the significant clockwise change of wind direction. The height of wind transition layer is about 2000m in wintertime at upslope side of CMR (46492, 46699) and becomes higher (~2500m) at south-eastern coast of CMR (46780). The wind flow at downslope side of CMR (46750) is weak below 2500m and appears abrupt strong south-western wind flow above 3000m. The weakness of NE monsoon wind happens in spring (April) at all radiosonde sites (Figure 3), but the strong western wind is still strong above ABL.

During summer monsoon season (June to August), local weather systems are related to land-sea breeze, thunderstorms over slope of CMR and tropical storms from Pacific Ocean occasionally. The vertical feature of wind vector from June to August might change a lot (not shown) at each site, but is similar to each other in July. The south-western (S-SW) monsoon flow covers all of Taiwan Island (Figure 4). Seasonal change from S-SW wind back to NE wind happens in September at ocean sites (46734 and 46780) and delays into October at land sites (46692, 46699) in Figure 5. But the site of 46750 has specific wind pattern at autumn season. Its large anti-V shape plain area CMR and ocean provide week feature of land-sea breeze circulation below 4000m.

The heights of the most-obvious and second-obvious turning points along θv profile were used to identify how evident the multi-layer feature below 2000m. Figure 6 to Figure 10 give the seasonal scattering diagrams of these two turning-point heights at each site. The characteristics in these figures are: (1) multi-layer feature of ABL is more evident in summer, and is less in spring. (2) nighttime (12:00UTC+08:00) is more obvious than daytime (00:00UTC+08:00), except 46734. (3) the flat island in Taiwan Strait (46734) with strong NE monsoon wind has more concentrated feature of these two heights in spring and winter. (4) highest diversity of these heights happens at the southern plain of Taiwan (46750) and CMR mountain foot site (46699) in summer. These messages from θv profile reveal the contribution of thermal convective effect of land on ABL development. Vertical structure of wind field above different landscapes with winter-summer-reversed synoptic monsoon system also plays the important role on local ABL feature. These observed features surrounding Taiwan could be treated as the critical validation of high-resolution models' simulation.

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Table 1: The information of balloon radiosonde sounding sites in this study.

Name (code)	Latitude, Longitude	Altitude (m)	Landscape	Organization*
Banchiao (46692)	24.99N, 121.88E	16	Urban Basin	CWB
Hualien (46699)	23.98N, 121.61E	19	Mountain foot	CWB
Penghu (46734)	23.57N, 119.63E	38	Flat island	CAF
Pingtong (46750)	22.68N, 120.47E	25	Plain airport	CAF
Green Island (46780)	22.01N, 121.48N	253	Hill of island	CAF
Taichung Harbor (46777)	24.26N, 121.52E	6	Flat port	NTU
Taichung City (46749)	24.18N, 120.65E	105	Urban basin	NTU

