Observed surface wind speed in the Tibetan Plateau since 1980 and its physical causes

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Abstracts: Climate warming on the Tibetan Plateau (TP) potentially influences many climate parameters other than temperature including wind speed, cloudiness and precipitation. Temporal trends of surface wind speed at 71 stations above 2000 m above sea level in the TP are examined during 1980-2005. To uncover causes of observed trends in wind speed, relationships with surface temperature, a TP index and sunshine duration are also analyzed. The TP index is calculated as the accumulated 500 hPa geopotential height above 5000 m over the region of 30°N-40°N, 75°E-105°E from NCEP/NCAR reanalysis. The annual mean wind speed patterns during 1980-2005 are similar to those in different seasons, with higher wind speeds in the northern and western parts of the TP. Highest mean wind speeds occur in spring and lowest in autumn. During 1980-2005, annual and seasonal mean wind speeds show statistically decreasing trends at most stations. The mean trend magnitude for annual mean wind speed is -0.24m/s/decade, with the maximum decline in spring (-0.29m/s/decade) and minimum in autumn (-0.19m/s/decade). Both annually and in different seasons, wind speed is significantly negatively correlated with mean temperature, minimum temperature, maximum temperature, and the TP index, but significantly positively correlated with sunshine duration. Wind speed trends fail to show a simple elevation dependency but speeds are positively correlated with meridional surface temperature/pressure gradients. Warming in the TP may weaken the latitudinal gradients of both regional temperature and surface pressure, thus altering the regional atmospheric circulation and accounting in part for the observed decline of wind speed.

Key words: Tibetan Plateau; wind speed; Tibetan Plateau index; Mann-Kendall analysis

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), global mean surface temperature has risen by 0.74 ± 0.18°C during the last 100 years (1906–2005), and the rate of warming over the last 50 years is almost 0.13 ℃/decade (*IPCC*, 2007). Future warming is estimated over the next 20 years to be a rate of 0.2 ℃/decade (*IPCC*, 2007). Due to a possible cryospheric feedback, the Tibetan Plateau (TP) is known as a "sensitive area" and "startup region" in China and has been characterized as both a "driving force" of and "amplifier" to global and regional climate change (*Feng et al.*, 1998; *Kang et al.*, 2010). Due to its unique physical environment and geographical position, the TP exerts profound thermal and dynamical influences on the atmospheric circulation, and controls regional energy and water cycles having a vital impact on not only China but also the whole of East Asia and even the globe (*Duan et al.*, 2006; *G X Wu et al.*, 2007). Under the impact of both climate change and increased human activities, the fragile environment in the TP has suffered fundamental changes in recent decades. Amongst the consequences there have been: significant rises of temperature and increases in temperature extremes (*Liu and Chen*, 2000; *You et al.*, 2008a), widespread and accelerated glacier retreat (*Yao et al.*, 2007; *Yao et al.*, 2012), exacerbating degeneration of permafrost (*T J Zhang*, 2007), reduced areal coverage of grasslands (*Cui and Graf*, 2009; *Cui et al.*, 2006), shrinking lake area (*G Q Zhang et al.*, 2011), and dramatic desertification of land (*Cui and Graf*, 2009; *Cui et al.*, 2006).

Most previous studies have concentrated on trends in temperature and precipitation. Annual mean temperature has increased by 0.16 ℃/decade during 1961-2002 (*Liu and Chen*, 2000), and precipitation has exhibited inconsistent trends (*Kang et al.*, 2010). A significant increase in annual precipitation and rain days is found in most parts of Tibet during 1971-2005, but decreases have occurred in Qinghai (*Ge et al.*, 2008). During 1971-2000, potential evapotranspiration in the TP has decreased, suggesting more humid conditions in most areas (*S H Wu et al.*, 2007). During 1961-2005, the frequencies of cold days and nights in the TP have reduced at -0.85 and -2.38 days/decade, respectively, while warm days/nights have increased by 1.26 and 2.54 days/decade. This has resulted in a negative trend of -0.20 ℃/decade for diurnal temperature range (*You et al.*, 2008a).

Although wind data on the TP is scarce, trends in surface wind speed have been studied on global and regional scales (*Fu et al.*, 2011; *Guo et al.*, 2011; *Jiang et al.*, 2010; *McVicar et al.*, 2008; *McVicar et al.*, 2012; *Pirazzoli and Tomasin*, 2003; *Pryor et al.*, 2009; *Tuller*, 2004; *Xu et al.*, 2006; *Yang et al.*, 2012; *You et al.*, 2010a). *Tuller* (2004) found that mean annual wind speeds along the west coasts of Canada had weakened from the 1940s to the 1990s, coinciding with stilling winds in the contiguous United States during 1973-2005 (*Pryor et al.*, 2009). In Australia, about 88% of stations show negative trends for wind speeds during 1975-2006 (*McVicar et al.*, 2008), consistent with decreasing wind speed at coastal Italian stations from 1951 to the mid-1970s. In lowland China, mean wind speeds during the periods of 1969-2000, 1969-2005, 1969-2009, 1961-2007 and 1956-2004 have been studied and the decline in wind speeds is pronounced, regarded as a cause of decreased surface evaporation and dust storm frequency (*Fu et al.*, 2011; *Guo et al.*, 2011; *Jiang et al.*, 2010; *Xu et al.*, 2006; *Yang et al.*, 2012). Comparisons of surface wind speeds with reanalysis wind components including NCEP/NCAR and ERA-40 in the TP (*You et al.*, 2010a), United States (*Pryor et al.*, 2009), and Australia (*McVicar et al.*, 2008), and show that there are discrepancies between reanalyses and observations. Furthermore, IPCC AR5 models exhibit lower inter-annual variability than reanalyses and observations during 1971-2005, and fail to reproduce the recent decline in wind speed observed in the near-surface observations (*Chen et al.*, 2012).

