The PANDA automatic weather station network- between the coast and Dome A, East Antarctica

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Abstract: This paper introduces a unique multiyear dataset and the monitoring capability of the PANDA automatic weather station network which includes eleven automatic weather stations (AWS) across Prydz Bay-Amery Ice Shelf-Ddome A area from the coast to the summit of the East Antarctica ice sheet. The ~1460 km transect from Zhongshan to Panda S station follows roughly along ~77° E longitude and covers all geographic and climatic units of East Antarctica. Initial inland observations, near the coast, started in the 1996/1997 austral summer. All AWSs in this network measure air temperature, relative humidity, air pressure, wind speed and wind direction at 1-hour intervals, and some of them can also measure firn temperature and shortwave/longwave radiation. Data are relayed in near real-time via the ARGOS system. Data quality is generally very reliable and the data have been used widely. In this paper, we firstly present a detailed overview of the AWSs, including the sensor characteristics, installation procedure, data quality control protocol, and the basic analysis of each variable. We then give an example of a short-term atmospheric event that shows the monitoring capacity of the PANDA AWS network. This dataset, which is publicly available, is planned to be updated on a near-real time and should be valuable for climate change estimation, extreme weather events diagnosis, data assimilation,

weather forecasting, etc. The dataset is available at https://doi.org/10.11888/Atmos.tpdc.272721 (Ding et al., 2022).

1. Introduction

Antarctica, covered by a vast ice sheet, has the coldest climate on Earth's surface (Qin and Ren, 2001; Van den Broeke and Van Lipzig, 2003; Zhou et al., 2009). Great efforts have been made to study Antarctic climate change under global warming because of its role in the climate system and its capability~~capacity~~ to greatly impact global sea level rise (IPCC, 2019; Huai et al., 2019). However, the reliability of Antarctic climate change estimation and weather forecasting is still under debate (Hines et al., 2019; Zhang et al., 2021). This is a consequence of the paucity of observations, especially at long term inland weather stations, which can be directly assimilated in to models and reanalysis data (Vignon et al., 2017; Wei et al., 2019).

The first attempt at automatic weather station (AWS) observations in Antarctica was in 1956/57, when station XG1 was deployed by the United States near McMurdo; but this station was short lived (Lazzara et al., 2012). Early attempts at AWS observations were also made off the coast of East Antarctica by the Australian National Antarctic Research Expedition (ANARE) at Chick Island (in 1961) and Lewis Island (in 1962). Both these stations were also short lived.

Development of automatic observational technology in polar regions was greatly advanced with initiation, in 1978, of the ARGOS data relay system on polar orbiting satellites. This, together with more robust and power-efficient electronics, saw successful Antarctic AWS deployments by the University of Wisconsin, USA, commencing in 1980. The Australian Antarctic Division (AAD) also tested its design of AWS at near-coastal sites in 1980 and deployed its first successful station on the inland ice sheet, at 1830 m elevation, in January 1982 (Allison and Morrissey, 1983). Subsequently, more and more Antarctic AWSs were installed: ~30 by 1990, ~55 by 2000, ~60 by 2010 and ~160 by 2020 (Bromwich et al., 2020). Many of these were installed as part of a United States network on the Ross Ice Shelf, inland from the Adélie Land coast for a study of katabatic wind flow, and at other interior ice sheet sites (Lazzara et al., 2012). During the International Antarctic Glaciological Project traverses from Casey station, ~~a number~~ of ANARE AWSs were deployed on the ice sheet, along about 110°E to 3096 m elevation. Australian glaciological traverses between Mawson and Zhong~~ S~~shan ~~stations~~ deployed 5 AWSs at 2500 m elevation around the interior of the Lambert Glacier Basin (LGB), between 1990 and 1994 (Allison et al., 1993; Allison, 1998; Heil, 2006). Further west in eastern Dronning Maud Land, stations were built and deployed on the ice sheet by Japan at Dome Fuji (in December 1993) and Relay (in January 1993) (Enomoto et al.,1995). To extend knowledge of the near-surface climate and heat budget of Antarctica, Netherlands started to deploy AWSs in western Dronning Maud Land in January 1997 (Reijmer and Oerlemans, 2002).

Several of the AWSs mentioned failed after a relatively short time, and those in high accumulation near-coastal areas became buried by snow. But quite a few continued to provide high-quality data for many years. For example, the Australian AWS at GC41, inland of Casey at 2760 m elevation, provided good data for more than 21 years until eventually buried, although it was never visited for maintenance. The interior ice sheet with low accumulation, relatively low wind speeds, and no liquid water is ~~actually a~~a benign environment for electronic systems if properly designed for very low temperatures. The higher latitude sites also see more transits of polar-orbiting satellites carrying the ARGOS data relay system.

These AWS observations have made valuable contributions to Antarctic research. Firstly, the data have been used to evaluate weather and climate changes (Turner et al., 2005; 2007; Wei et al., 2019; Wang et al., 2022). For example, Schwerdtfeger (1984) gave a brief characterization of the inland Antarctica climate from AWS data. Allison et al (1993) analyzed the influence of ice sheet topography on surface meteorology using 10 AWSs from both the US-French network in Adélie Land and the Australian network inland of Casey. Secondly, AWS data, including radiation measurements, can be used to investigate ice/snow-atmosphere interaction processes in Antarctica. Van den Broeke et al. (2004a; 2004b; 2005; 2006) studied the daily and seasonal variation of the surface energy balance in detail in Dronning Maud Land. Ding et al. (2020; 2021a) improved the surface energy balance simulation scheme at Dome A and the inland Antarctic area with long term AWS measurements. Thirdly, AWS observations are also critical in evaluating the applicability of reanalysis data and numerical models in Antarctica. Nigro et al. (2011) estimated the performance of Antarctic Mesoscale Prediction System (AMPS) under varied synoptic conditions with AWS data for the Ross Ice Shelf. Xie et al (2014) assessed the accuracy of daily mean surface pressure from different meteorological reanalyzes against in situ observations from automatic weather stations in East Antarctica. Dong et al. (2020) evaluated the robustness of near-surface wind speed of multiple global atmospheric reanalysis in Antarctica based on many AWS and meteorological observations made at staffed stations. Recently, Wei et al. (2019) and Turner et al. (2020) used multiple meteorological records to give the spatial/temporal distribution of temperature extremes across Antarctica for the first time.

However, most staffed observational sites and AWSs in Antarctica are still mainly located in the coastal area, and data from the sparse inland sites is interrupted frequently (e.g., the anemometer was often frozen during austral winter at Eagle~~,~~ and Dome A) (Wendler et al., 1988; Van As et al., 2005; Zhou et al., 2009; Lazzara et al., 2012; Sun et al., 2018; Bromwich et al., 2020). More continuous and systematic AWS observation, are still required from Antarctica.

Commencing in the 1996/1997 austral summer, the Chinese National Antarctic Research Expedition (CHINARE) started deploying AWSs between the coastal Zhongshan and inland Panda S (the PANDA transect).The first stations ~~was~~ deployed on this transect were manufactured by the ~~Australian Antarctic Division~~AAD, but after 2012, the Chinese Academy of Meteorological Sciences made great progress in AWS design, especially the ultra-low temperature power supply system (patent for invention, Ding et al., 2021b), and deployed 7 further AWSs along the PANDA transect.

Initial studies using these observations focused on the coastal area or a single site (e.g., van den Broeke et al., 2004a; 2004b; Chen et al., 2010) while later studies used data from more inland stations (Ma et al., 2010; Ding et al., 2021a). Only a few studies have used meteorological information (shown in Table~~.~~ 1) from the whole transect (Zhou et al. 2009; Ma et al. 2010; Bian et al. 2016). That is because only 5 of the initial AWSs were still operating~~ed~~~~survived~~ ~~till~~ in 2012 (~~include~~ Dome A, Eagle, ~~and~~ Panda N, Zhongshan and Panda S), others had~~ve~~ been buried by snow accumulation or ~~stop operation~~failed due to low air temperature (Ding et al., 2021a). ~~, and s~~Subsequent~~ly~~ AWSs have been installed close to the~~ir~~ locations of the failed stations to extend the measurements (e.g., Panda 200 was installed close to LGB69). ~~These were Dome A, Eagle, and Panda N (Australian Antarctic Division), Zhongshan and Panda S (Chinese Academy of Meteorological Sciences).~~ The more recent deployments now provide ~~a~~ consistent, high quality and real time meteorological observations from the PANDA AWS network. Some data from the PANDA AWS network have been compiled by WMO (e.g., Dome A ID: 89577, Eagle ID: 89578, Kunlun ID: 89572, Taishan ID: 89576) and some are available as monthly means from the Scientific Committee on Antarctic Research (SCAR) Reference Antarctic Data for Environmental Research (READER) (https://www.bas.ac.uk/project/reader/~~http://www.antarctica.ac.uk/met/READER/~~). But most of these data have not been published before. Here, ~~in order to~~to promote and make available the value of these AWSs data, we provide metadata of the dataset that will be updated ~~on a~~in near-real time ~~in A~~on the platform "Big Earth Data ~~Platform~~ for Three Poles" (http://poles.tpdc.ac.cn/zh-hans/). We also provide an overview of the climate characteristics of the ~~site~~region.

