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OPINION

Is Global Strong Wind Declining?

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1 Introduction

To mitigate global warming, the call for using clean energy, developing low-carbon economy and initiating green environmental protection has never been louder. One of the hot topics, which has received widespread attentions in the world, is the development and utilization of wind energy. At the same time, some of the climate change studies focus on the changes in global wind speeds and strong winds which are related to wind energy utilization. The issues, which are the subjects of these studies, can be summarized in the following.

2 Is global mean surface wind declining?

Based on the results of *Jiang et al.* [2009] and the in situ observational data for the last 50 years, trends of the annual and/or seasonal mean wind speed over the globe, in the Northern Hemisphere, and in some regions and/or countries have been calculated. It is found that declining trends of the land-surface wind speeds are present over both middle and lower latitudes, and increasing trends over high latitudes and some oceanic regions. Table 1 gives examples from the latest global study of the trends. The first five rows are based on the continuous data from 822 in situ observation stations in the Northern Hemisphere for 1979–2008 [*Vautard et al.*, 2010]. It is evident that the declining trends are in Central Asia, East Asia, Southeast-South Asia, Europe, and North America. Over these areas, the surface wind speeds in the last 30 years have declined by about 5%–15% with a high confidence level (α=0.05). These results are consistent with the results of the studies for many regions and/or countries. To provide more cases, results from China and Australia are also shown in Table 1. Based on seven studies on surface mean wind in China for 1956–2004, annual and seasonal mean surface winds have apparent declining trends, especially in spring and in Northwest China [*Jiang et al.*, 2009; 2010a; *Guo et al.*, 2010; *McVicar et al.*, 2008; *Zhang et al.*, 2009].

It should be pointed out that some calculations based on reanalysis data of both NCEP/NCAR for the last 30 years and ERA40 for the last 20 years do not indicate any obvious declining trends of the near surface (at 10 m) annual winds over China. A study with the ERA40 data for the last 20 years found a 10% wind speed reduction over North America, a 50% reduction over Europe, and no obvious trends over other regions [*Vautard et al.*, 2010]. But *Jiang et al.* [2010a] found that with the NCEP/NCAR and ERA40 datasets for 1956–2004, the near surface annual mean wind speeds over China had declining trends of –0.12 and –0.05 m s^{-1} per decade, respectively.

The global distributions of trends in annual mean wind speed calculated from the two reanalysis data and the in situ observational data are so different. The conclusions derived from these calculations are vastly

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inconsistent. This naturally leads us to ask: is this caused by the impact of urbanization on the in situ observational data, by uncertainties in climate models, or by other reasons? There should be more attentions and further researches to resolve this issue.

Table 1 Samples of declining trends in annual mean wind speeds in some regions of the world (years for the first five rows are 1979–2008)

Regions	Number of stations	Wind change trends (m s^{-1} per decade)	Wind change rate (% per decade)
Europe (20°W–40°E, 30°–75°N)	276	–0.09	–2.9
Central Asia (40°–100°E, 30°–75°N)	96	–0.16	–5.9
East Asia (100°–160°E, 30°–75°N)	190	–0.12	–4.2
Southeast-South Asia (40°–160°E, 0°–30°N)	40	–0.08	–5.0
North America (170°–50°W, 30°–75°N)	170	–0.07	–1.8
China (1956–2004)	>500	–0.12	–5.0 to –9.0
Australia (1975–2006)	160	–0.09	–5.0

3 Are global surface strong winds weakening and their frequencies decreasing?

Some studies [*Vautard et al.*, 2010] indicated that the declining trends of the mean wind speeds over most regions of the world were the result of weakening in strong winds and decreasing in the frequencies. It was noted that the frequencies of winds with speed exceeding 5 m s^{-1} over East Asia, Central Asia, Europe, and North America decreased significantly, especially in East Asia (Table 2). Chinese studies provided more evidences on this. The annual and seasonal numbers of days with strong wind speed in China for the last 50 years have decreasing trends, especially in spring. The declining trends are also evident for both maximum wind speeds and the intensity of strong winds. On the other hand, both the number of days and intensity of non-strong-winds are increasing slightly [*Jiang et al.*, 2010a]. Other results for the regions (or countries) of the middle and lower latitudes have reached similar conclusions [*Jiang et al.*, 2009].

Table 2 Changes in annual frequency of wind exceeding a given threshold during 1979–2008

Wind speed (m s^{-1})	Europe (%)	Central Asia (%)	East Asia (%)	North America (%)
⩾1	0	0	2	–1
⩾3	–1	–6	–4	–2
⩾5	–5	–13	–10	–4
⩾7	–7	–18	–15	–5
⩾9	–11	–23	–19	–3
⩾11	–12	–24	–23	–3
⩾13	–11	–22	–30	–3
⩾15	–12	–23	–37	–11

Note: Annual frequency of wind ⩾1 m s^{-1} is the number of days with wind speed ⩾1 m s^{-1} in a year, others are defined in the same manner

4 Is global wind in the troposphere and stratosphere declining?

As mentioned above, the surface winds especially the strong winds in many regions are declining. How are the global winds changing in the whole atmospheric column? Table 3 shows the trends in wind at seven vertical levels in five regions of the world based on the radiosonde data [*Vautard et al.*, 2010; *Zhang et al.*, 2009]. It is noticed in Table 3 that there were increasing trends in wind speeds at six levels in Europe and North America with the exception at 1000 hPa where the wind speeds were decreasing. The wind speeds under 500 hPa were declining in Central Asia and East Asia, while increasing above 500 hPa. In China, the wind speeds from 1000 hPa to 200 hPa were declining. Why do different regions have different trends in wind speed in the atmospheric column?