This study analyzes surface wind speeds on the TP based on surface observations between 1980 and 2005. This is the period which has shown a rapid warming across the region (*You et al.*, 2010a). Spatial and temporal characteristics of the wind field and the forcing factors of surface wind speed are investigated. Understanding these forcing factors will enable future trends in wind speed to be predicted with greater confidence.

2. Data and methods

Monthly mean wind speeds at 71 observational stations in the TP were provided by the National Climate Center, China Meteorological Administration (CMA). Stations were selected (Figure 1) according to procedures outlined in previous papers (*You et al.*, 2008a; *You et al.*, 2010a). Chosen stations are all above 2000 m above sea level, and a histogram showing the distribution of station elevations can be found in Figure 2 in *You et al.*, (2010a). As the method of wind speed observation was changed at the beginning of the 1970s (*Xu et al.*, 2006), data for the period of 1980-2005 are selected in this study, excluding the earlier part of the dataset. In order to examine causes of changes in wind speed, the mean monthly temperature, maximum and minimum temperature, and sunshine duration were also selected for each station. A TP geopotential height index was calculated as the accumulated value of 500 hPa geopotential height above 5000 m (based on adding up each grid point over the region of 30°N-40°N, 75°E-105°E). For example, a height of 5730 m would give a value of 730. Higher geopotential heights (higher TP index) means higher atmospheric pressure over the region. The 500 geopotential heights are taken from the

National Center for Environmental Prediction/National Center for Atmospheric Research Reanalysis (NCEP/NCAR hereafter), which is provided by the National Oceanic and Atmospheric Administration (NOAA) /Earth System Research Laboratory (ESRL) /Physical Sciences Division (PSD), Boulder, Colorado, USA, from their website at http://www.cdc.noaa.gov/ (*Kalnay et al.*, 1996). Latitudinal gradients in mean atmospheric pressure were also calculated using pressure fields from the NCEP/NCAR reanalysis.

The Mann-Kendall test for a trend with Sen’s slope estimates was used to detect and estimate trend magnitudes and their significances (*Sen*, 1968). This non-parametric method is widely used to calculate trends in the climate change community (*S H Wu et al.*, 2007; *You et al.*, 2008a).

The Mann–Kendall statistic S is calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad \mathrm{sgn}(x_j - x_k) = \begin{Bmatrix} +1 & if & x_j - x_k > 0 \\ 0 & if & x_j - x_k = 0 \\ 1 & if & x_j - x_k < 0 \end{Bmatrix}$$

The variance for the statistic S is defined by:

$$\mathrm{Var(S)} = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)}{18}$$

The test statistic Z is estimated as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & if \quad S < 0 \end{cases}$$

In which Z follows a standard normal distribution; If $|Z| > Z_{1-\alpha/2}$, where α denotes the significance level, then the trend is significant. Sen’s method is used to estimate the Kendall slope, and is defined as the median slope over all combinations of record pairs for the whole dataset. It is given as follows:

$$Q = Median(\frac{x_j - x_k}{j-k}); i = 1, ...N .$$

A trend is considered to be statistically significant if $P<0.05$.

3. Results and Discussion

3.1 The temporal and spatial distribution of wind speed

Figure 1 shows the distribution of mean wind speed over the TP during 1980-2005. The mean annual wind speed (top panel) gradually increases from the south-east to the north-west. The maximum mean wind speed occurs in the Hoh Xil area and the Qaidam Basin, with smaller values in the south and east of the TP. The minimum mean wind speed is recorded in eastern Tibet and northern Sichuan. The mean annual mean wind speed is 2.25m/s, but individual stations range from 4.98m/s in Wushaoling, Gansu, to 0.96m/s in Qamdo, Tibet.

Seasonal mean wind speed patterns are broadly similar to the annual pattern, with increases from the south-east to the north-west. In all seasons there is a relative minimum of wind speed where the three provinces of Tibet, Sichuan, and Qinghai meet. Maximum mean wind speed occurs in spring (2.78m/s), and values range from 5.69m/s to 1.27m/s (Maerkang in Sichuan). Winter is almost as windy (mean 2.18m/s), with a maximum of 5.21m/s (Wudaoliang, Qinghai) and a minimum of 0.78m/s (Qamdo, Tibet). In both winter and spring, surface and upper atmospheric circulation is controlled by the prevailing westerly wind belt (*Kang et al.*, 2010), resulting in stronger wind speeds overall. In summer, and to a lesser extent in autumn, the establishment and northward propagation of the south-west Indian monsoon and the movement of the upper westerly circulation system to the north, reduces mean wind speeds. The summer mean is 2.12m/s, with a maximum of 4.75m/s and minimum of 0.83m/s (Yushu, Qinghai). Autumn is even less windy (mean 1.91m/s) with a maximum of 4.72m/s and minimum of 0.77m/s in Qamdo, Tibet.