2 Observation region and data pre-processing

2.1 Observation region and site descriptions

The PANDA transect is approximately along 77° E longitude, and stretches approximately 1460 km from the coast at Zhongshan to the ~~dome region at~~ Dome A, region at the summit of the East Antarctic Ice Sheet. This transect is highly representative of East Antarctica~~ highly,~~ for it covers Prydz Bay, Lambert Glacier/Amery Ice Shelf, high inland and dome summit regions. According to Zhang et al. (2008) and Ding et al. (2011), the PANDA transect can be divided into three typical topographies: a coastal region characterized by steep terrain (corresponding to Zhongshan to Panda 200), an inland region with strong katabatic wind (Panda 300 to Eagle), and a dome region (Panda 1100 to Panda S). ~~The PANDA transect includes almost all the climate types in East Antarctica.~~

The PANDA AWS network had 11 AWSs in operation in 2022: Zhongshan, Panda 100, Panda 200 (LGB 69), Panda 300, Panda 400, Taishan, Eagle, Panda 1100, Dome A, Kunlun and Panda S. All of them are located on the western side of the ~~Lambert Glacier Basin~~LGB (Fig. 1), at different latitudes (69° S-83° S) and at different elevations (detailed information can be found in Table 1). The first site, Zhongshan was established in March 1989, when CHINARE first arrived in East Antarctica (Zeng et al., 2021). It was initially a Staffed Weather Station but has now ~~has~~been replaced by an AWS. LGB 69 (192 km from the coast) was first deployed in January 2002 during the AAD Lambert Glacier Basin traverse. This station was in a region of high ice velocity (17.7 m a^{-1}) and high accumulation rate (199 kg m^{-2} a^{-1} for 2002-2003) (Zhang et al., 2008; Ma et al., 2010; Ding et al., 2011; 2015) and it became buried approximately every 3 years, requiring digging up and redeploying on the surface. It stopped operating by 2008 (Ding et al., 2021a). Since it was difficult to maintain an AWS at the original site, PANDA 200 was deployed 200 km from the coast in December 2016, and is considered as a replacement AWS for LGB 69. In January 2005, Eagle and

Dome A were installed during the CHINARE 21~~th~~st which reached the summit of East Antarctic Ice Sheet, ~1248 km from the coast~~,~~. ~~the observed lowest air temperature was -80.36 °C (0300 UTC, 3 September 2007) at height of 4 m on Dome A.~~ Then in January 2008, Panda S was deployed in cooperation with the University of Wisconsin as a contribution to the International Polar Year, but this AWS has ~~been~~ only operated intermittently~~intermittent~~. The other AWSs ~~were deployed during 2012 and 2019, and~~ were manufactured by the Chinese Academy of Meteorological Sciences and were deployed during 2012 (Taishan) and 2019 (Panda 100, Panda 300, Panda 400). The hourly data from the all AWSs are remotely collected and relayed in near real-time ~~only~~ by the ARGOS System ~~and not saved internally~~. The data is not stored internally.

It should be noted that these AWSs are of several different designs for different scientific purposes. All include sensors for air temperature (T_a) and wind speed (*WS*), initially at 1, 2, 4 and/or 6 m ~~height~~ above surface ~~(the surface height and station tilt are not part of the monitored variables, all sensors height in this paper is initial height from build stations)~~, and wind direction (*WD*), relative humidity (*RH*) and air pressure (*P*). Sensor height above the surface and station tilt are not part of the monitored variables, and all sensor heights in this paper are the heights at initial deployment. Panda 300, Taishan, Eagle and Dome A AWSs are also equipped with surface and firn temperature probes (detailed information can be found in Table 1). The Zhongshan is designed to WMO service regulation so the initial height of wind measurement is 10 m.

~~The Chinese Academy of Meteorological Sciences designed AWSs use a HMP155 resistance probe to measure air temperature and relative humidity; Panda S and which uses a Weed PRT 2-wire bridge and Vaisala HMP35A; and Eagle and Dome A use FS23D thermistors and HMP35D humidity probe (Xiao et al., 2008).~~ The AWSs that were designed by the Chinese Academy of Meteorological Sciences use a Vaisala HMP155 resistance probe to measure air temperature and relative humidity. Panda S use a Weed wire bridge and Vaisala HMP35A. Eagle and Dome A AWSs use FS23D thermistors and HMP35D humidity probes (Xiao et al., 2008). The Vaisala HMP15 is an integrated air temperature and relative humidity sensor ~~is an integrated sensor, which itself considers the conversion of ice and water form~~ and automatically accounts for whether RH is relative to water or ice. ~~The air pressure is single-layer at most stations (except Panda 300).~~ The air pressure ~~of~~ sensor for Eagle and Dome A is ~~measured by~~ a Paroscientific 6015A. Panda 100 and Taishan use Vaisala PTB110 and Zhongshan uses Campbell Scientific CS106 to measure air pressure. A Paroscientific Model 215A preessure sensor is mounted to monitor air pressureused at Panda S. The, and all other AWSsstations use Vaisala PTB210. The Eagle and Dome A AWSs have cup anemometers which stall freeze during extreme austral winter cold (Zhou et al., 2009; Ma et al., 2010),). Tbut the other AWSs are equipped with Huayun Zhongyi XFY3-1 wind propeller anemometers and somethey of them are optimized to prevent “diamond dust” “accumulation on the instruments. Some stations (Panda 100, Panda 200, Panda 300, Panda 400, Taishan, Panda 1100, Kunlun) also make radiation measurements. These are not discussed in this paper, but are available detailed and available for download from the data site. Further Ddetails of the sensor and AWS schemes can be found in Table1.

All sensors are calibrated before the AWS deploymentfieldwork, but extremelysuper cold weather below -60 ℃ may bring uncertainty. The height of the sensors above surface gradually decreases with snow accumulation, except for Zhongshan which is on rock. This has been ignored in the preliminary analysis presented here.

2.2 Data quality control

All data are checked initially to ensure integrity, consistent with the approach of Ma et al. (2010), Lazzara et al. (2012), and Wawrzyniak and Osuch (2020). SA schematic diagram of data processing workflow wasis shown in Figure 2. Firstly, ARGOS reception may lead to duplicated records, or time dislocation (Fig. 2) and , these are removed. For those AWSs with measurements of air temperature and wind speed at multiple levels, a check of the vertical profiles is a particularly strong validation. If the vertical profiles gradients are near logarithmicphysically consistent, then the absolute values are sure likely to be accurate. Secondly, different variables are compared to check their consistency. For instance, wind direction will be eliminated when wind speed is zero. In addition, the height of sensors might change with snow accumulationng. The A correction method to for this error have has been introduced in Ma et al. (2008) and Smeets et al. (2018). In addition, the logger box was buried in the snow at installation, which has the advantage of not interfering with the radiation measurement. Daily mean values are averaged from hourly data and then monthly and annual mean values are progressively calculated. Similarly to the methodology of Maturilli et al. (2013) and Zou et al. (2021), missing values are handled depending on their duration. If more than 21% data (5 hours) during one day, or 12% data (4 days) within one month, or 25% data (3 months) within one year are missing, the this daily/monthly/annual data is considered a missing value.

The measurements at Zhongshan were made only four times a day (00:00, 06:00, 12:00 and 18:00~~,~~ UTC) from 1 March 1989 to 31 January 2002.~~,~~ Hence, we analyzed diurnal data only from 2002 to 2020~~ for consistency~~, but monthly~~/~~ and annual ~~data~~ values from 1989 to 2020. The average of meteorological variables at other AWSs were calculated for different ~~spans~~ periods depending on their deployment dates, which are not the same (Table 1): Panda100, Panda 300, Panda 400 and Panda 1100 span from 2019 to 2021; Panda 200 spans from 2016 to 2021; Taishan spans from 2012 to 2021; Eagle and Dome A span from 2005 to 2020; Kunlun spans from 2017 to 2021; Panda S spans from 2008 to 2021. All variables are analyzed at a height of 4 m, except at Zhongshan, Panda 200 and Panda 400. The wind speed and direction at Zhongshan are at 10 m~~ height~~, and the air temperature and relative humidity at Panda 200 and Panda 1100 are at 6 m and 2 m~~ heights~~, respectively.

Due to heavy hoar frost in the Antarctic inland, the anemometers with a vertical axis at Eagle, Dome A and Panda S ~~was~~ often froze~~n~~ during austral winter~~ at Eagle, Dome A and Panda S~~, which ~~may~~ leads to invalid measurements (Zhou et al., 2009). We used a different type of anemometer on the other AWSs and deleted the wintertime wind speed and direction data for ~~those~~ these three AWSs.