*CWB: Central Weather Bureau

*CAF: Chinese Air Force

*NTU: National Taiwan University

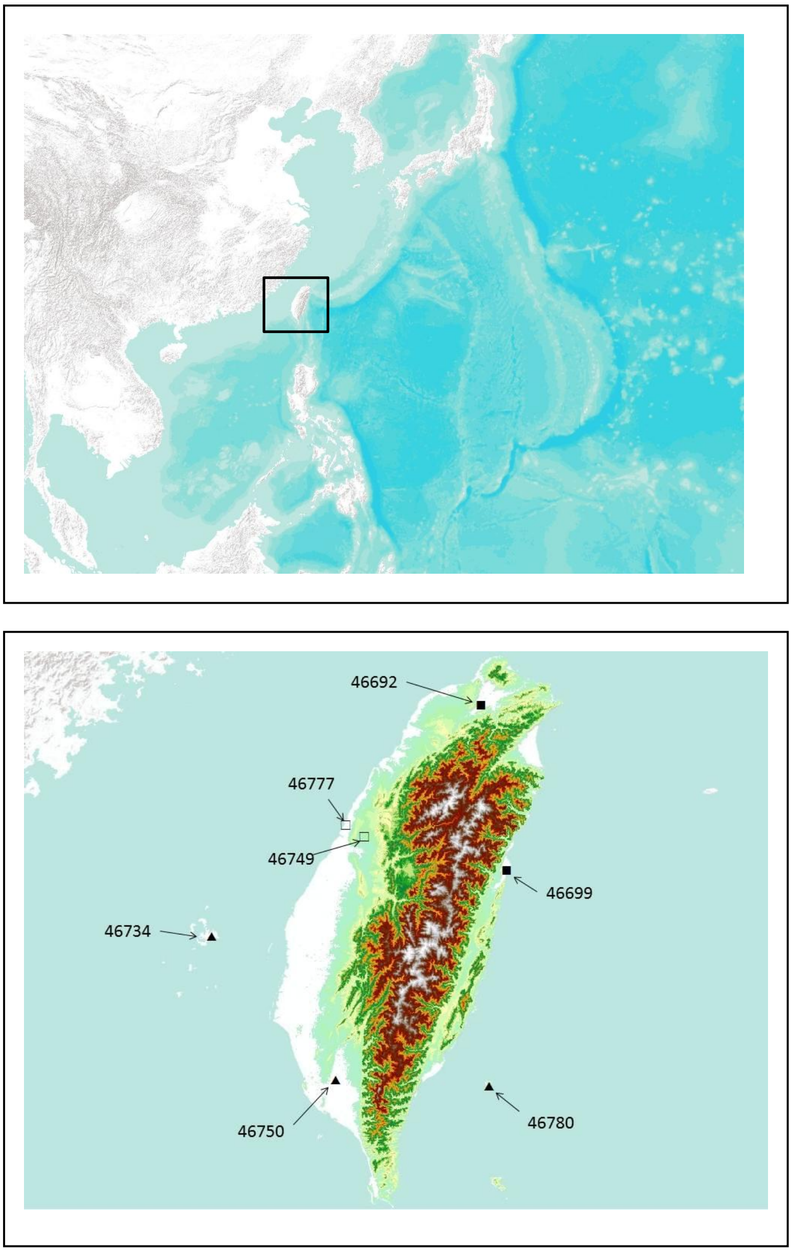

Figure 1: the geo-location of Taiwan and the radiosonde sounding sites with code.

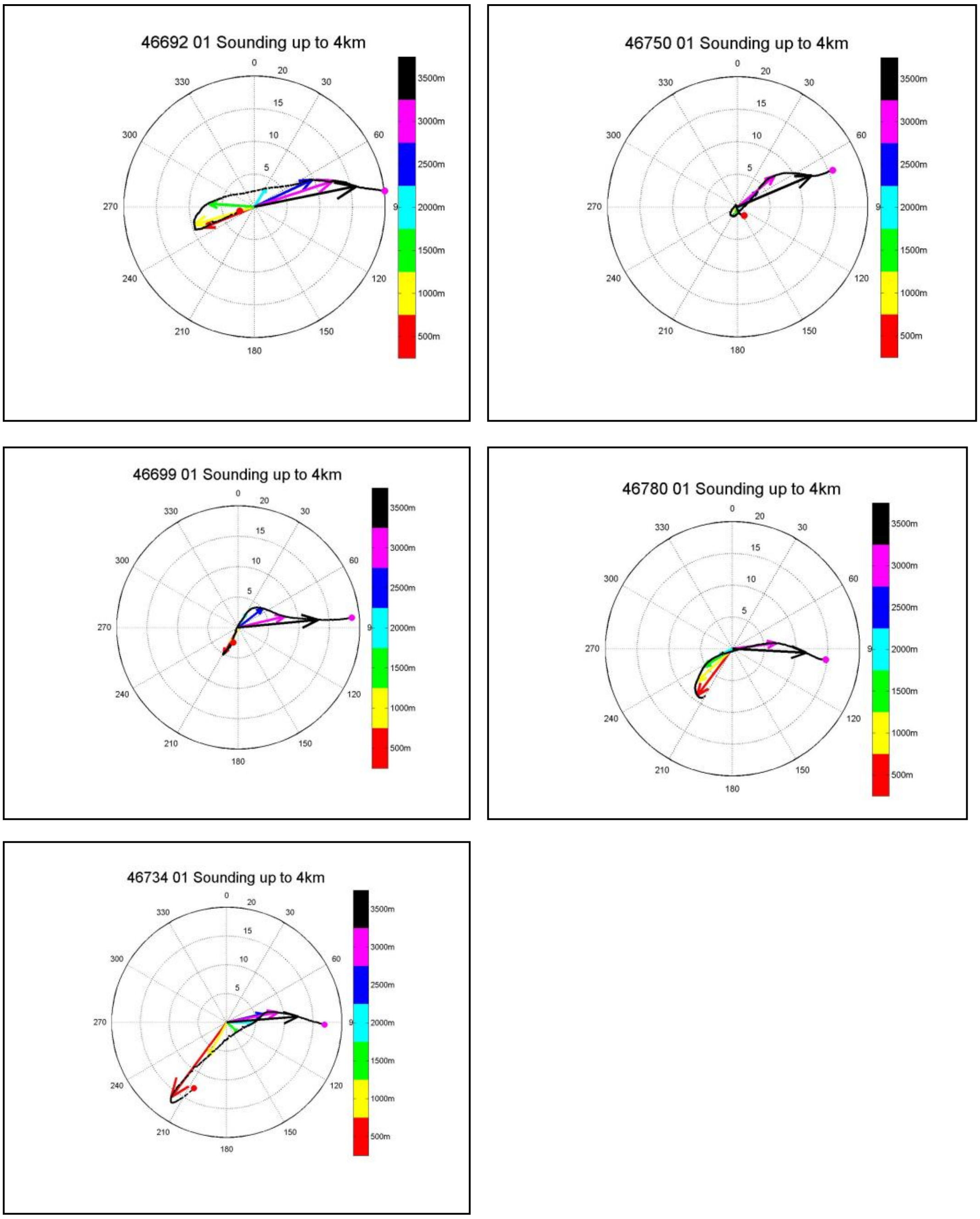

Figure 2: The vertical change of wind vector from 500m to 4000m with 500m interval at 46692, 46699, 46734, 46750 and 46780 in January (2010-2011).