3.2 Trend analysis of wind speed since 1980

Figure 2 shows time series of wind speed over the whole TP during 1980-2005 on both an annual (top panel) and seasonal basis (other panels). Annual wind speed shows a statistically significant decrease of -0.24 m/s/decade (P <0.0001) (*You et al.*, 2010a). The decrease is rapid since 1990 and the lowest value was recorded in 2002. Since then there has been a slight short-term recovery.

The decrease is widespread with 87% of stations showing decreasing trends (significant at 66% of all stations). Trend magnitudes vary from -1.16m/s/decade to -0.25 m/s/decade. The strongest decreases appear to be concentrated around the northwestern Qaidam Basin, and parts of the south west and south east of the TP, consistent with rapid increases of the annual mean temperature in the same regions (*Kang et al.*, 2010; *You et al.*, 2008a). Further analysis of this relationship is discussed in section 3.3.1.

Seasonal wind speeds on the TP also show significant negative trends during 1980-2005. Wind speeds in all seasons are positively correlated with the annual mean, particularly in spring (r=0.94) and summer (r=0.96), so are expected to have broadly similar trends. Again trends are steepest in north-western and south-western parts of the TP. The spring decrease averages -0.29m/s (P<0.05) and about 89% of stations show a decrease (62% significantly so). Summer also has a significant reduction of 0.24 m/s/decade, with 93% (62%) of the stations showing negative (significant negative) trends. Rates for autumn and winter are slightly weaker at -0.19 and -0.23m/s/decade, respectively, with 89% (51%) and 89% (44%) of stations showing decreases (statistically significant decreases) (*You et al.*, 2010a).

3.3 Wind speed forcing factors

The following sections examine the relationships between wind speed changes and various air temperatures, solar radiation, atmospheric dynamics (as measured by the TP index) and elevation.

3.3.1 Relationship between wind speed and air temperature

Table 1 lists annual and seasonal trends of mean, minimum and maximum temperature in the TP during 1980-2004. Stations are selected from the China homogenized historical temperature dataset (1951-2004, version 1.0) (*Li et al.*, 2004), from the China Meteorological Administration. All mean temperatures, maximum and minimum temperatures show a significant increase. In most seasons warming rates for minimum temperature are more rapid than for maximum temperatures, thus leading to a reduced diurnal temperature range in the TP, consistent with previous studies (*Kang et al.*, 2010; *You et al.*, 2008a). Table 2 summarizes correlation coefficients between wind speed and mean, maximum and minimum temperature. Wind speed is negatively correlated with all three temperatures. Highly significant relationships occur both on an annual basis ($r=-0.60$, $p<0.001$ for minimum temperatures) and in summer and autumn ($P<0.001$). Strong negative relationships with minimum temperatures are particularly surprising since one might expect cold air drainage to encourage lower minima when conditions are calm (this would lead to a positive relationship). However this effect is overridden, and suggests that larger scale mechanical forces are just as influential. Weakening wind speeds are associated with rising temperatures in the TP, especially at night.

The horizontal pressure gradient is a direct cause of horizontal air flow. This in turn is driven by the horizontal temperature gradient (*You et al.*, 2010a). To examine whether weakening wind speed may be a result of larger scale weakened temperature (and thus pressure) gradients, the relationships between mean annual wind speed, surface temperature and pressure gradients were examined between low latitude (20°N-25°N; 85°E-105°E), middle latitude (35°N-40°N; 85°E-105°E) and high latitude (50°N-55°N; 85°E-105°E) bands (Figure 4), again using NCEP/NCAR reanalysis data. Wind speed has significant positive correlations not only with the surface temperature gradient between different latitudinal bands (Figure 4a, b) but also the surface pressure gradient in the same bands (Figure 4c, d). Clearly surface temperature and pressure gradients are positively correlated (Figure 4e, f). In previous work (*You et al.*, 2010a), it has been demonstrated that asymmetric warming trends in low, middle and high latitudinal bands have caused significant weakening in the latitudinal pressure gradients (both low to mid, and mid to high latitudes). This will lead to a regional decrease of horizontal temperature and pressure gradients and thus weaker winds. In winter this effect is dominated by warmer and more rapid warming in the north of the country, whereas in summer, slight cooling in the south east of China and warming over adjacent seas has weakened the land-sea temperature difference and therefore thermally generated wind speeds (*Guo et al.*, 2011; *Xu et al.*, 2006).

3.3.2 Relationship between wind speed and sunshine duration

Table 1 also shows that annual and seasonal sunshine duration in the TP during 1980-2005 have significantly decreased with an annual reduction of -65.12 hours/decade ($P < 0.01$), and an even steeper reduction in percentage terms in summer. The dimming may be associated with the observed increase in total cloud amount, especially low cloud cover, and an increase in atmospheric water vapor pressure and precipitation, as well as increased atmospheric aerosol content (*Wild*, 2009; *You et al.*, 2010b). Figure 3d illustrates that annual wind speed shows a positive correlation with sunshine duration ($r=0.59$:$P<0.001$). The relationship also holds in most seasons, apart from winter (Table 2). Despite the TP having the highest mean income of solar radiation in China, even here incoming solar radiation appears to be declining, consistent with dimming reported across the globe since the beginning of 1960s (*Wild*, 2009; *You et al.*, 2010b). This is not inconsistent with warming temperatures. Greenhouse warming is manifest more clearly at night, but even during the day, increased greenhouse long wave absorption would more than offset any cooling effect which would result due to dimming of solar radiation. Decreasing sunshine duration is also likely to weaken turbulence and atmospheric instability in the surface boundary layer, contributing to the overall reduction in wind speed.