3 Results

3.1 Air temperature

The ~~M~~mean diurnal variation of air temperature is ~~obviously an~~ approximately sinusoidal curve at all AWSs (Fig. 3). The maximum air temperature occurs at 0900-1100 UTC (1400-1600, Local ~~Standard~~Solar Time LST), and the minimum was at 2200-2300 UTC (0300-0400, LST). From the coast to the dome area, the standard deviation of diurnal variations gradually increases (from 0.64 °C at Zhongshan to 1.42 °C at Panda S), consistent with the result of -King et al. (2006). This regularity may be the result of katabatic wind, marine effect and cloud (van den Broeke, et al., 2004a; Zhou et al., 2008).

The monthly mean air temperatures~~ all~~, particularly for the more southern AWSs, show a “coreless” winter with a single “valley” pattern; in other words, there is no distinctive ~~minima~~minimum during austral winter (Fig. 4) (Allison et al., 1993; Chen et al., 2010; Ma et al., 2010). The variability (standard deviation of monthly air temperature) in austral winter is much larger than in austral summer, e.g., 2.46 °C vs

1.67 °C at Taishan. This indicates that the Antarctic~~a~~ Ice Sheet experiences more weather activities during austral winter. For example, sometime cyclones from the surrounding ocean may bring warm, moist air masses (Qin et al., 2017; Ding et al., 2020). In addition, the inland region exhibits more dynamic weather ~~either~~ than either the coast or the dome summit regions, coinciding with a larger standard deviation in monthly air temperature. This is 1.5 times (3.24 °C) that of the others two regions (2.19 °C, and 2.39 °C respectively).

With consideration of the length of the observation period, the trend in annual mean air temperatures is shown for only 4 AWSs in Fig. 5. These are Zhongshan (1989 to 2020), Taishan~~,~~ (2013 to 2020), Eagle (2005 to 2020) and Dome A (2005 to 2020). They have annual means of -10.0 °C, -35.4 °C, -41.2 °C and -50.4 °C respectively, ~~similar to~~like the results of Ma et al. (2010). This difference can be attributed to differences in elevation/topography and latitude (Allison et al., 1993). ~~The annual variations of air temperature at the four sites are multivariate. There has been a warming trend at Zhongshan of 0.10 °C/decade, and significant increase of air temperature at Taishan of 1.07 °C/decade. However, there has been no significant change at Eagle (-0.13 °C/decade) or Dome A (-0.07 °C/decade), unlike that at Vostok and South Pole which are experiencing warming (Clem et al., 2020).~~

3.2 Relative humidity

The variation of local atmospheric moisture is driven by a combination of large-scale advection and local evaporation/sublimation effects (Maturilli et al., 2013). Figure 6 shows a similar distribution to a previous study (Ma et al., 2010); the austral summer is more humid than the austral winter at all AWSs. However, coastal relative humidity fluctuates largely on the monthly scale but there is a little difference between austral summer and winter. At the inland and dome summit regions, the monthly relative humidity has a very clear seasonal cycle (except Dome A).

Figure 7 shows the annual averages and trends of relative humidity at Zhongshan, Taishan, Eagle and Dome A. Relative humidity varied considerably at all sites, with the driest records at Dome A. Interestingly, the relative humidity is well correlated with air temperature except at Zhongshan, partially because its weather is controlled by the adjacent ocean.

3.3 Air Pressure

Air pressure obviously decreases with elevation from coast to dome area, and the seasonal cycle~~s also~~ becomes clearer. Monthly mean air pressure shows a semi-annual oscillation with equinoctial minima near the coastal and inland areas along the PANDA AWS network, but is much less distinct at the dome area~~, this~~. The semi-annual oscillation there could be ~~submerged~~ hidden under larger annual oscillation (Fig. 8) (Radok et al., 1996). Coastal areas like Zhongshan, Panda 100 and Panda 200 have little air pressure difference between austral summer and winter, but there are obvious differences for the inland area, with a stable-strong low-pressure structure at the plateau surface in austral winter. However, there ~~are~~ is more ~~cyclone~~ cyclonic ~~activities~~ activity in the inland area (Panda 300 to Eagle) (Ding et al., 2020).~~, showed~~ This is shown by the highest standard deviation of air pressure, (705±4 hPa), higher than the coastal (858±3.10 hPa) and the dome areas (585±2.74 hPa). The annual averages (Table 2) and trend of air pressure at the AWS shows no systematic variation, consistent with Zhou et al. (2009) and most ~~of the~~ other studies in East Antarctica.

3.4 Wind speed and direction

Diurnal variation in wind speed shows most clearly in the coastal katabatic region (Fig. 9). The maximum wind speed occurs around 0400-0800 UTC (0900-1300 LST) and the minimum around 1400-1600 UTC (1900-2100 LST at near-coastal AWSs. Diurnal variation of wind speed gradually decreases from the coast to the dome region, from Panda 1100 to Panda S~~, which~~. Panda S showed very weak fluctuation because the dome area is a sink center for atmosphere circulation and the origin of Antarctic surface wind flow (Parish and Bromwich, 1987; Van den Broeke and Van Lipzig, 2003; Aristidi et al., 2005; Das et al., 2013). This phenomenon is also reflected in the vertical temperature gradient difference. At all times of day, the surface atmosphere has a positive temperature gradient (the 4 m air temperature is higher than 2 m). Thus, the wind is ~~stable and~~ weak and wind direction is stable at Dome A. Similarly, Zhou et al. (2009) and Bian et al. (2016) also found that there was a persistent and stable inversion layer due to strong surface cooling of the Antarctic ~~ice~~ Ice ~~sheet~~Sheet.

There is evidence of seasonal variations of wind speed at ~~most~~all AWSs except Eagle, Dome A and Panda S. The austral winter wind speed is higher than austral summer (Fig. 10). This is related to the intensity of surface cooling and topography of the ice sheet.

Wind flow can be accelerated by cooling along a slope (Van den Broeke et al., 2002). The fluctuation of wind speed was much greater in austral winter than in summer, e.g., the standard deviations at Panda 200 in austral winter and summer were 1.43 m s^{-1} and 0.99 m s^{-1} in austral winter and summer respectively. From the coast to dome area, the wind speed became weakerdecreased, which has also been discussed by Ma and Bian (2014) and can be attributed to the katabatic wind effect. Zhongshan is an exception,: its wind speed is weaker than at the other coastal AWSs. This AWS was deployed on rock at the edge of Antarcticamore than 2 km from the edge of the ice sheet whose where the katabatic wind effect was ishas weakened. This pattern is also coincidence with aerodynamic roughness length, momentum transfer coefficient and friction velocity (Van den Broeke et al., 2002; Zhou et al., 2009, Ma et al., 2010).

In Over the long-term, the wind speed showed a weakening trend over the whole transect (Fig. 11). The trend at Zhongshan was -0.41 m s^{-1}/decade ($p < 0.01$) from 1989 to 2020. and there was also a decrease at Taishan (-0.08 m s^{-1}/decade) from 2013 to 2020. This phenomenon deserves future investigation.

As has been previously noted, the vertical axis anemometers of Dome A and Eagle are often frozen during austral winter, and the data quality of wind during austral fall is poor. Therefore, we only analyzed analyzed wind direction in only the half yearfor the months from (September to -February) at these two sites. Figure 1 showed the wind rose distribution of all AWSs. The wind directions at coastal and inland areas (from Zhongshan to Taishan) were relatively stableregular: during austral summer, constant easterlies determine the wind speed on the ice sheet surface wind, which is thus mainly from NE to SE. In austral winter, katabatic forcing from strong surface cooling, large-scale pressure gradient and Coriolis force, dominates, it also resulting in winds showed from NE to SE (Van den Broeke et al., 2002; Van den Broeke and Van Lipzig, 2003). At the dome summit region, the wind direction has a broad distribution with weak wind speed south, southeast and west. Especially at theAt Dome A, no prevailing wind has showed from ~18 years observation16 years of observations result inshow no prevailing wind direction.

4. Capability of monitoring short-term atmospheric events

Compared to other meteorological observations, one advantage of the PANDA AWS network is that it covers all terrain and climatic sectors of East Antarctica. The local weather conditions can be deducedreflected from the meteorological surface measurements. Figure 12 shows the course of air pressure, air temperature, relative humidity and wind speed ~~on~~ from 30th July~~-~~ to 3rd August 2020, which indicates the ~~occured~~ occurrence of a prominent blocking event. To assess the capability to monitor weather conditions, this physical atmospheric process was ~~analyzed~~ analyzed ~~by~~ using the PANDA AWSs network dataset.

