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Changes in ocean surface wind with a focus on trends in regional and monthly mean values

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ABSTRACT

Data collected from ships and satellites has frequently been used to estimate trends in surface wind speed. Although these data sets consistently show an increase in global average wind speed over recent decades, the magnitude of this increase varies depending on the data source used. Observations of the ocean surface by satellites, namely altimeter and SSM/I, provide reasonably long datasets with global coverage. These well calibrated and validated datasets are analysed for linear trends of regional mean monthly time series and mean time series for each calendar month over the period from 1991 to 2008. Differences between the resulting trends are investigated and discussed. The data indicate that the observed global trend is not uniformly distributed and can be linked to a significant positive trend in regional average time series across equatorial regions and the Southern Ocean. When trends for each calendar month are considered, the Southern Ocean showed a consistent increase for at least three continuous months. Although altimeter trends are consistently stronger than trends from SSM/I, the two datasets share similarities. For example, for some regions the trends are up to 2.0 times the global average trend. The data also show that the month of May exhibits one of largest positive trends and this was found across the North Indian Ocean which may indicate a shift in the onset time of the monsoon season.

1. Introduction

A number of recent studies have shown that over the last 30 to 50 years the ocean surface wind (and wave) climate has changed on global and regional scales (Wentz et al., 2007; Thomas et al., 2008; Tokinaga and Xie, 2011; Young et al., 2011; Hemer et al., 2013). Although these reports are based on a number of different observational techniques including ship observations and satellite data, all show a consistent positive trend over the last decades (Tokinaga and Xie, 2011; Young et al., 2012, provide reviews). Numerical model reanalysis with data assimilation systems provide additional support for such trends (Tokinaga and Xie, 2011; Young et al., 2011). However, trends obtained from numerical model reanalysis data may be artificial in nature due to changes in assimilation systems and physical upgrades to the model (e.g. Chawla et al. (2013)).

If mean surface winds are truly increasing, then there is the potential that the extreme values are also increasing, which in turn is critical for coastal and offshore engineering design (Young et al., 2012; Hemer et al., 2013). As global data (satellite) spans only a few decades it is, however, possible that rather than being a long term trend, the increasing wind speed may be part of a multi-decadal oscillation.

In all, there are five different data sources which suggest increasing trends in wind speed: ship observations (Gulev et al., 2003), in situ buoy data (Thomas et al., 2005), numerical model reanalysis studies (Tokinaga and Xie, 2011), altimeter data (Alves and Young, 2003; Young et al., 2011; Vinoth and Young, 2011) and Special Sensor Microwave/Imager or SSM/I data (Wentz et al., 2007; Tokinaga and Xie, 2011). However, the magnitudes of the trends reported vary significantly. Almost all of these studies involve the study of either global average trend or the trend at specified points obtained from monthly mean values. The development of a better understanding of the mechanisms responsible for the observed results requires studies which consider how the observed trend varies by region and whether the trend varies by month (e.g. does the trend change with season?). In addition, the apparent inconsistency in reported values of the magnitude of the trend requires investigation.

This paper extends these previous studies by comparing calculated trend from SSM/I and altimeter, not only at specified points over the duration of the record but also across regions of the globe and by month. The paper contrasts the difference in the calculated trend and compares these instruments as well as

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commenting on the other data sources. In particular, the limitations of each of the instruments are highlighted as they relate to the determination of the trend in wind speed.

The arrangement of this paper is as follows. Following the Introduction in Section 1, Section 2 provides a summary of previous studies of changes in ocean wind speeds and compares these results. Section 3 looks critically at the instrumentation and data analysis used in these previous studies and attempts to rationalize the differences in reported trend. Section 4 describes the data and analysis techniques used in the present paper. This is followed by Section 5, which describes the results and discusses the implications of these results. Conclusions are provided in Section 6.

2. Observation of long term trends in wind speed

As noted above, there are five instrumentation systems which have been used to study trends in wind speed: ship observations, in situ anemometers, numerical model reanalysis studies and remote sensing data from altimeters and SSM/I radiometers. In addition, wave measurements from buoys and satellite altimeters (Young and Holland, 1996; Young, 1994, 1999b) add some addition insight, as changes to wave climate are related to changes to winds.