3.3.3 Relationship between wind speed and Tibetan Plateau index

Table 1 also lists trends in the annual and seasonal TP index during 1980-2005. The index is essentially one of anticyclonicity with higher accumulated heights meaning higher atmospheric pressure over the plateau (and warmer air). The index shows positive trends over the period for all seasons, in accordance with general warming in the region (*Fu et al.*, 2011; *Liu and Chen*, 2000; *You et al.*, 2008a). The most pronounced upward trend occurs in winter with a rate of 10.30 m/decade ($P<0.05$), and only the trend in summer is insignificant. On an annual scale, wind speed is negatively correlated with the TP index ($r=-0.68$:$P<0.0001$). Negative correlations also occur in all four seasons, especially in autumn ($r=-0.73$, $P<0.05$) (Table 2). The TP is known to influence global and regional atmospheric circulation systems, such as mid-latitude westerlies and the Asian monsoon, through its powerful thermal and dynamic role (*Duan et al.*, 2006; *Kang et al.*, 2010; *G X Wu et al.*, 2007; *Yao et al.*, 2007; *Yao et al.*, 2012). An increasing TP index is therefore consistent with weaker surface wind speeds over the TP, but how this relates to long term changes in the mechanical and thermal forcing of the large scale circulation requires more research. A weakening of surface airflow over the TP, which at the height concerned (500 mb) is at the level of the westerly jet stream, suggests that the westerly circulation may have weakened. This would be consistent with the enhanced warming reported in the northern parts of the plateau (in comparison with the south) which would weaken the meridional temperature gradient (and hence pressure gradient) – see section 3.3.1. In summer however, monsoon winds are known to have weakened (*Xu et al.* 2006) which would also be consistent with a weakening of the thermal low pressure center (and thus an increase in TP index) with relatively rising pressure heights over the TP. However this is the only season in which the trend in TP index is insignificant in our study, so patterns are a lot less clear in this season.

3.3.4 Relationship between wind speed and elevation

Since topography and elevation can influence spatial patterns of wind speed in the TP (*You et al.*, 2010a) we examined the relationship between wind speed trends and elevation. Figure 5 shows the relationship between elevation and trend magnitude in wind speed during the studied period, and there is no strong pattern. Wind speed declines more or less consistently in all elevation bands, inconsistent with results from the south west of China (*Yang et al.*, 2012). *Yang et al.* (2012) demonstrated that the decrease of the mean wind speed was more pronounced at higher elevations in the Yungui Plateau of China, and that the correlation between elevation and trends of wind speed was statistically significant. However in that study all stations were below 1500 m. The failure to capture the elevation dependency above 2000 m in our study is in accordance with results examining trends in temperature and temperature extremes (*You et al.*, 2008b). Future studies are required to understand the inconsistent results on this issue (*Rangwala and Miller*, 2012).

4. Possible causes of weakening wind speed in the TP

Our analysis has demonstrated strong decreasing trends in wind speeds over the TP. These are associated with increased air temperatures, decreased meridional temperature and pressure gradients, decreased solar radiation and an increased TP index. Whilst many of these changes are consistent, it is important to understand the broader scale physical processes at work. In theory weakening wind speed could originate from a number of factors, which can be divided into two categories: natural and anthropogenic. Possible natural causes include increasing land surface roughness due to an increase in vegetation cover (*McVicar et al.*, 2012; *Vautard et al.*, 2010), a weakened meridional pressure gradient caused by asymmetric global warming (*Guo et al.*, 2011; *You et al.*, 2010a), regional and global changes in atmospheric circulation (*Vautard et al.*, 2010), changes in synoptic scale storm patterns (*Klink*, 1999), and topographic effects (*You et al.*, 2010a). Anthropogenic causes include land use change (*Klink*, 1999; 2002), urbanization (*Ren et al.*, 2008), anthropogenic emissions and air pollution (*Klink*, 1999; 2002), and changes of wind speed measurement, site maintenance and wind speed sensors (*McVicar et al.*, 2012). Both natural and anthropogenic causes interact to some extent. For example, both human air pollution such as coal combustion and emissions of sulfur aerosols, and urbanization associated withbuilding construction, can modify surface roughness and alter atmospheric stability in a similar way to natural vegetation cover, increasing friction and reducing kinetic energy of horizontal airflow, thus reducing wind speed (*McVicar et al.*, 2012; *Pryor et al.*, 2009; *Xu et al.*, 2006). However, compared with eastern China, the TP is influenced relatively less by human activities and its wind observations affected less by urbanization. Therefore natural causes are more likely to be the dominant influence on the trends seen in this analysis.

5. Conclusion

Spatial and temporal patterns of mean wind speed at 71 stations in the TP are examined, long term trends are described, and the relationships between wind speed and a number of related factors (sunshine duration, air temperature, temperature gradients and the TP index) are analyzed during 1980-2005. The following conclusions are drawn.

(1) Annual and seasonal mean wind speeds in the TP during 1980-2005 gradually increase from the south-east to the north-west of the region. Highest mean wind speeds occur in the Hoh Xil, Qaidam Basin, and a relative minimum occurs at the junction of Qinghai, Sichuan and Tibet. In most regions, spring is the windiest season, followed by winter, summer and then autumn.