On 1st August 2020, the blocking stretched southward to around 100° E, forming a high-pressure ridge in the interior of ice sheet (~~not shown~~Fig. 13). The deep low-pressure system was blocked from moving eastward and thus stagnated near Prydz Bay. This situation facilitated the meridional advection of warm, moist air masses. It can be seen in Fig. 12, that the air temperature, relative humidity, air pressure and wind speed from Zhongshan to Dome A changed with the development of the event. The uppermost site to detect the blocking is Dome A ~~with~~ at 4093 m a.s.l. and the average speed of the blocking event across transect was about 40 km/h. Before 1st August, there was a drastic drop in air pressure at AWSs from Zhongshan to Taishan, reaching the lowest value at local noon, but the air pressure from Eagle to Dome A showed no such changes. Meanwhile, the air temperature, relative humidity and wind speed show the opposite change at all AWSs, rising sharply and reaching the highest values at local noon, ~~average rose nearly 26%, 19% and 173% (compared with the time from 30th July to before the blocking event), respectively,~~ indicative of maritime air intrusions to the PANDA transect. On 3 August, the deep low-pressure system was slightly weaker (not shown). The southern section of the Indian Ocean subtropical high became ~~flat~~ weak in the geopotential height anomaly field, and the blocking event moved eastward and eventually dissipated along the coast~~ or over the ocean surface~~. This event was ~~similar to~~like a recent abrupt warming event ~~in~~at Dome C (Ding et al., 2022a). Therefore, the PANDA AWS network provides high spatial-temporal observations and can play an important role in ~~short-term weather forecast~~ the mesoscale circulation research on the Antarctic Ice Sheet.

5. Data availability

This dataset is publicly available and it is planned that it will be updated on a near-real time. The data from ~~the other~~ all AWSs will be publicly available on the ~~A~~ platform "Big Earth Data ~~Platform~~ for Three Poles"~~,~~. ~~the~~ The links are as follows: Zhongshan, Panda 100, Panda 200, Panda 300, Panda 400, Taishan, Panda 1100 and Kunlun, t~~T~~he data can be downloaded from https://doi.org/10.11888/Atmos.tpdc.272721 (Ding et al., 2022b). Eagle and Dome A data has been published on the data portal of AAD: http://aws.cdaso.cloud.edu.au/datapage.html. Panda S data has been posted on the data portal of the University of Wisconsin: https://doi.org/10.48567/1hn2-nw60 (AMRDC Data Repository).

6. Conclusion

In this paper, we have introduced the PANDA AWS network which can monitor the meteorology from the coastal Zhongshan AWS to ~~beyond~~ Panda S in the interior of the Antarctic continent with high spatial and temporal resolution. The data collected during the past decades are reliable after calibration and homogenization, and have been used widely in meteorological and climate change research in Antarctica (e.g., Xie et al., 2016, Ding et al. 2021a). The data can also be used to ~~derive surface energy balance,~~ assimilated into reanalyzes, and used to evaluate climate models and to validate satellite data.

In a preliminary analysis, the diurnal, monthly, annual averages ~~and~~ as well as~~the~~ long~~-~~ term changes ~~of air temperature, relative humidity, air pressure, wind speed and direction~~ have been presented. They show distinct~~ly~~~~significant~~ differences between coastal, inland and dome summit regions. An example has also been given of a short-term atmospheric process to show this dataset's capability for weather monitoring and investigating.

Author contributions.

MD, IA and XZ designed the experiments and wrote the manuscript; MD carried out the experiments; XZ and DY analyzed the experimental results. MD, XZ, PH and DY revised the manuscript; CL, QS and WZ provides the information of AWS; DY, LB and CX discussed the results.

Competing interests.

The authors declare that they have no conflict of interest.

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Figures and Table:

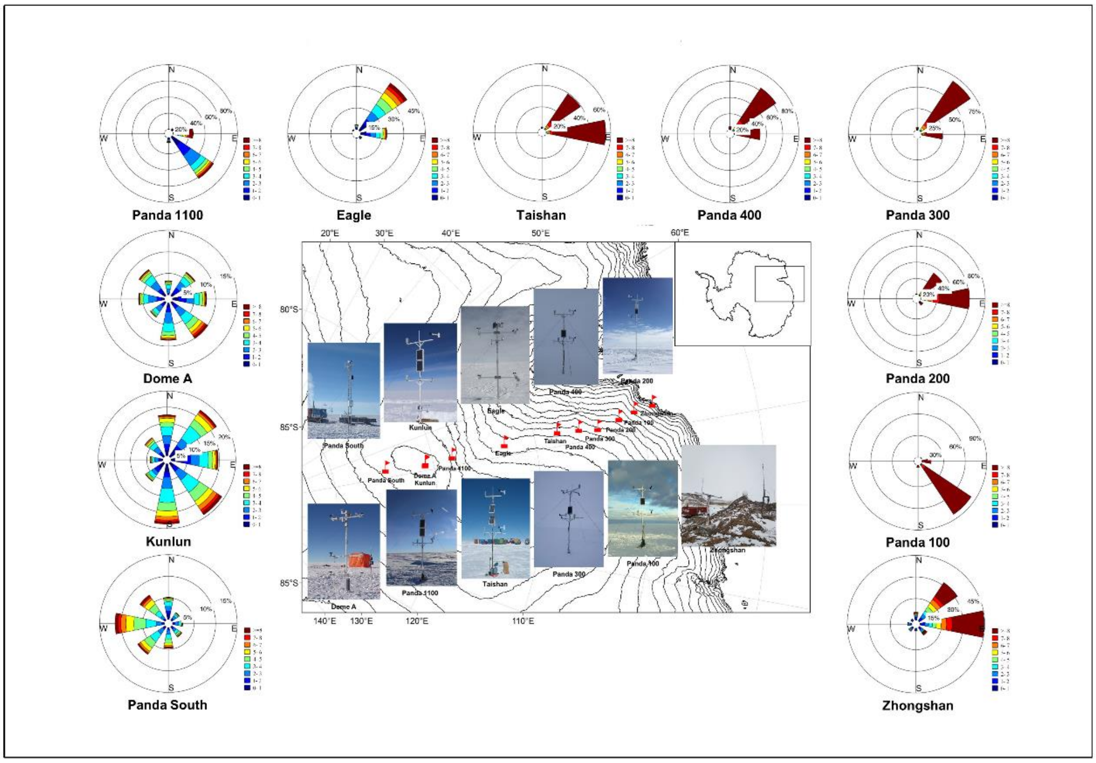


Figure 1. The location and Wind roses of AWSs in the PANDA network. The red flags are AWSs; the black solid lines are 200 m interval contours. The wind directions are divided into 22.5° sectors. Zhongshan is calculated during 1989-2020; Panda 100, Panda 300 and Panda 400 are calculated during 2019-2021; Panda 200 is calculated during 2016-2021; Taishan is calculated during 2012-2021; Eagle and Dome A are calculated during 2005-2020; Kunlun is calculated during 2017-2021; and Panda S is calculated during 2008-2021. Note however that, because some winter data were unreliable, Eagle averages exclude Mar-Aug; Dome A averages exclude March-October; and Panda S averages exclude May-September.

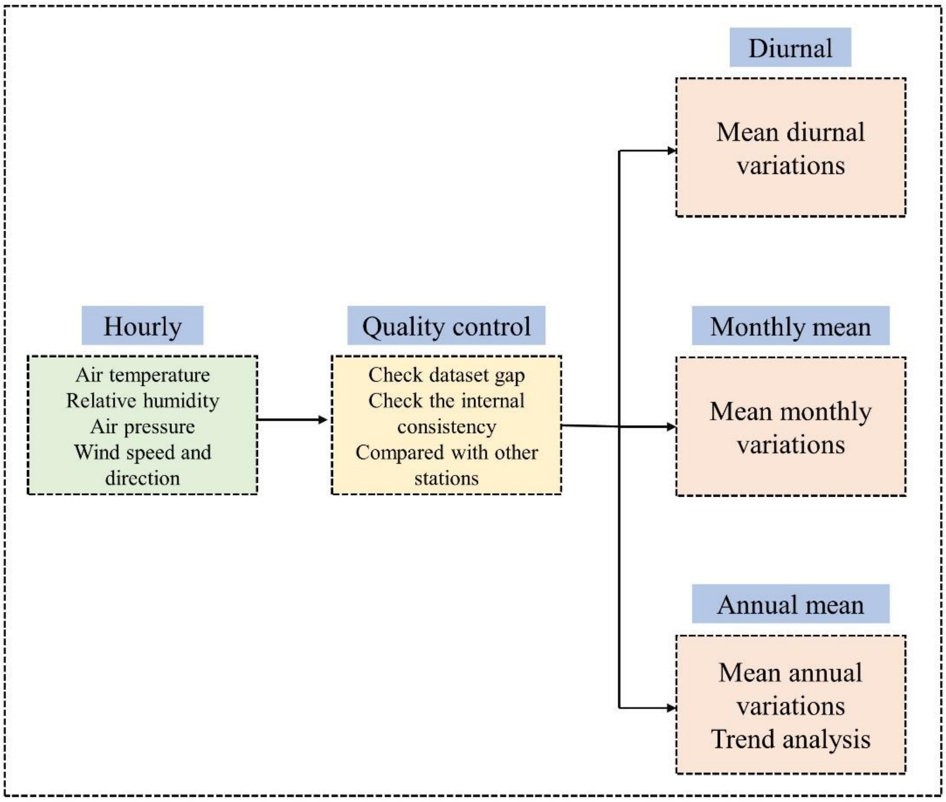


Figure 2. Schematic diagram of data processing workflow used to compile the AWS meteorology dataset for the network.