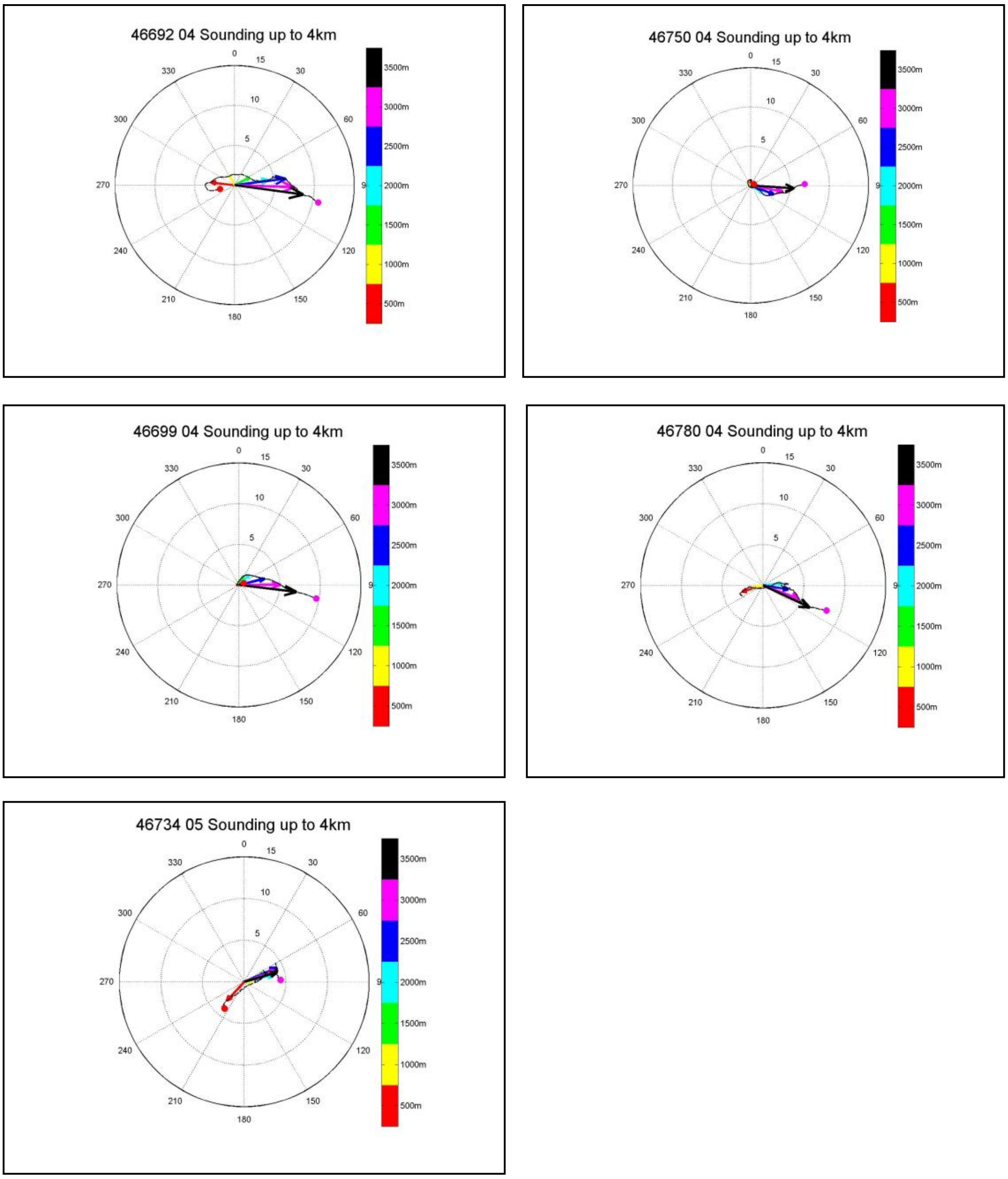

Figure 3: same to Figure 2, but is April (2010-2011). The radisonde system at 46734 was shut down temporarily in April. The wind vector is replaced by May.