(2) During 1980-2005, the regional annual wind speed has shown a significant decrease with a rate of 0.24m/s/decade. A (statistically significant) decrease is shown at (66 %) 87% of stations. Most stations with the steepest declines are in north-western and south-western areas but are not solely in these regions. The rate of decline accelerates after 1990, and lowest values were reached in 2002. Winds also show significant reductions in individual seasons, particularly in spring (0.29m/s/decade ($P<0.05$)) and summer (0.24 m/s/decade).

(3) During the same period, annual and seasonal mean temperature, maximum and minimum temperature, and the TP index (mean geopotential height) show significant increases, while sunshine duration has declined. In most cases, wind speed is significantly positively correlated with mean temperature, maximum and minimum temperature, and the TP index, and negatively correlated with sunshine duration, suggesting that those factors contribute to the change of observed wind speed. Climate warming may weaken the meridional temperature gradient and hence pressure gradient, which would account for weakening of wind speed in this region.

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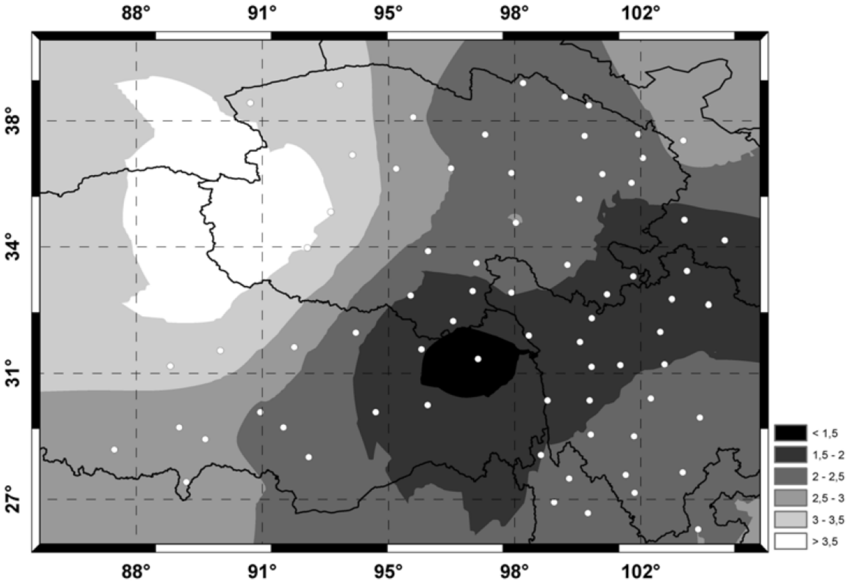
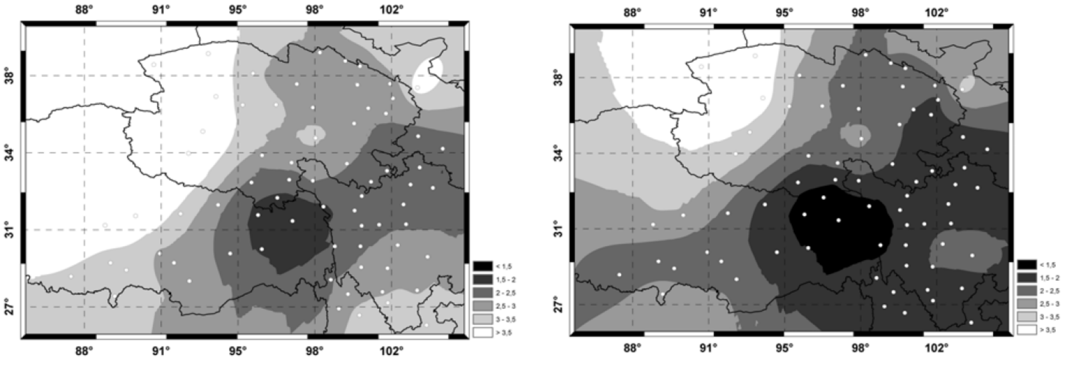
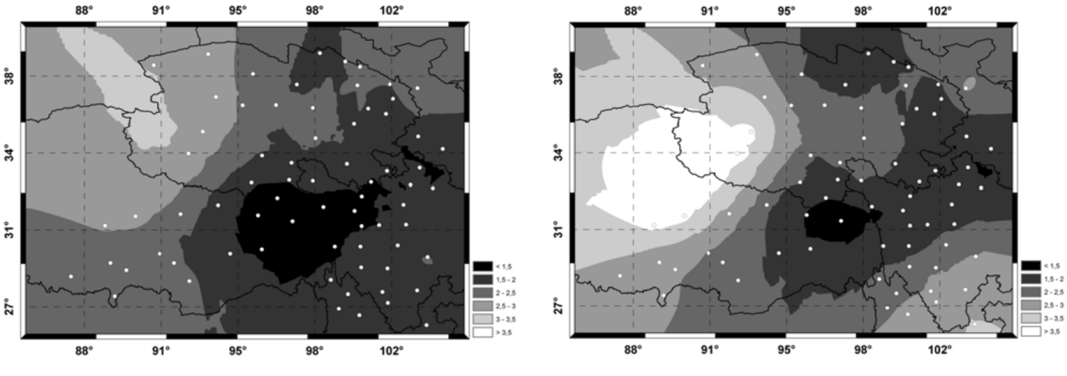
Figure



Annual



Spring Summer



Autumn Winter

Figure 1 The spatial patterns of annual and seasonal mean wind speed in the Tibetan Plateau during 1980-2005 (m/s)