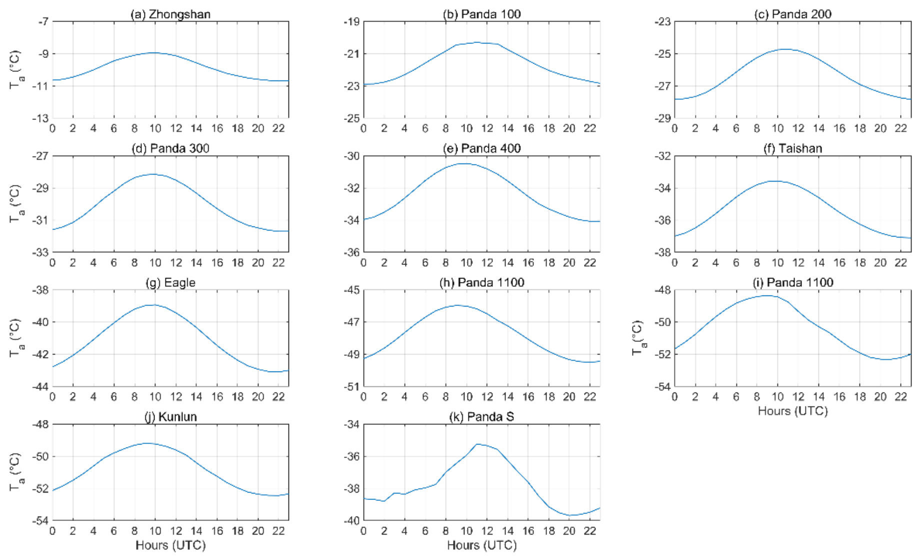


Figure 3. Average diurnal variation of air temperature at AWSs in the PANDA network. The calculation years for these sites are the same as ~~in~~ for Fig. 1, excepting that Zhongshan is calculated during 2002-2020.

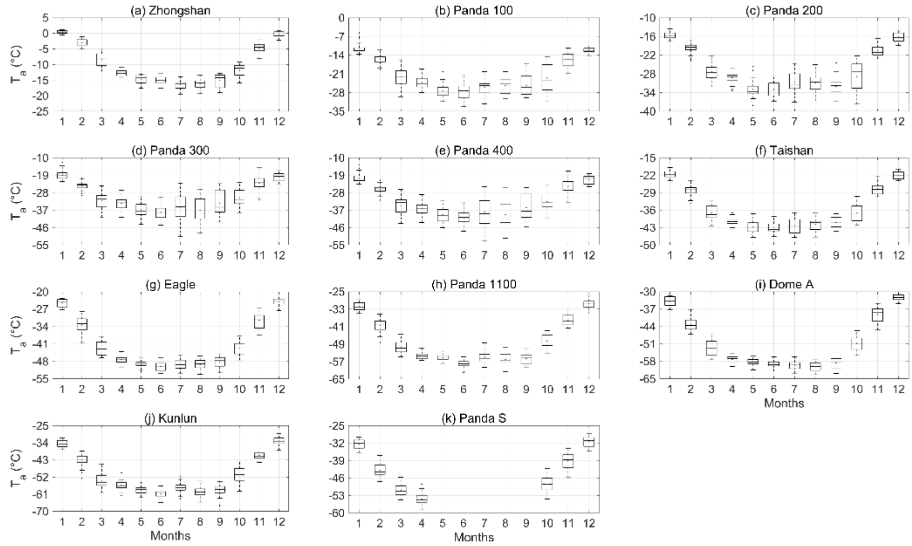
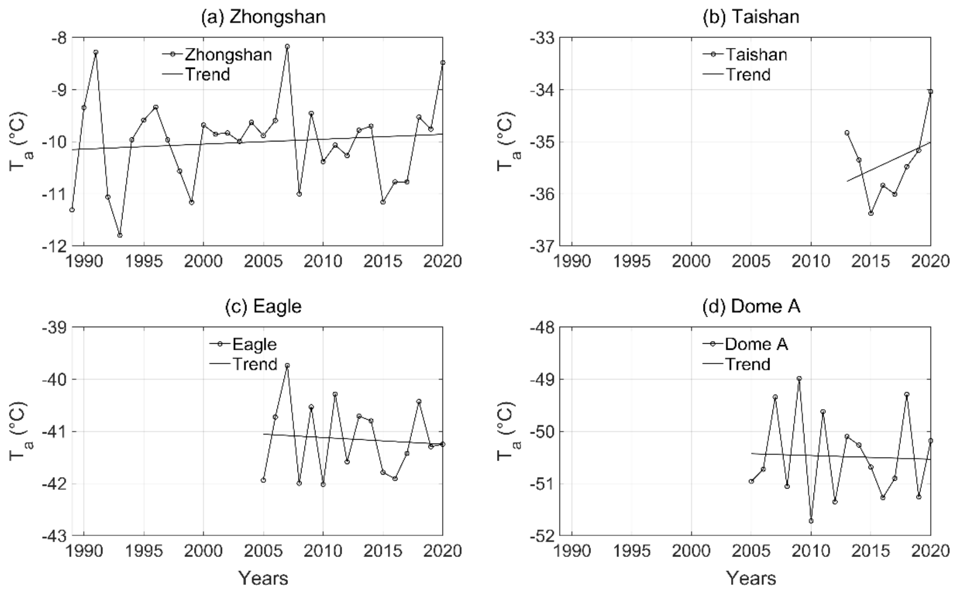


Figure 4. Variation of monthly mean air temperature at AWSs in the PANDA network. The calculation periods for these sites are the same as ~~in~~ for Fig. 3, For each monthly box, the central line indicates the median, the red dot represents the mean, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively.



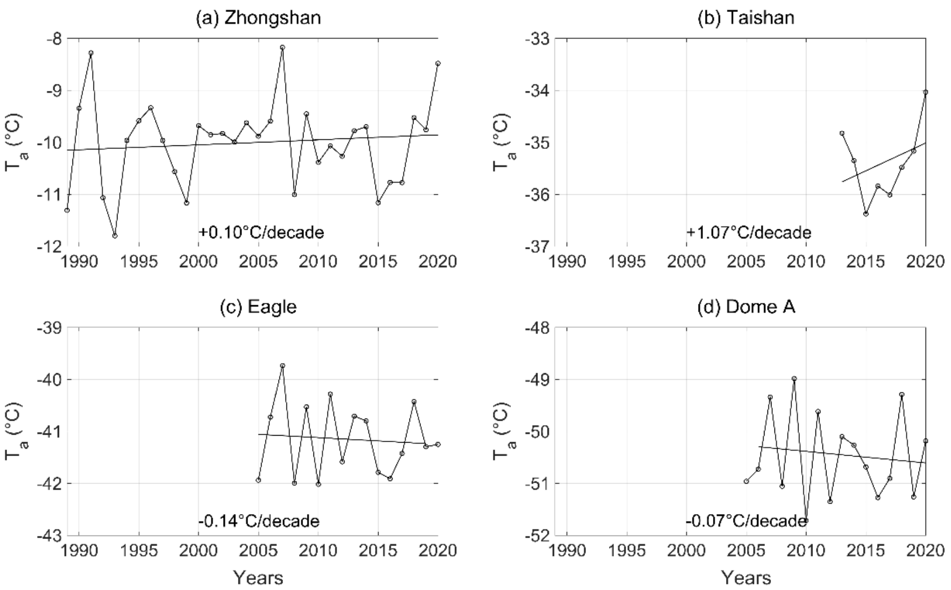


Figure 5. Interannual variation of~~Variation of annual mean~~ air temperature at Zhongshan, Taishan (P<0.05), Eagle and Dome A. Zhongshan is calculated during 1989-2020; Taishan is calculated during 2013-2020; Eagle and Dome A are calculated during 2005-2020.