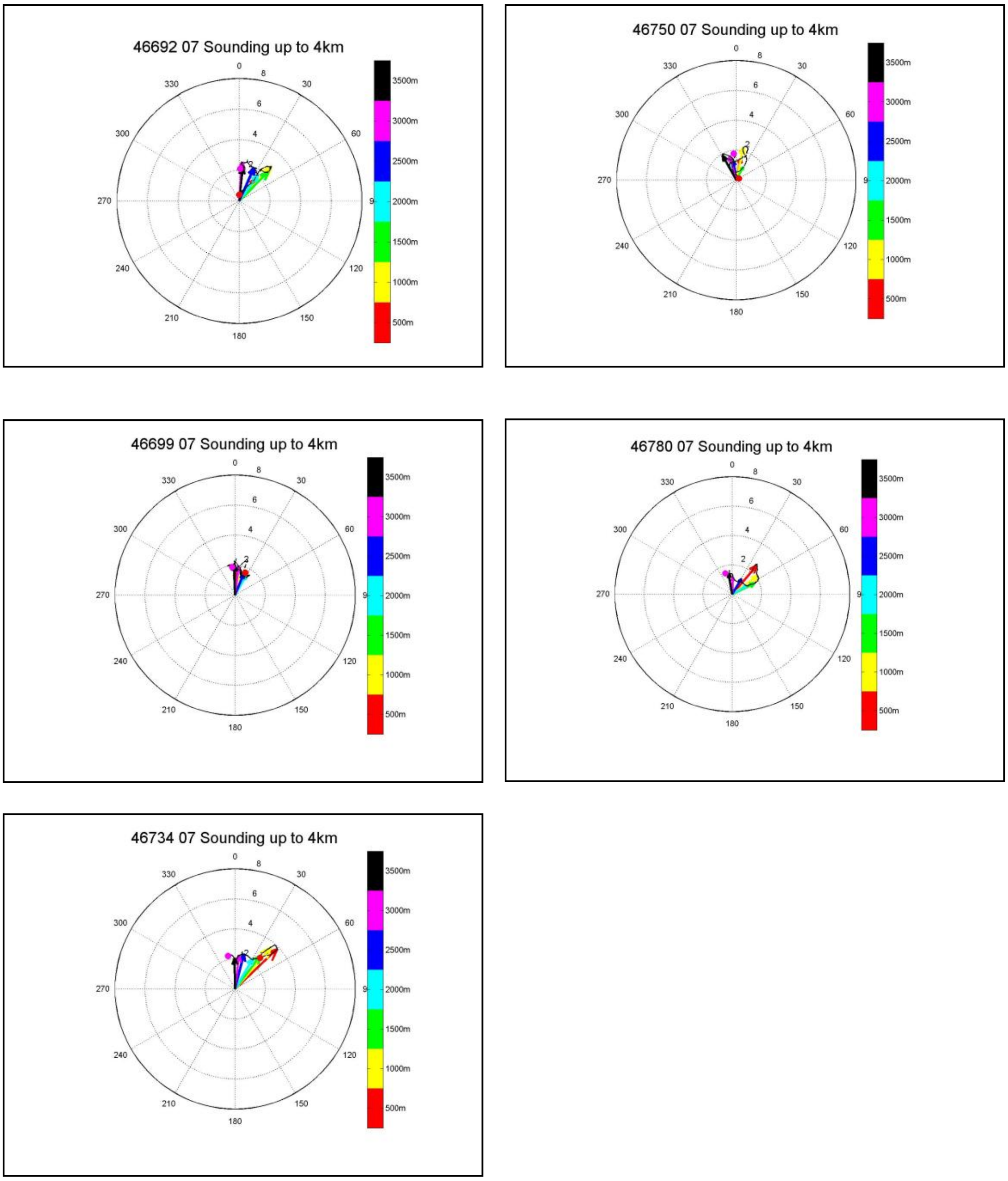

Figure 4: same to Figure 2, but is July (2010-2011).