Table 3 Trends of wind in troposphere and stratosphere (unit: m s^{-1} per decade)

Height	Europe	Central Asia	East Asia	North America	China
1000 hPa	–0.07	–0.13	–0.08	–0.12	–0.16
850 hPa	0.14	–0.05	–0.01	0.19	–0.04
700 hPa	0.14	–0.07	–0.02	0.17	–0.04
500 hPa	0.10	–0.08	–0.07	0.16	–0.12
400 hPa	0.20	–0.02	0.00	0.20	–0.18
300 hPa	0.35	0.05	0.09	0.25	–0.17
200 hPa	0.45	0.12	0.16	0.30	–0.17

Note: All data are from radiosonde data

What are the possible reasons for these characteristics? There have been limited number of studies in this field. Further researches are needed to answer these questions.

5 Cause of changes in global wind speed

Based on the in situ observational data, the surface mean and strong wind speeds over the land in the middle and lower latitudes over the past decades are declining, and the number of days of strong winds are also decreasing. Questions are what caused the declining.

5.1 *Changes in atmospheric circulation related to wind speeds*

The evidences indicated that cyclones in the middle latitudes of the Northern Hemisphere had drifted towards high latitudes in the past 50 years. Therefore, cyclone activities in the middle latitudes were decreasing, and the opposite was true in the high latitudes. This is the main reason why the mean wind speed and the number of strong wind days have been declining in the middle latitudes while increasing in the high latitudes [*IPCC*, 2007].

Some of the researches, which are concentrated on East Asia, have found that in the past 50 years annual, winter, and summer meridional circulation index in this region had decreasing trends, whereas zonal circulation index had increasing trends. Both the intensity of East Asian winter and summer monsoons were decreasing. Correspondingly, frequencies of cold waves and dust storms in the winter half years were decreasing remarkably. All these have contributed to the declining trends. Besides, the decreasing frequencies of tropical cyclones over the western North Pacific have led to the declining in mean wind speed in the coastal area [*Jiang et al.*, 2009; 2010a; *Jiang and Zhao*, 2011; *Zhang et al.*, 2009]. These investigators and their supporters believe that the change in atmospheric circulation can explain about 10%–50% reduction in wind speed [*Vautard et al.*, 2010].

5.2 *Land-surface changes*

The land-surface changes include urbanizations, land-surface properties, and wind farms. First, many studies focused on urbanization which caused wind speed declining due to fast growing of high buildings. Wind speeds in urban areas are smaller than those in rural areas. But the urbanizations do not change the declining trends of wind speeds [*Jiang et al.*, 2010a; *Guo et al.*, 2010; *Zhang et al.*, 2009].

Second, scientists have paid more attention to land-use changes. For example, afforestation and better vegetation conditions than before, as well as changes in agricultural practice had good relationship with wind speed changes. A numerical simulation using MM5 with roughness height change showed the impacts of land-use change on wind speeds. Based on the remote-sensing observations in 1982–2006, there was a widespread increase of vegetation in the Northern Hemisphere. The modeling results showed significant relationships between vegetation increase and decrease in wind speed and the magnitude of the wind speed reduction was in agreement with the observations [*Vautard et al.*, 2010].

Lastly, many wind farms have been built up and are in operation. The impact of wind farms on wind speeds in the downstream regions has been studied. Both the observed and modeling results indicated that wind farms reduce the downstream wind speeds, especially for the very large-scale wind farms. Suppose 10% or more of the total energy demand in the world by 2100 will be from wind powers, the wind farms will occupy 58×10^6 km^2 on land surface and 10×10^6 km^2 on the coastal regions. Based on this scenario, numerical simulation experiments using NCAR CCM3 were designed. Surface friction, roughness, drag and near-surface turbulence in the affected areas depend on the heights and the diameters of the wind turbines. The simulation results showed significant impact of wind farms on wind speeds. The intensities and extents of wind speed changes depended on height, horizontal areas and power capacity of wind farms [*Wang et al.*, 2009]. The investigators with this point view put forward that increased land-surface roughness in the past decades can explain about 25%–60% of wind speed reduction in the same period [*Vautard et al.*, 2010].

5.3 *Impacts of global warming caused by anthropogenic emissions on wind speed*

As projected by the IPCC AR4 climate models with the anthropogenic emissions, the sea level pressure is likely to decrease over high latitudes, polar region, North America, and Eurasia continent by the end of the 21st century. The projections also show that the temperate cyclones are likely to shift to high latitudes. Most atmospheric active centers will be weakening, and the winter monsoons will be declining. Therefore, wind speeds at middle latitudes in the respective winters of both hemispheres will continue to decline. However, different models projected inconsistent changes of summer monsoons [*Jiang et al.*, 2009; 2010a; *IPCC*, 2007]. A Chinese research obtained similar results as those projected by 20 global climate models and three regional models with the anthropogenic emissions [*Jiang et al.*, 2010b]. Thus, the effect of global warming on wind speed should be investigated further. Besides, there is a lack of studies on the possible existence of quasi-periodic oscillations and decadal variability of wind speed. This should be also considered in future. The investigations on the cause of declining in wind speeds in middle and lower latitudes are crucial for the prediction and projection of future global wind speed changes, as well as wind energy development and utilization. Research on wind speed changes has become a key topic in the world.

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