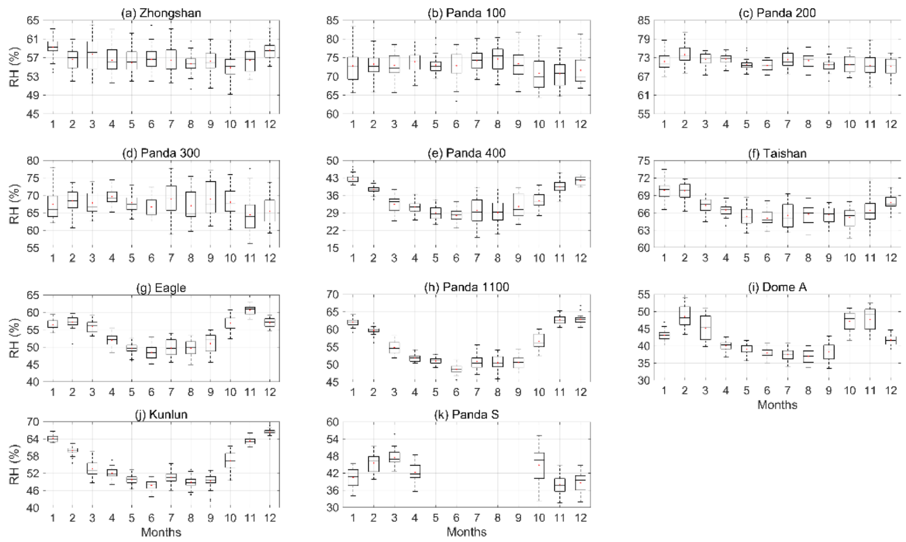
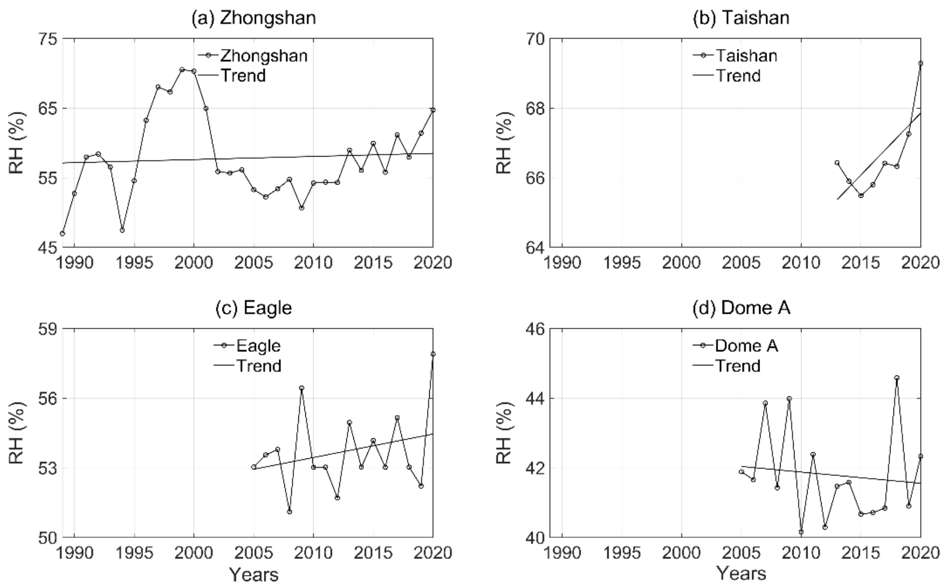


Figure 6. Monthly variation of relative humidity at AWSs in the PANDA network. The calculation periods of these sites are the same as ~~in~~ for Fig. 3.



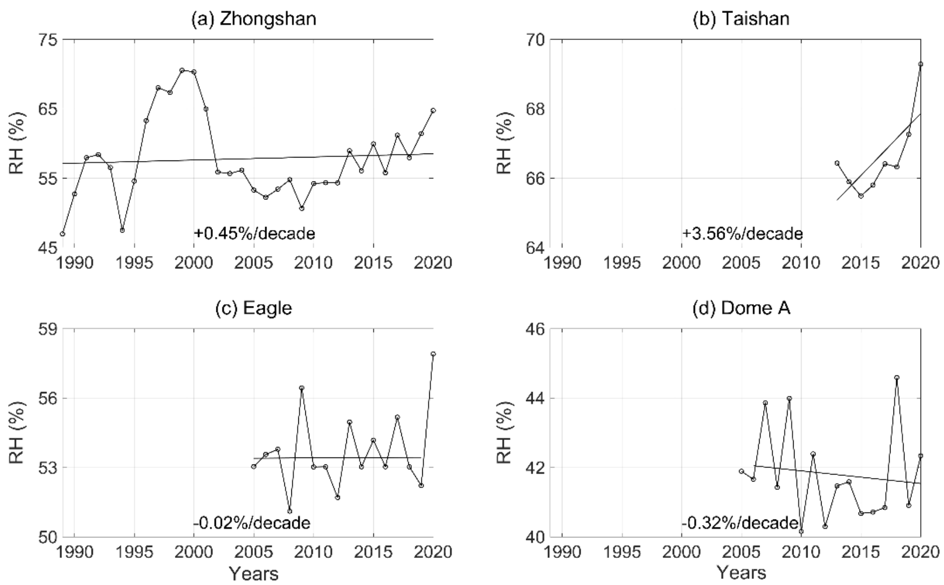


Figure 7. Interannual ~~Annual~~ variation of relatively humidity at Zhongshan ($p<0.05$), Taishan ($p<0.05$), Eagle and Dome A.

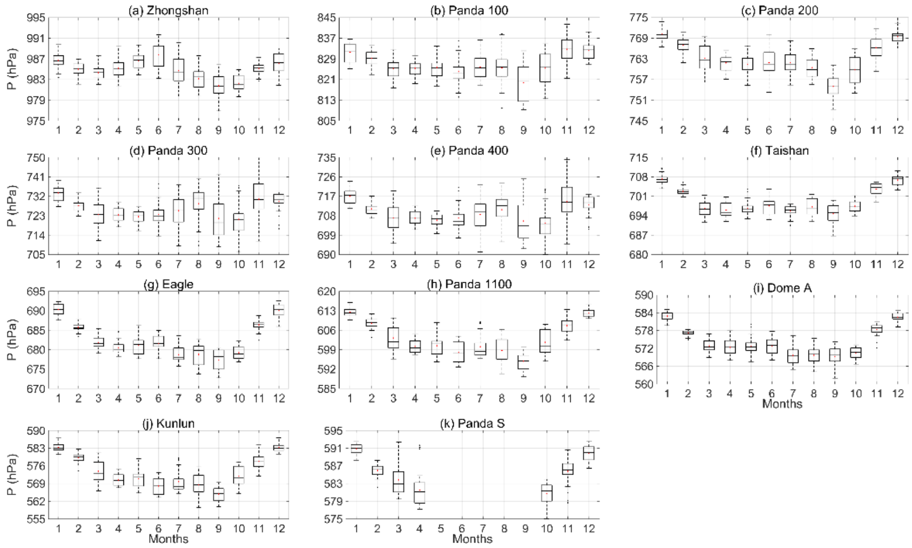


Figure 8. Monthly variation of air pressure at AWSs in the PANDA network. The calculation periods at these sites are the same as ~~in~~ for Fig. 3.

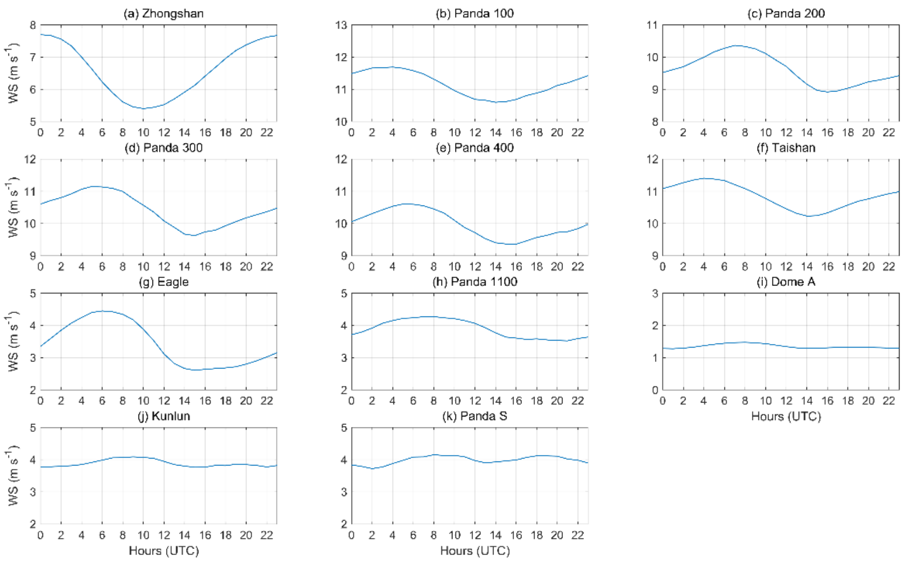


Figure 9. Diurnal variation of wind speed of PANDA AWSs network. The calculation periods of these site are the same ~~with~~ as for Fig. 1, Zhongshan is calculated during 2002-2020.

