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Assessment of the global ocean wind energy resource

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ABSTRACT

Against a background of an environmental and resources crisis, the exploitation of renewable and clean energy can effectively alleviate the energy crisis and contribute to emission reduction and environmental protection, thus promoting sustainable development. This study aims to develop a grade classification map of the global ocean wind energy resource based on CCMP (cross-calibrated, multi-platform) wind field data for the period 1988–2011. We also calculate, for the first time, the total storage and effective storage of wind energy across the global ocean on a $0.25^\circ \times 0.25^\circ$ grid. An optimistic increasing long-term trend in wind power density was found. In addition, the global ocean wind energy resource was analyzed and regionalized by considering the temporal and spatial distributions of wind power density, wind energy levels, and effective wind speed, as well as through a consideration of wind energy storage and the stability and long-term trends of wind power density. This research fills a gap in our knowledge in this field, and provides a reference point for future scientific research and development into wind energy resources such as wind power generation, water pumping, and wind-heating.

Contents

1. Introduction

Against a background of an environmental and resources crisis, the ongoing development of clean energy sources seems increasingly inevitable if we are to deal with climate change and the

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Nomenclature

ADEOS-II	advanced earth observing satellite, 2nd generation
AMSR-E	advanced microwave scanning radiometer-earth observing system
CCMP	Cross-calibrated, multi-platform
C_v	coefficient of variation
DOE	Department of Energy of the United States
ECMWF	European Centre for Medium-Range Weather Forecasts
ECOP	ECMWF operational
ERA-40	40-year ECMWF re-analysis
MAM	March, April, and May
M_v	monthly variability index
PO.DAAC	Physical Oceanography Distributed Active Archive Center
RSS	remote sensing systems
SSM/I	special sensor microwave imager
S_v	seasonal variability index
TC-114	Technical Committee 114
TMI	tropical rainfall measuring mission microwave imager
VAM	variational analysis method
WW3	WAVEWATCH-III

energy crisis [1,2]. Currently, the utilization of solar and on-land wind energy is trending towards industrialization, although both are restricted by geographical factors. Despite nuclear power generation being an effective energy source, it is also vulnerable to natural disasters and human error. For example, both the nuclear leakage caused by the tsunami in January 2011 in Japan, and the Chernobyl nuclear disaster caused by operator errors in 1986, resulted in extremely serious consequences. Offshore wind energy offers substantial advantages over land-based turbines, including resource storage and greater stability [3–6]. Electivity generation by wind power is the principal mode of wind energy resource development, but wind power also has wide applications within navigation, water pumping, wind-heating, etc. However, offshore wind power generation can provide the solutions of most practical value and so meet urgent demands associated with problems such as coastal cities with a high demand for electricity, thereby closing the huge energy gap, and can serve remote islands, lighthouses at sea, marine weather buoys, and other power supply scenarios in marine areas. This largely impeded the economic leap of the coastal city and rural island, meanwhile this predicament promises offshore wind power with broad prospects. Consequently, the promise of abundant wind energy has become a particular area of interest for developed countries [7,8].

The distribution of wind energy resource shows significant regional and seasonal differences, and in the large-scale development of wind power, the basic principle is one of ‘resource evaluation and planning ahead’. Blanco [9] calculated the onshore and offshore wind energy cost in Europe and pointed out that the local wind resource is by far the most important factor affecting the profitability of wind energy investments. An on-land wind energy distribution map of the United State was drawn up in 1986 using observations from 1000 weather stations [10]. The Risoe National Laboratory in Denmark collected observational data from 220 stations in 12 European countries, and then developed an on-land wind-energy distribution map for Europe [11]. Previous researchers have made great contributions to the assessment of the potential of wind energy, but due to the lack of offshore wind data, most previous studies have focused on land, coastal, or local sea sites, rather than the global ocean wind-energy resource. In 1994, Gaudiosi [12] presented the characteristics of offshore wind-energy activity for the Mediterranean and other European seas. Emphasis was given to wind resource assessment, technical development, applications, economics, and environment. To promote wind energy in Senegal, Youm et al. [13] analyzed the wind energy potential along its northern coast, using wind data collected over a period of 2 years at five different locations. With an annual mean wind speed of 3.8 m/s, an annual energy of 158 kWh/m^2 could be extracted. Results show that a potential use of wind energy in these locations is water pumping in rural areas. Karamanis [14] analyzed the wind energy resources on the Ionian–Adriatic coast of southeast Europe and showed that the mean wind-power densities were less than 200 W/m^2 at 10 m height, suggesting the limited suitability of these sites for the usual wind-energy applications. However, these results indicate that wind power plants, even in lower-resource areas, can be competitive in terms of the energy payback period and reducing greenhouse emissions. With the rapid development of ocean observation technology, increasing amounts of satellite wind data have been used to analyze wind-energy resources. In 2008, NASA [15] and Liu et al. [16] contoured global wind-power density in JJA (June, July, and August) and DJF (December, January, and February), using QuikSCAT wind data. They found that the wind power density in the winter hemisphere is significantly higher than that in the summer hemisphere. During JJA, the regions of highest wind power density are located mainly around the Southern Hemisphere westerlies (ca. 1000–1400 W/m^2) and the waters surrounding Somalia (ca. 1200 W/m^2). During DJF, the areas of highest wind power density are located mainly around the Northern Hemisphere westerlies (ca. 1000–1400 W/m^2). Obviously, the wind power around the Southern Hemisphere westerlies during DJF is less than that during JJA.

However, until now, there has been no comprehensive assessment of the distribution of the grade (see Table 1) of global ocean wind energy resources. This study presents a grade classification map of the global ocean wind energy resource based on CCMP (cross-calibrated, multi-platform) wind field data for the period 1988–2011, and also calculates, for the first time, the total storage and effective storage of wind energy across the global ocean (on a $0.25^\circ \times 0.25^\circ$ grid). Synthetically considering the wind power density, the distribution of wind energy levels and effective wind speeds, the stability and long-term trend of wind power density, and wind energy storage, we were able to analyze and regionalize the global ocean wind energy resource. The aim of this research is to fill the gap in our understanding in this field and provide guidance for future scientific research and development into wind energy resources such as electricity generation, water pumping, and wind-heating. We also hope to make a contribution towards alleviating the energy crisis and promoting sustainable development.

2. Wind field data

The CCMP wind field data are hosted at the Physical Oceanography Distributed Active Archive Center (PO.DAAC) and have been evaluated and utilized extensively by the scientific community [17]. The data are derived through the cross-calibration and assimilation of ocean surface wind data from SSM/I (Special Sensor Microwave Imager), TMI (Tropical Rainfall Measuring Mission Microwave Imager), AMSR-E (Advanced Microwave Scanning Radiometer-Earth Observing System), SeaWinds on QuikSCAT, and SeaWinds on ADEOS-II (Advanced Earth