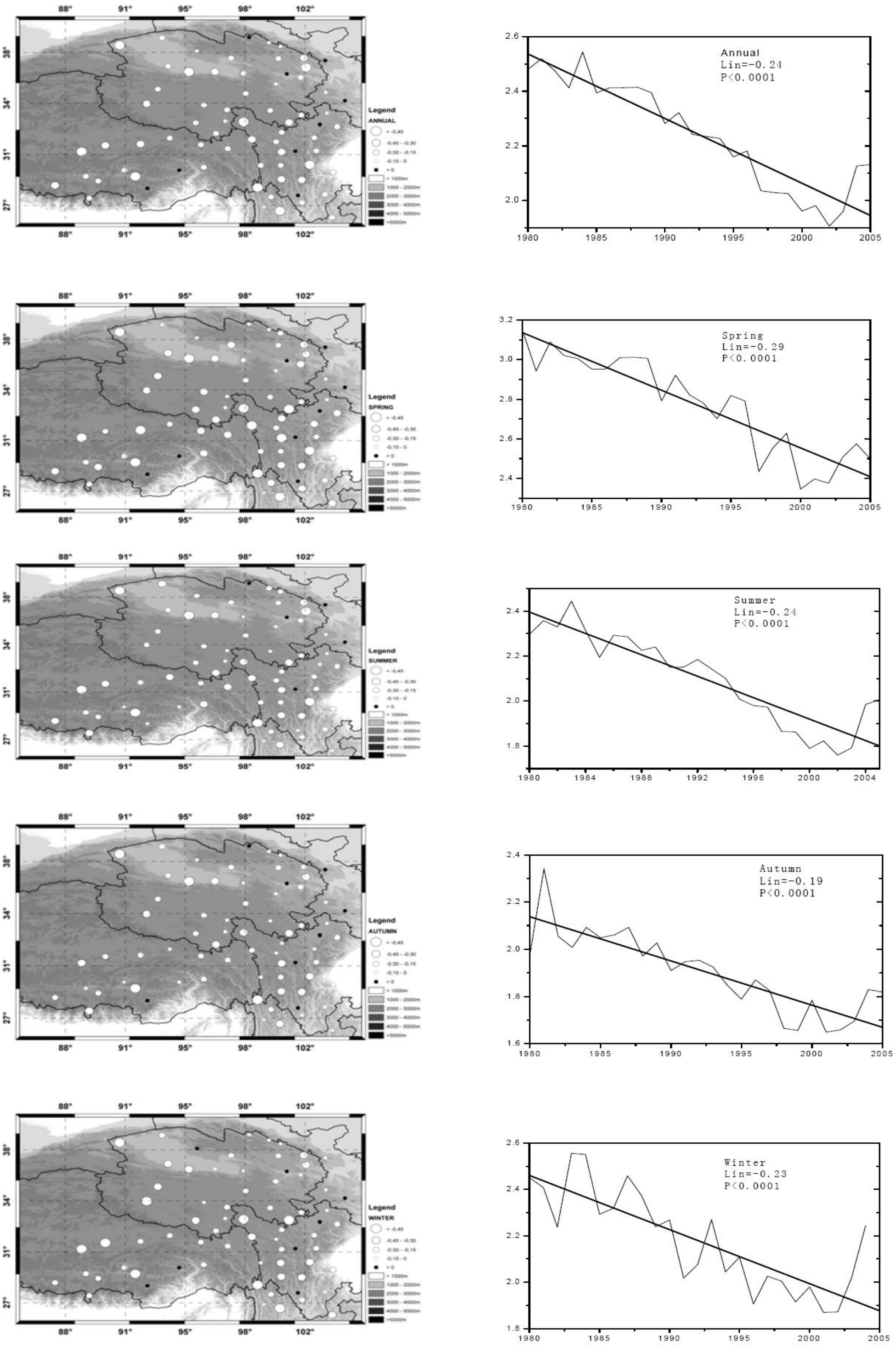


Figure 2 Maps of trend magnitude (from top left: annual, spring (MAM), summer (JJA), autumn (SON) and winter (DJF)) for mean annual/seasonal wind speed (m/s). Trend magnitudes are in m/s/decade. Graphs (from top right: annual, spring, summer, autumn, winter) of regionwide mean wind speed between 1980 and 2005. Lin represents the gradient of the trendline (converted to