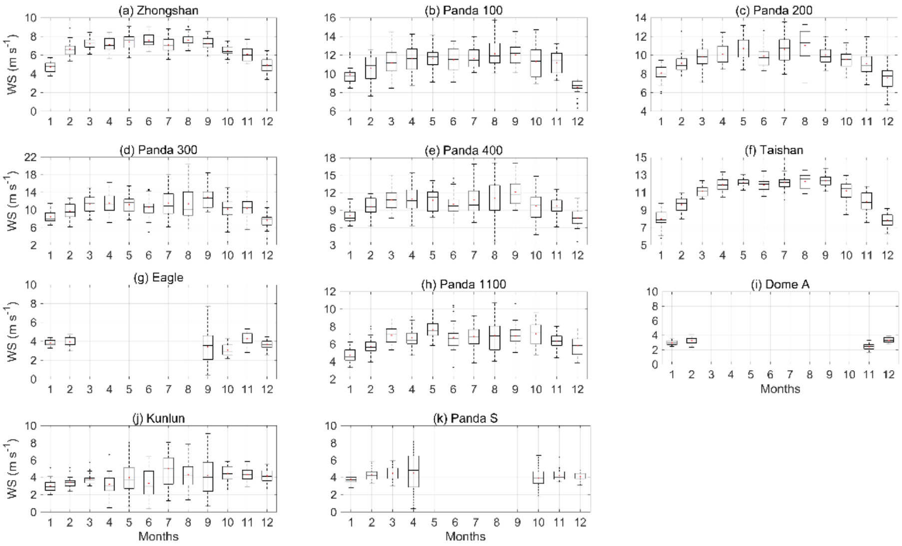
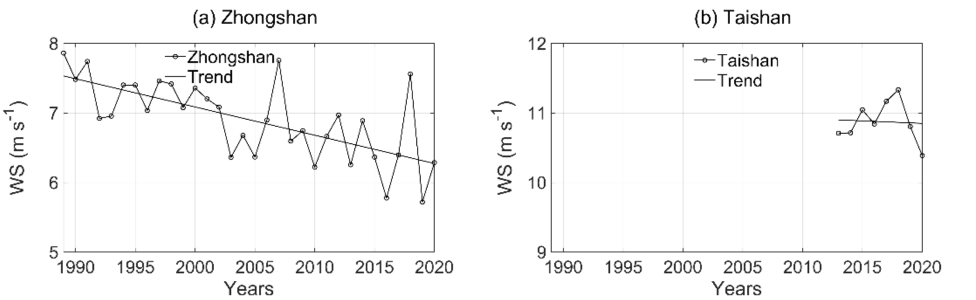


Figure 10. Monthly variation of wind speed of PANDA AWSs network. The calculation periods of these sites are the same ~~with~~ as for Fig. 1.



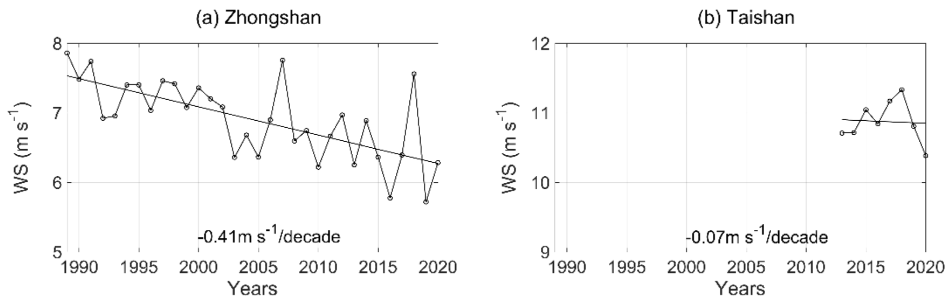
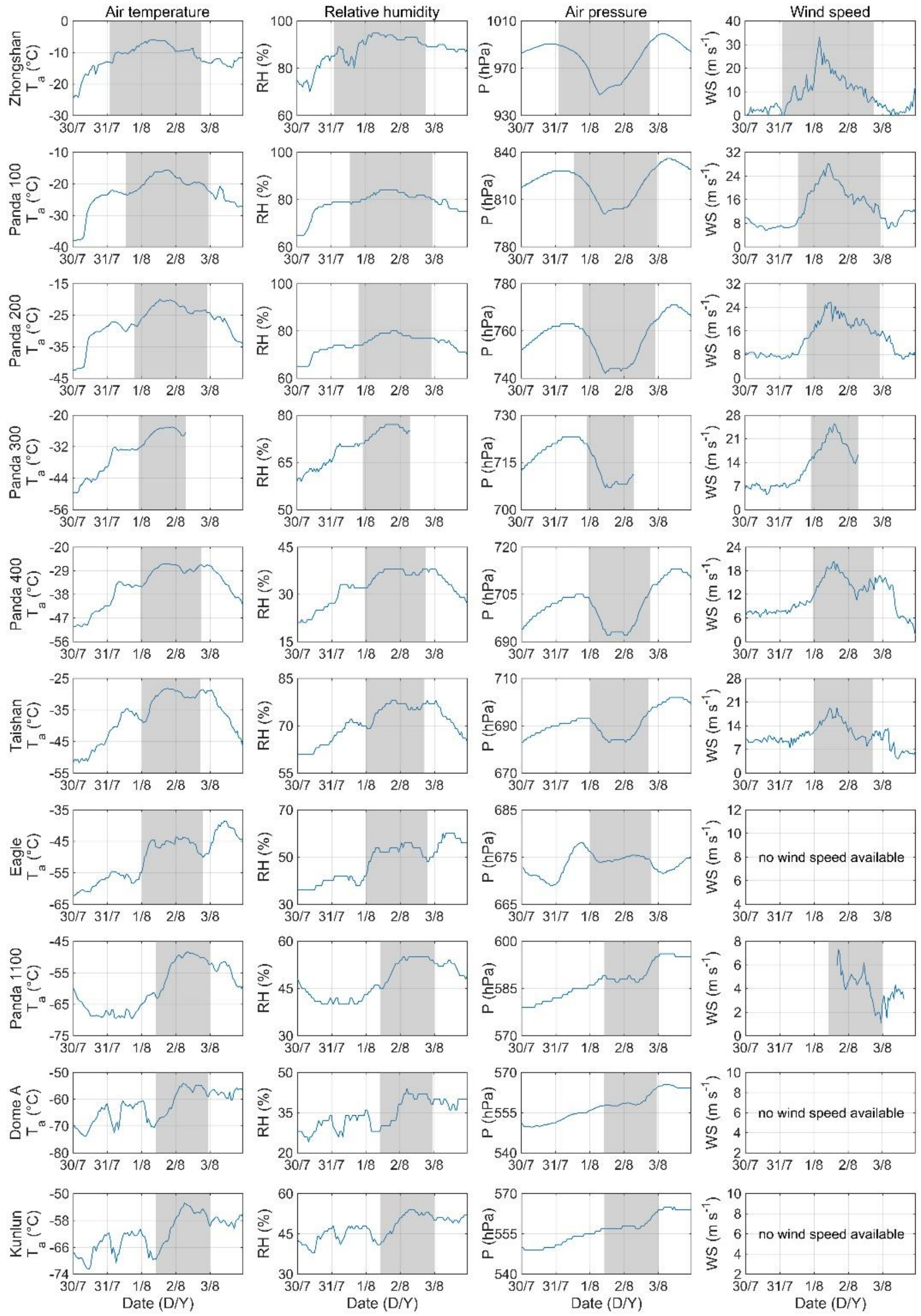


Figure 11. Annual variation of wind speed at Zhongshan (P<0.05) and Taishan (P<0.05). The calculation periods of these site are the same ~~with~~ as for Fig. 5.


Air temperature
Relative humidity
Air pressure
Wind speed
Zhongshan
Panda 100
Panda 200
Panda 300
Panda 400
Taishan
Eagle
Panda 1100
Dome A
Kunlun
T_a (°C)
RH (%)
P (hPa)
WS (m s^-1)
no wind speed available
Date (D/Y)
30/7 31/7 1/8 2/8 3/8