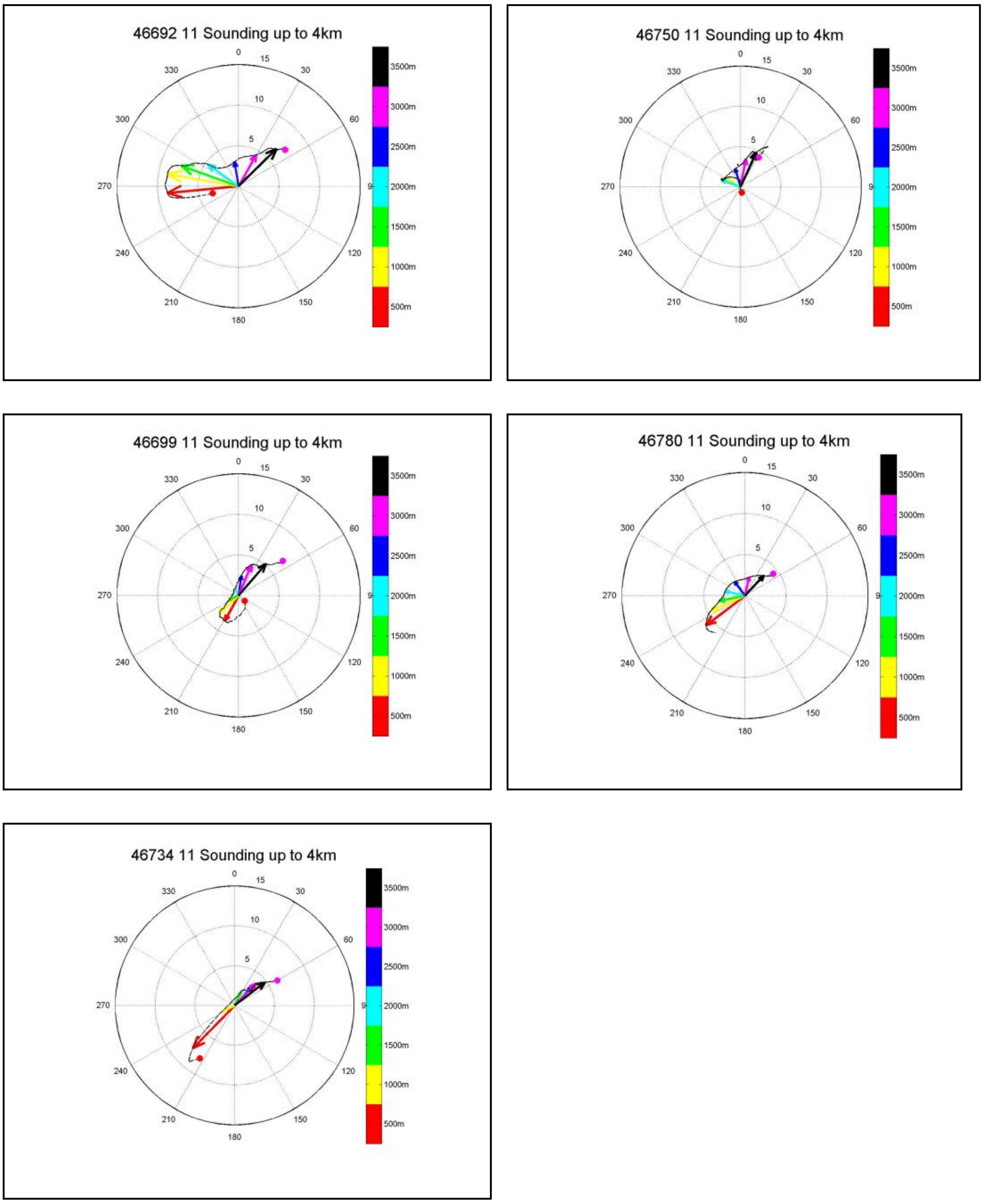

Figure 5: same to Figure 2, but is November (2010-2011).

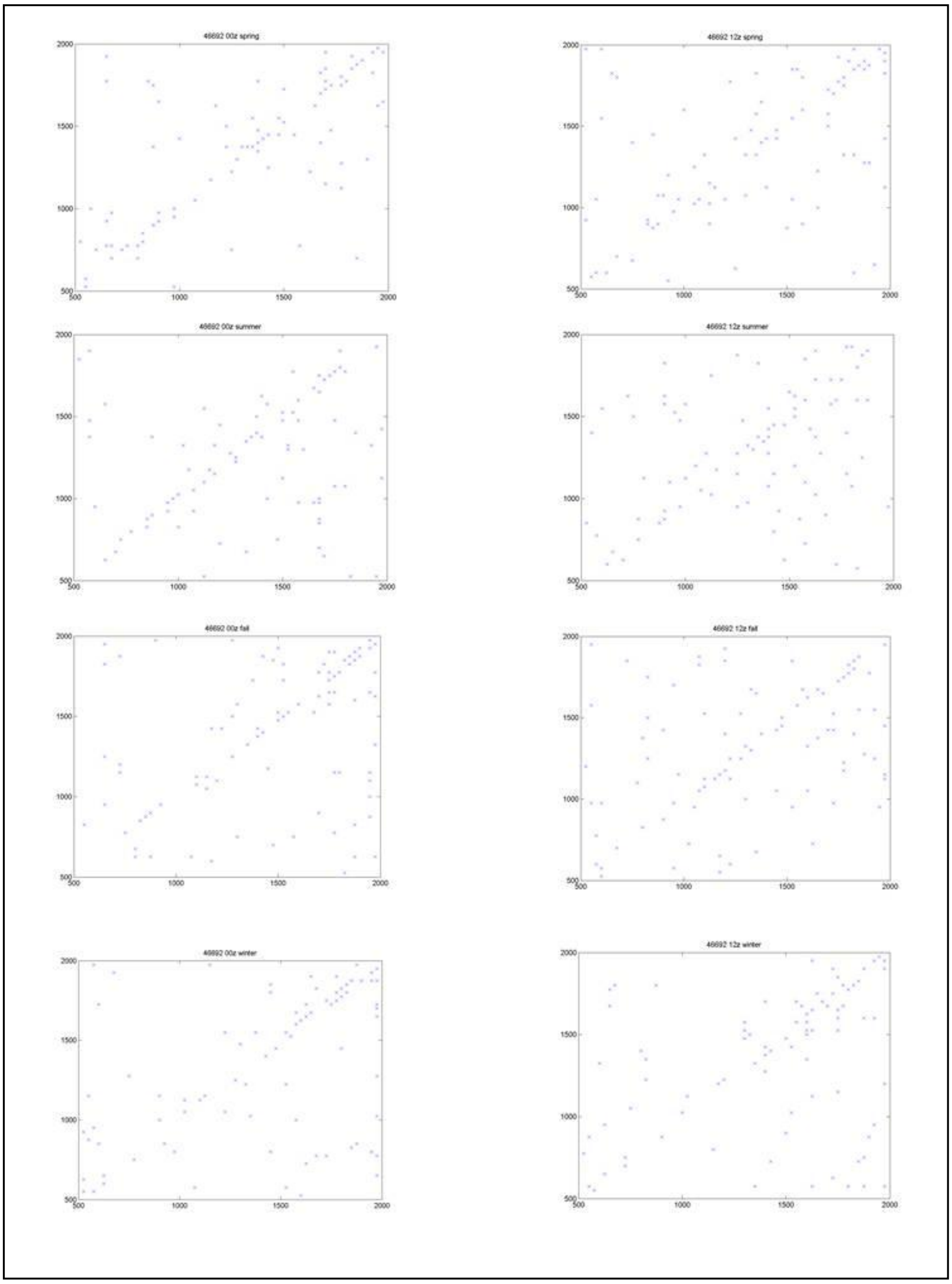

Figure 6: The seasonal scattering diagrams at 46692 site between heights of the most-obvious (X axis) and second-obvious turning point (Y- axis) along θv profiles below 2000m. Left panel is daytime (00:00UTC+08:00) and nighttime (12:00UTC+08:00) is on the right panel. Up-to-down panels are spring, summer, autumn and winter season.