Ship observations provide the longest data record of oceanic winds, although the geographic distribution is limited to major shipping routes. Cardone et al. (1990) and Thomas et al. (2008) used the International Comprehensive Ocean-Atmosphere Data Set (ICOADS, Worley et al., 2005) and reported a positive trend in mean wind speed since the 1940s. Further analysis by Peterson and Hasse (1987) and Ramage (1984), however, attributed much of this apparent increase in wind speed to spurious effects caused by changes in ship anemometer height over time. Thomas et al. (2005, 2008) adjusted the data records for changes in anemometer height, finding a positive trend of up to 0.10 m s^{-1} decade^{-1} (for the period 1958–1981), with higher values in more recent years. Tokinaga and Xie (2011) reanalyzed these same records in detail to develop the Wave and Anemometer-Based Sea Surface Wind (WASWind) archive and determined a global trend in mean wind speed of 0.084 m s^{-1} decade^{-1} (for the period 1988–2008) and 0.107 m s^{-1} decade^{-1} (for the period 1979–2008). Note that these results are not truly global averages as they are limited to areas where ship observations are available. As a result, areas such as the Southern Ocean are largely excluded. Despite ongoing questions about the reliability of ship observations, these studies consistently report positive trends of approximately 0.10 m s^{-1} decade^{-1}.

Buoy data is clearly limited in geographic extent. Gower (2002) considered buoy data from a number of locations across the North Pacific and determined wind speed trends ranging from −0.02 to 0.35 m s^{-1} decade^{-1} (for the period 1977–2000). Young et al. (2011) examined data from 12 National Data Buoy Centre (NDBC) buoys from the continental US coast and Hawaii. They found positive trends in wind speed from all buoys ranging from 0.005 to 0.056 m s^{-1} decade^{-1} (for the period 1991–2008). Trends in wave height from these same buoys was, however, less conclusive with a generally positive trend but a minority of buoys showing a negative trend in mean wave height. Although buoy measurements of wind speed might initially be regarded as "ground truth", as pointed out by Kent et al. (2013) buoy data is limited by influences such as: correcting measurements to a reference height of 10 m, atmospheric stability which alters the structure of the atmospheric boundary layer and the impact on long-term records caused by changes in instrumentation and buoy structure over the period of the data record.

Tokinaga and Xie (2011) also considered global trends in wind speed predicted by four numerical model reanalysis data sets: National Center for Environmental Protection (NCEP)/National Center for Atmospheric Research reanalysis (NRA1, Kalnay et al., 1996), NCEP-Department of Energy Reanalysis 2 (NRA2, Kanamitsu et al., 2002), European Centre for Medium-Range Weather Forecasting 40 Year Reanalysis (ERA40, Uppala et al., 2006) and the Japanese Reanalysis (JRA, Onogi et al., 2007). All four reanalysis data sets indicated positive trends in global average wind speed, ranging between 0.066 and 0.171 m s^{-1} decade^{-1}. Young et al. (2011) also considered the NCEP (Kalnay et al., 1996) reanalysis, obtaining a global trend in mean wind speed of 0.108 m s^{-1} decade^{-1} (for the period 1992–2009).

Wentz et al. (2007) and Tokinaga and Xie (2011) both considered SSM/I satellite radiometer data, obtaining global average mean wind trends of 0.08 and 0.134 m s^{-1} decade^{-1}, respectively. The difference is presumably due to different analysis techniques, different periods over which the trend was determined and different regions included in the global average. Young et al. (2011) considered altimeter data from multiple missions obtaining a trend in mean global wind speed of 0.192 m s^{-1} decade^{-1}. The Young et al. (2011) data indicated that trends in 90th and 99th percentiles were larger than the mean, suggesting that extreme winds were increasing faster than the mean conditions. This possibility was further investigated by Young et al. (2012). The corresponding Young et al. (2011) altimeter wave height data indicated a smaller trend in mean significant wave height, consistent with the buoy data. The altimeter wave height data did, however, indicate an

Table 1
Trends in mean surface wind speed from selected reports based on various analysis techniques and data sources (see Section 2 for acronyms). Regions analysed are listed by region (e.g. NH—northern hemisphere, SH—southern hemisphere).

Database	Period	Trend (m s^{-1} decade^{-1})	Coverage	Reference	
Ship reports	ICODS	1958–1981	0.100	NH, partially SH	Thomas et al. (2008)
		1882–2002	0.200		
	WASWind	1979–2008	0.107		Tokinaga and Xie (2011)
		1988–2008	0.084		
Buoys	-	1977–2000	−0.02–0.35	North Pacific	Gower (2002)
	NODC	1991–2008	0.005–0.056	US Coast, Hawaii	Young et al (2011)
Model reanalysis	ERA40	1982–2002	0.060	NH, partially SH	Thomas et al. (2008)
	NRA1	1982–2002	0.050		
	NRA1	1988–2008	0.066		Tokinaga and Xie (2011)
	NRA2	1988–2008	0.120		
	JRA	1988–2008	0.171		
	NRA1	1991–2008	0.108	NH, SH	Young et al (2011)
Satellites	SSM/I	1987–2006	0.080	NH, SH	Wentz et al. (2007)
		1998–2008	0.134	NH, partially SH	Tokinaga and Xie (2011)
	Altimeter	1991–2008	0.192	NH, SH	Young et al. (2011)