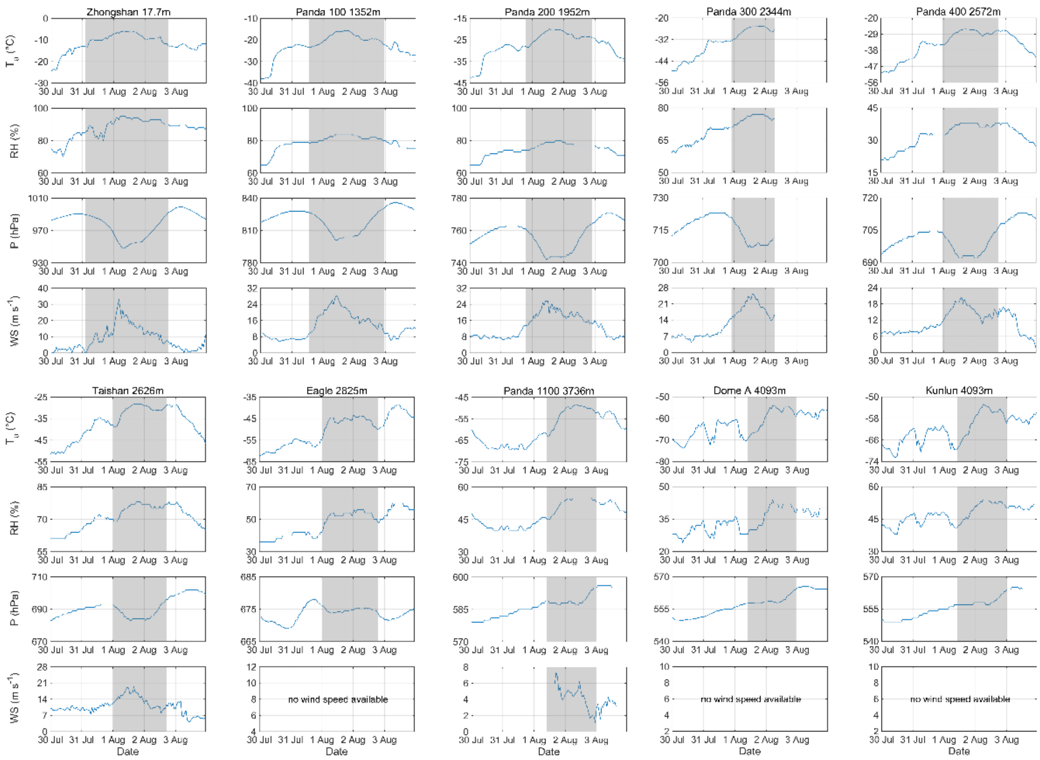


Figure 12. Time series of~~Changes in~~ air temperature, relative humidity, air pressure and wind speed at AWS of the PANDA network (except Panda S) from 00:00 30th July to 23:00 3rd August 2020 (UTC); gray zone: blocking event.

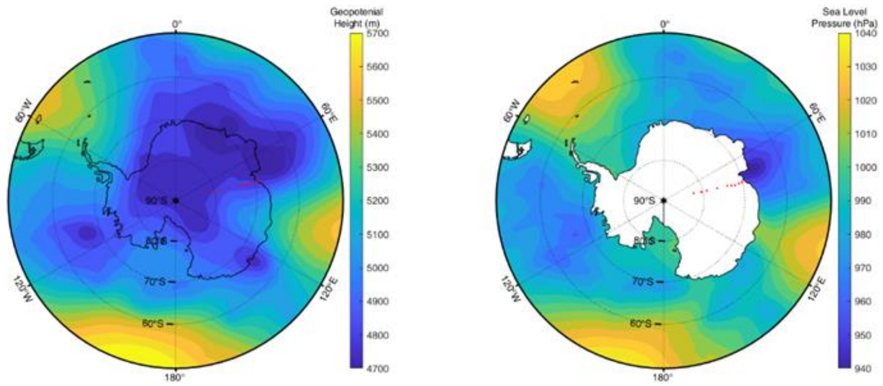


Figure 13. The mean 500 hPa geopotential height (left) and sea level pressure (right) on 12:00 1st August (red dot: surface weather station).

Table 1. Locations, operational periods, observed variables and heights, and instrumentation and accuracies of AWSs in the PANDA network

Stations	Location	Altitude	Period(Y/M)	Variable	Sensor	Accuracy	Height
Zhongshan	69.37°S 76.38°E	17.7 m a.s.l.	1989/03-2020/12	Ta/RH	Vaisala HMP155	(0.2260-0028*Ta) °C/1%	2m
				P	Campbell CS106	1.5hPa	2m
				WS/WD	Huayun XFY3-1	1m s^{-1}/5°	10m
Panda 100	70.22°S 76.65°E	1352 m a.s.l.	2019/02-2021/07	Ta/RH	Vaisala HMP155	(0.2260-0028*Ta) °C/1%	2/4m
				P	Vaisala PTB110	0.3hPa	2m
				WS/WD	Huayun XFY3-1	1m s^{-1}/5°	2/4m
				~~SDR/SUR~~	~~Li200X~~	~~5% Max/3% Typical~~	~~2m~~
Panda 200	70.97°S 77.19°E	1952 m a.s.l.	2016/12-2021/07	Ta/RH	Vaisala HMP155	(0.2260-0028*Ta) °C/1%	4/6m
				P	Vaisala PTB210	0.5hPa	4m
				WS/WD	Huayun XFY3-1	1m s^{-1}/5°	4/6m
				~~SDR/SUR~~	~~Li200X~~	~~5% Max/3% Typical~~	~~4m~~
Panda 300	72.00°S 77.95°E	2344 m a.s.l.	2019/12-2021/07	Ta/RH	Vaisala HMP155	(0.2260-0028*Ta) °C/1%	2/4m
				P	Vaisala PTB210	0.5hPa	2/4m
				WS/WD	Huayun XFY3-1	1m s^{-1}/5°	2/4m
				~~SDR/SUR~~	~~Li200X~~	~~5% Max/3% Typical~~	~~2m~~
Panda 400	72.86°S 77.38°E	2572 m a.s.l.	2019/12-2021/07	Ta/RH	Vaisala HMP155	(0.2260-0028*Ta) °C/1%	1/2/4m
				P	Vaisala PTB210	0.5hPa	2m
				WS/WD	Huayun XFY3-1	1m s^{-1}/5°	1/2/4m
				~~SDR/SUR/LDR/LUR~~	~~Li200X~~	~~5% Max/3% Typical~~	~~2m~~
Taishan	73.86°S 76.98°E	2626 m a.s.l.	2012/12-2021/07	Ta/RH	Vaisala HMP155	(0.2260-0028*Ta) °C/1%	2/4m
				P	Vaisala PTB110	0.3hPa	2m
				WS/WD	Huayun XFY3-1	1m s^{-1}/5°	2/4m
				~~SDR/SUR~~	~~CNR4~~	~~10%~~	~~2m~~
Eagle	76.42°S 77.02°E	2825 m a.s.l.	2005/01-2020/12	Ta	FS23D	0.05°C	1/2/4m
				RH	Vaisala HMP35D	2%	2m
				P	Paroscientific 6015A	0.5hPa	2m
				WS/WD	RM Young 12170C/ Aanderaa 3590B	0.5m s^{-1}/6°	1/2/4m
				~~Ta~~			

				RH P WS/WD			
Panda 1100	79.01°S 76.99°E	3736 m a.s.l.	2019/01- 2021/07	Ta/RH P WS/WD SDR/SUR	Vaisala HMP155 Vaisala PTB210 Huayun XFY3-1 Li200X	(0.2260-0028*Ta) °C/1% 0.5hPa 1m s^{-1}/5° 5% Max/3% Typical	2/4m 2m 2/4m 2/4m
Dome A	80.37°S 77.37°E	4093 m a.s.l.	2005/01- 2020/12	Ta RH P WS/WD Ta RH P WS/WD	FS23D Vaisala HMP35D Paroscientific 6015A RM Young 12170C/ Aanderaa 3590B	0.05°C 2% 0.5hPa 0.5m s^{-1}/6°	1/2/4m 4m 2m 1/2/4m
Kunlun	80.43°S 77.12°E	4093 m a.s.l.	2017/01- 2021/07	Ta RH P WS/WD SDR/SUR	Campbell 109/ Vaisala HMP155 Vaisala HMP155 Vaisala PTB210 Huayun XFY3-1 Li200X	(0.2260-0028*Ta) °C/1% (0.2260-0028*Ta) °C/1% 0.5hPa 1m s^{-1}/5° 5% Max/3% Typical	2/4m 4m 2m 4m 2m
Panda S	82.33°S 75.99°E	4027 m a.s.l.	2008/01- 2021/04	Ta RH P WS/WD	PRT 2-wire Bridge Vaisala HMP35A Paroscientific Model 215 A RM Young/10K Ohmpot	0.5°C 5% 0.2hPa 0.2±0.5m s^{-1}/3°	4m 4m 4m 4m

Statement: SDR: downward shortwave radiation; SUR: upward shortwave radiation; LDR: downward longwave radiation; LUR: upward longwave radiation.

Table 2 The mean values of meteorological variables on AWSs in the PANDA network

Stations\ elements	Air temperature /°C	Relative humidity/%	Pressure /hPa	Wind speed /m s-1	Number of hourly values[IA1]
Zhongshan	-10.0	58	985	6.9	184695
Panda 100	-21.6	73	827	11.2	21216
Panda 200	-26.5	72	763	10.9	40010
Panda 300	-30.0	68	726	10.4	13811
Panda 400	-32.0	34	710	10.0	13783
Taishan	-35.4	67	699	10.9	74893
Eagle	-41.2	54	683	3.6	139608
Panda 1100	-47.7	55	603	3.6	39648
Dome A	-50.5	42	575	2.9	140484
Kunlun	-50.8	55	574	3.9	39515
Panda S	- ~~-39.2~~	- ~~42~~	- ~~587~~	- ~~4.0~~	-