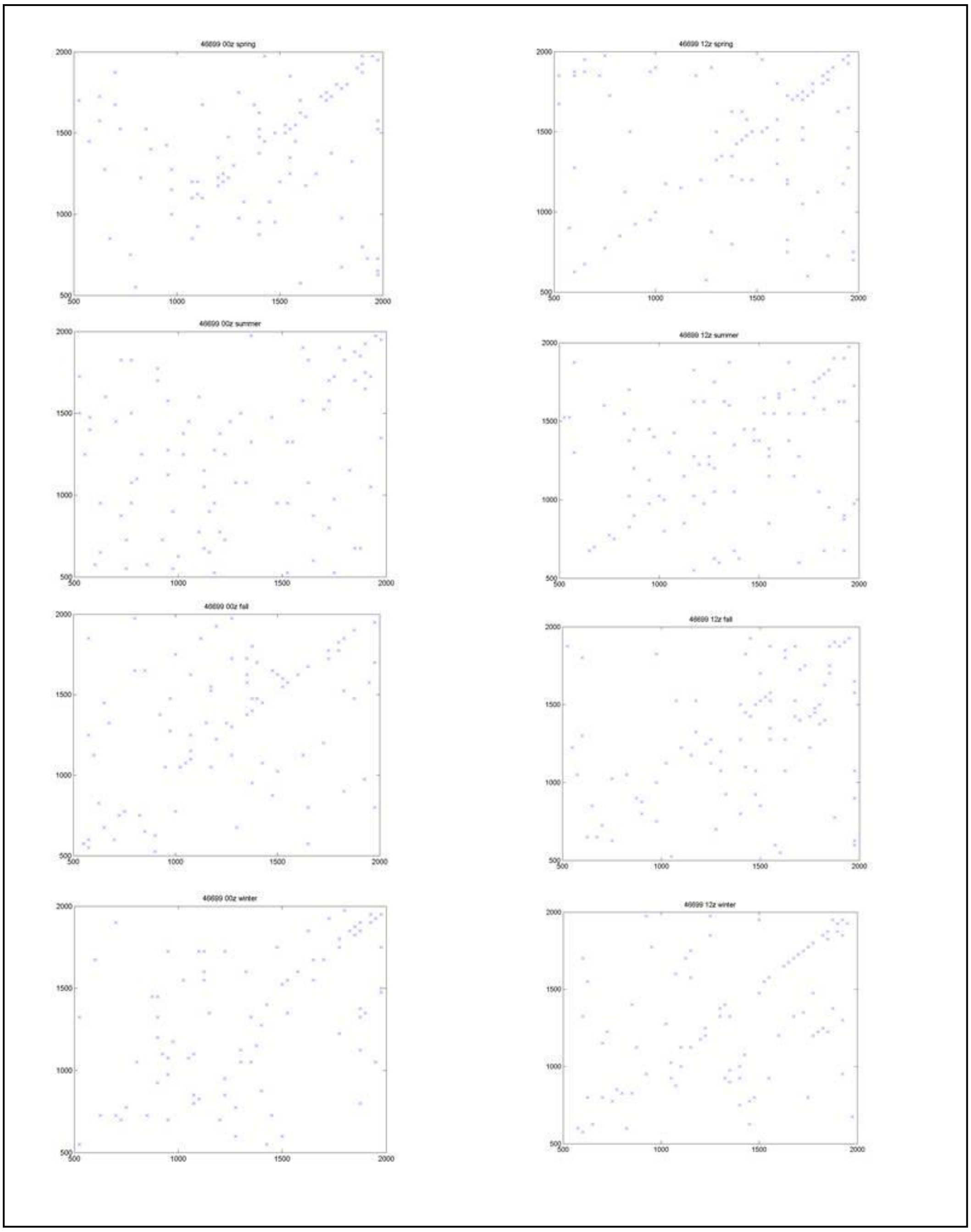

Figure 7: same as figure 6, but at the site of 46699.