m/s/decade) and P for significant level

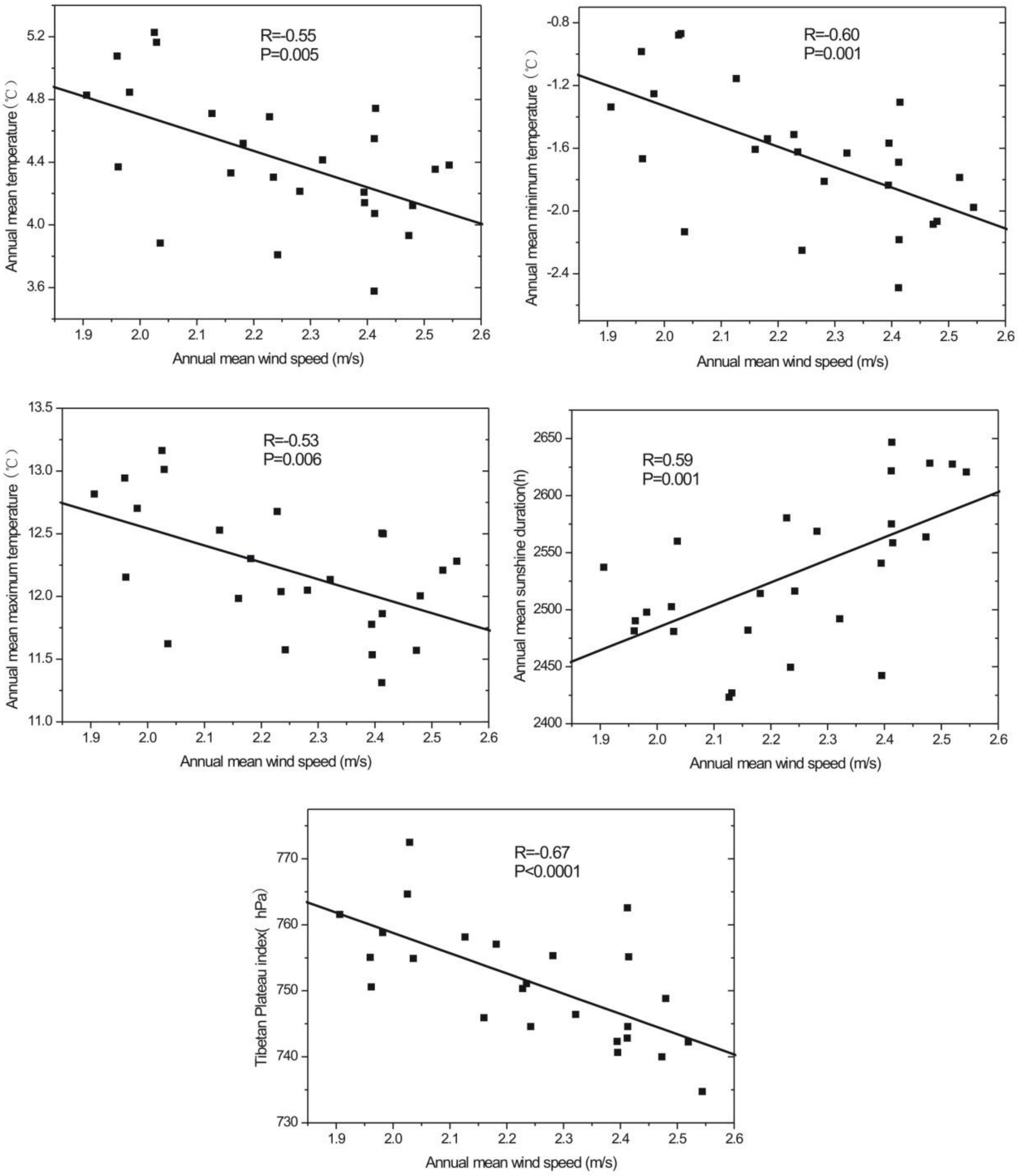


Figure 3 Relationships between annual mean wind speed and a) annual mean air temperature (top left), b) annual mean minimum air temperature (top right), c) annual mean maximum air temperature (middle left), d) annual mean sunshine duration (middle right) and e) Tibetan Plateau index (bottom) in the Tibetan Plateau during 1980-2004. R is the correlation coefficient and P the significance level