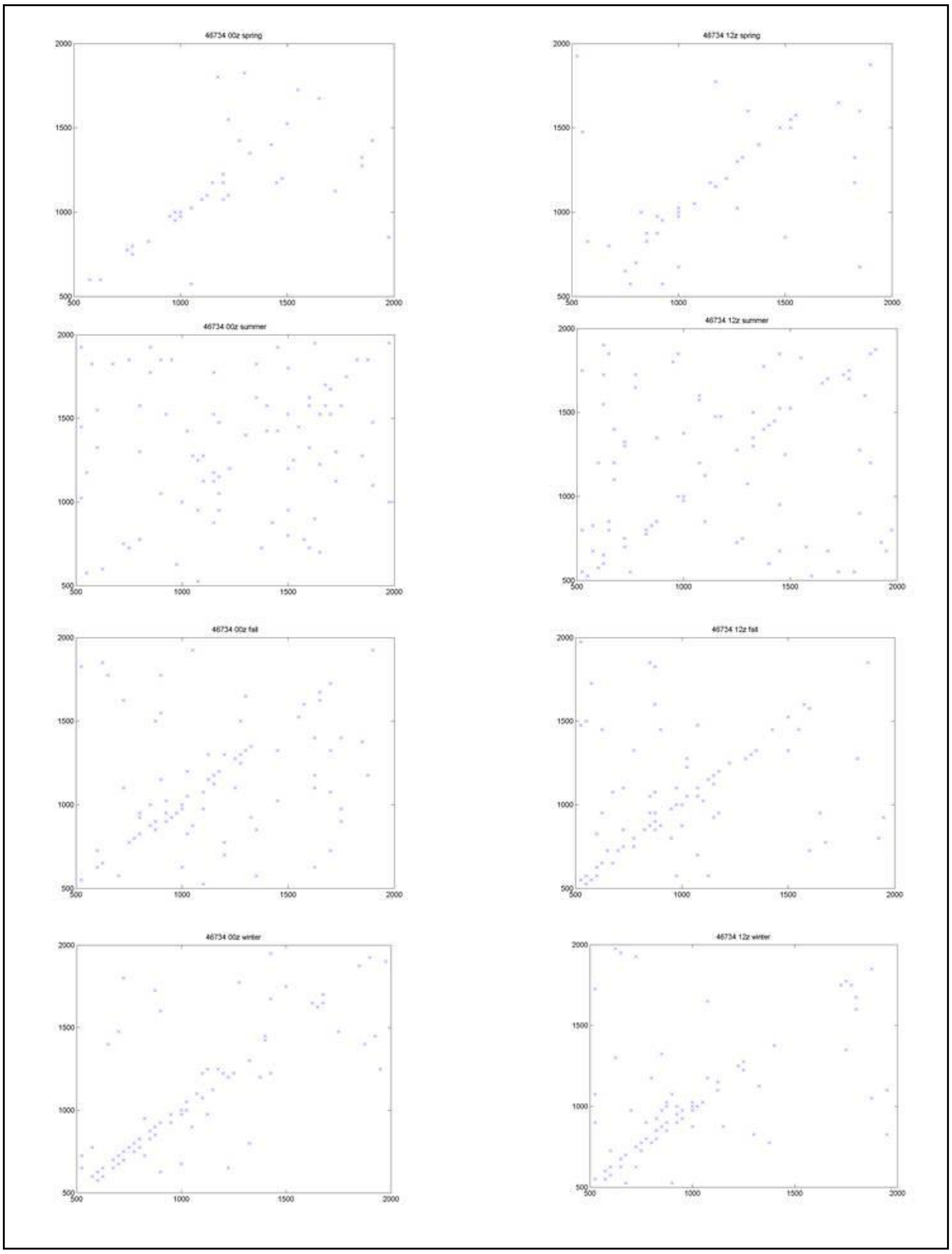

Figure 8: same as figure 6, but at the site of 466734.