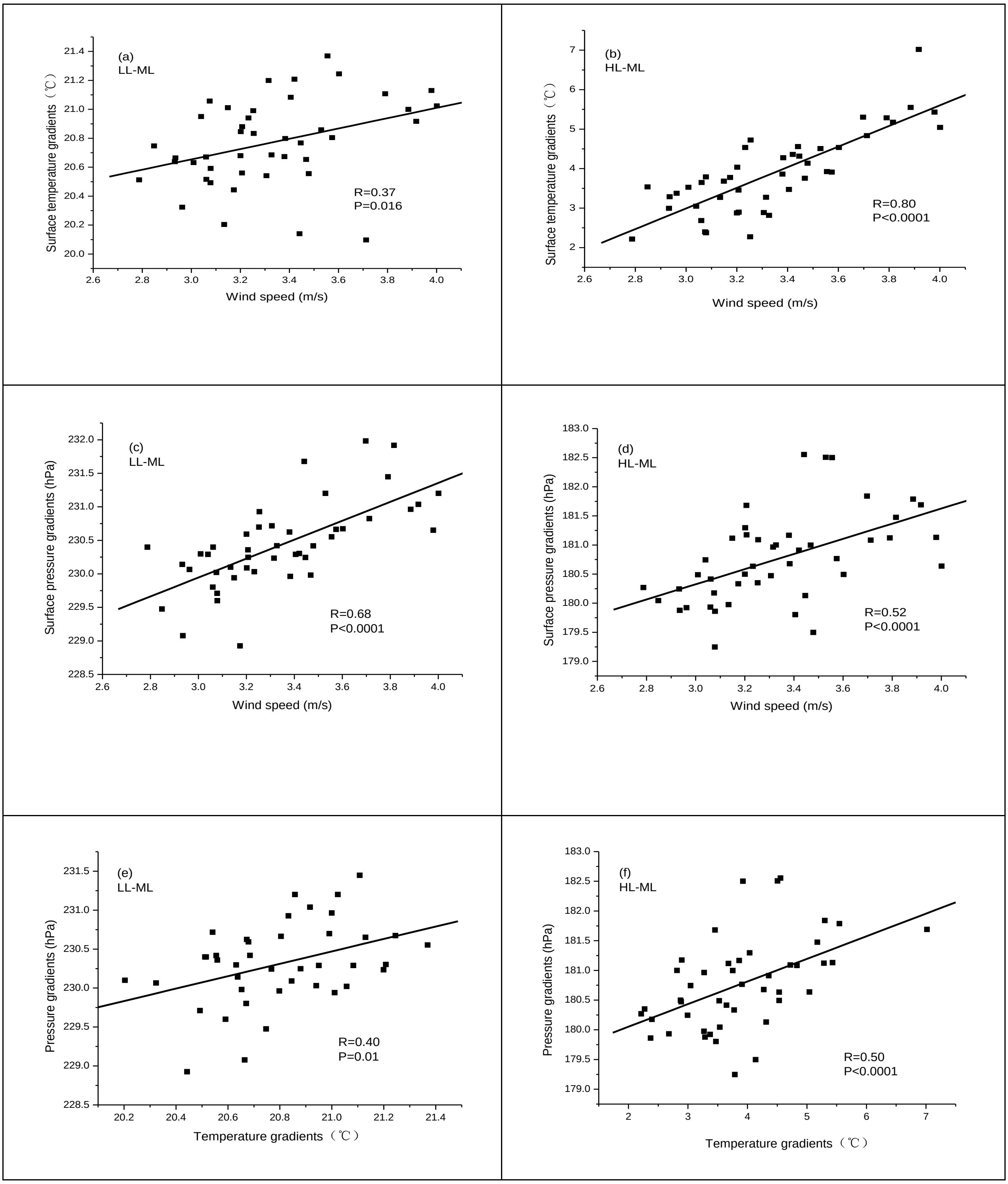


Figure 4 Relationships between annual regionwide mean wind speed, annual surface temperature gradients, and annual surface pressure gradients during 1961-2005. The straight lines are linear fits, and R stands for the correlation coefficient and P for statistical significance. Three regions of the Tibetan Plateau (85°E-105°E) are defined based on NCEP/NCAR reanalysis to define the

meridional temperature/pressure gradients: low latitude (LL) (20°N-25°N), middle latitude (ML) (35°N-40°N), and high latitude (HL) (50°N-55°N). Left hand panels relate to low vs middle latitudes (LL-ML), and right hand panels to middle vs high laitutdes (ML-HL)

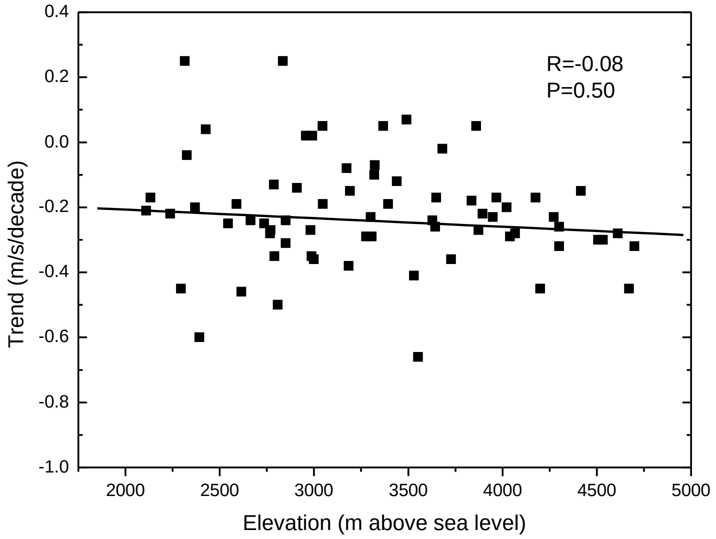


Figure 5 Relationship between the trend magnitude of annual mean wind speed and station elevation. The trend is calculated by the Mann-Kendall method during 1980-2005. R is the correlation coefficient and P the significance level

Table 1 Trends of mean air temperature, mean minimum air temperature, mean maximum air temperature, sunshine duration and the Tibetan Plateau index in the central and eastern Tibetan Plateau during 1980-2004 on an annual and seasonal basis

	Annual	Spring	Summer	Autumn	Winter
Mean temperature (°C/decade)	0.34**	0.38*	0.31**	0.38*	0.34
Minimum temperature (°C/decade)	0.39***	0.43**	0.38**	0.44*	0.42*
Maximum temperature (°C/decade)	0.42**	0.46*	0.32*	0.40	0.32
Sunshine duration (hr/decade)	-65.12***	-16.33***	-25.14*	-12.57*	-13.60*
Tibetan Plateau index (m/decade)	8.08***	9.32**	4.02*	7.04**	10.30**

Note: *** means P<0.01,** means P<0.05 and * means P<0.1

Table 2 Correlation coefficients between mean wind speed (m/s) and mean air temperature (°C), mean minimum air temperature (°C), mean maximum air temperature (°C), sunshine duration (hrs) and the Tibetan Plateau index (m) during 1980-2004 on an annual and seasonal basis

	Annual	Spring	Summer	Autumn	Winter
Mean temperature	-0.55***	-0.31	-0.59***	-0.60***	-0.05
Minimum temperature	-0.60***	-0.40	-0.56***	-0.63***	-0.11
Maximum temperature	-0.53***	-0.32	-0.46**	-0.56***	-0.07
Sunshine duration	0.59***	0.48**	0.42**	0.50**	0.26
Tibetan Plateau index	-0.68***	-0.67***	-0.53***	-0.73***	-0.48**

Note: *** means P<0.01, ** means P<0.05 and * means P<0.1