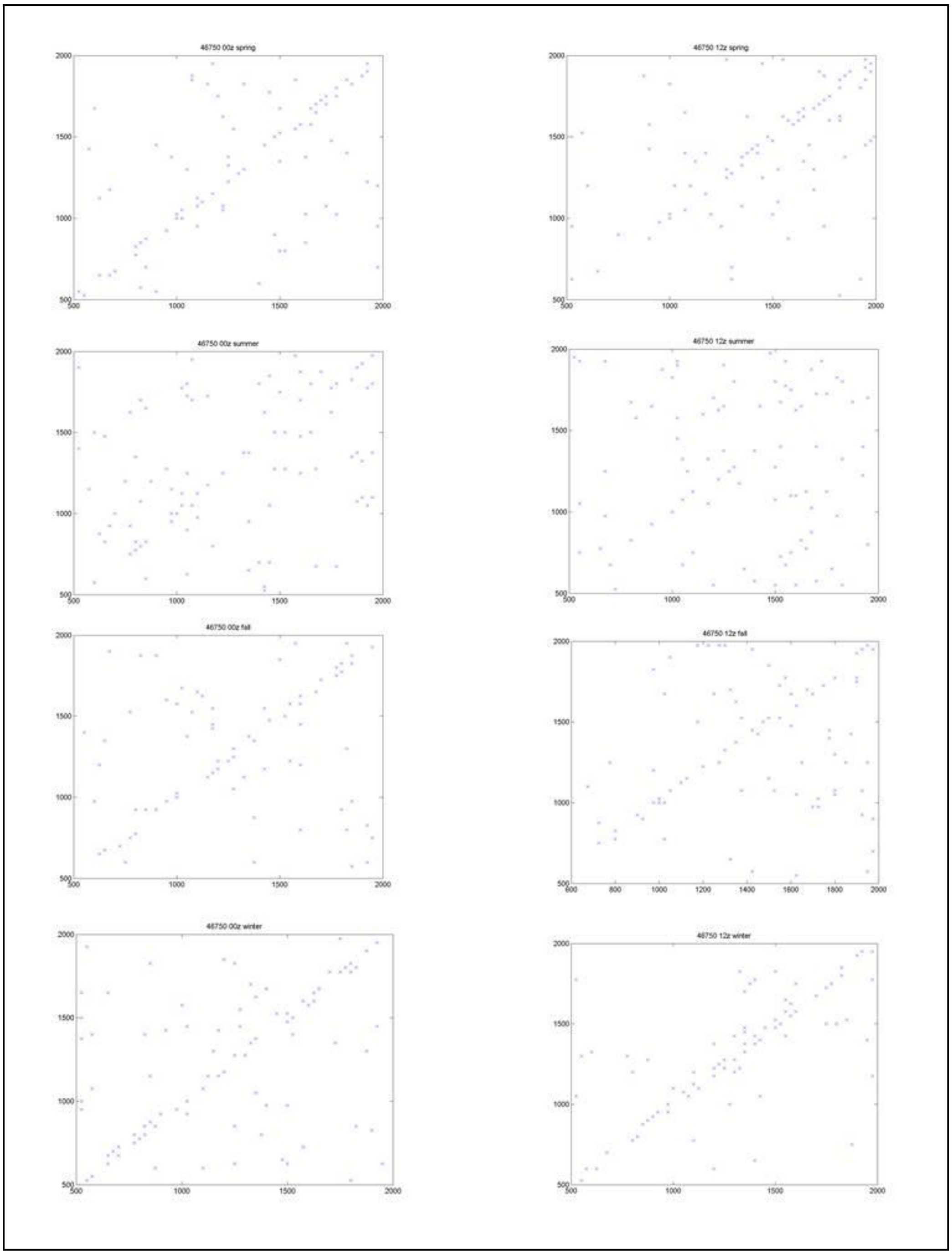

Figure 9: same as figure 6, but at the site of 46750.

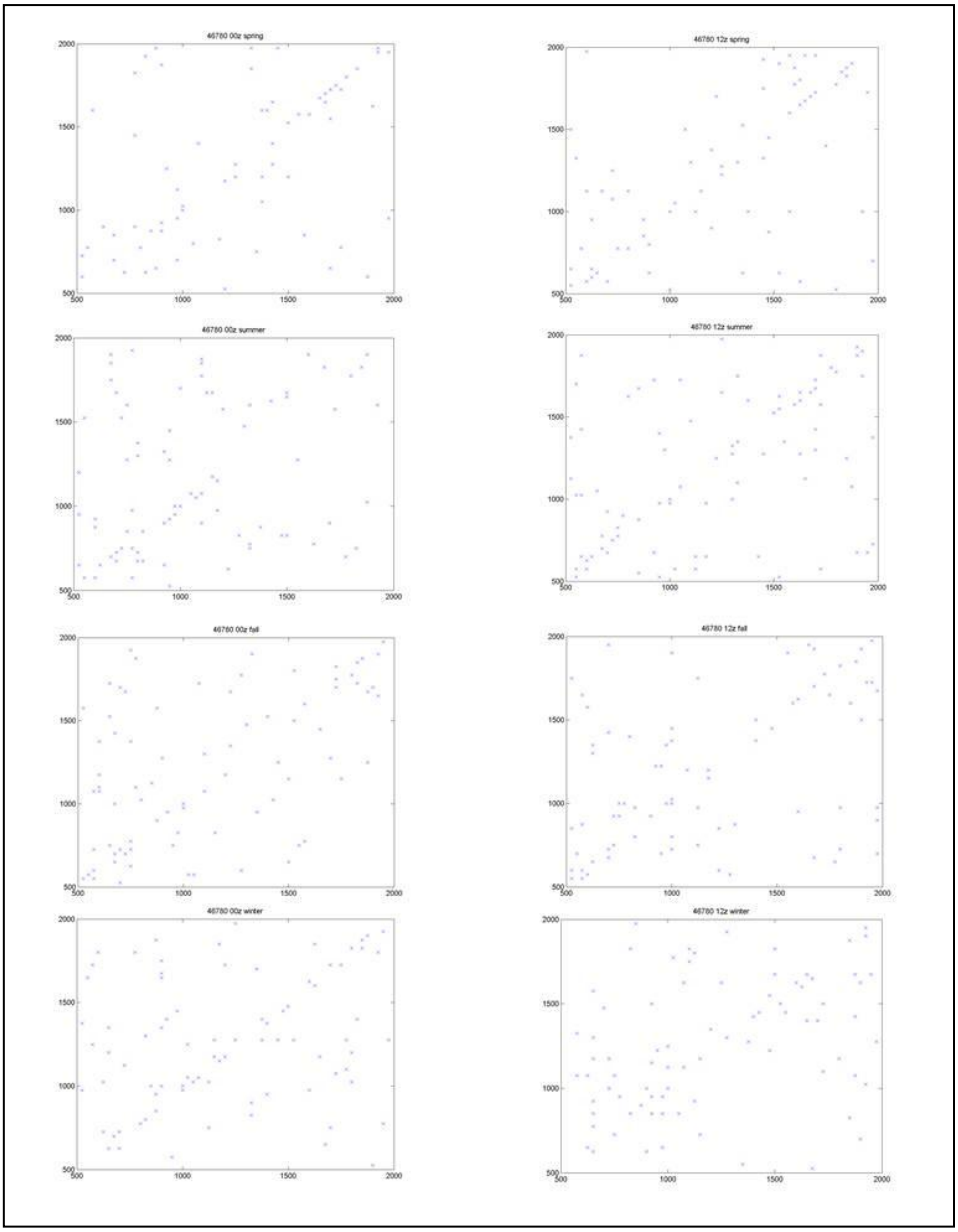

Figure 10: same as figure 6, but at the site of 46780.