

COASTAL WIND ANALYSIS BASED ON ACTIVE RADAR IN QINGDAO FOR OLYMPIC SAILING EVENT

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ABSTRACT:

The purpose of this research is to investigate the Qingdao coastal wind field properties as a preparation for the 2008 Olympic sailing event based on space-borne Scatterometer and Synthetic Aperture Radar (SAR). Scatterometer data from SeaWinds instrument onboard QuikSCAT from 1999 to 2007 are collected as the main data source for a spatial and temporal wind field analysis near the Qingdao coast. Envisat Advanced Synthetic Aperture Radar (ASAR) images are used, too for this case study for the Qingdao 2007 International Regatta Sailing Competition. Wind speed retrieved from the ASAR image is compared to QuikSCAT data and *in-situ* buoy measurements.

1. INTRODUCTION

Qingdao, a coastal city in eastern China will host the 2008 'Good-Luck' Beijing Olympic Sailing Events in August. The sailing competition spots are shown as red line circle and marked A, B, C, D, and E in Figure 1. The position of the buoy marked with red A, B and C in the racing area is shown as well in the figure.

Qingdao is a city surrounded by sea and hills. In the south of the city, i.e., in the north of the sailing area, there are some mountains in particular Qingdaoshan (150m), Fushan (370m) and Laoshan (1100m). The topography is complex and local weather is variable. The dominant weather system in summer season is the subtropical high pressure system over the western Pacific Ocean. According to historical records and analysis, the weather in Qingdao is usually calm, humid and wind speed is lowest in August.

Accurate wind field measurements play an important role for the sailing competitions. The proper wind speed for sailing is 2.5-18 m/s. The measured error for wind speed is requested less than 1 m/s and 50 degrees for wind direction. Traditional *in-situ* buoy data obtained are insufficient, as data time series are too short, and only defined at a single location. Furthermore the wind flow models usually used are difficult to accurately extrapolate the data from the point measurement over the entire area of interest.

Previous researches on the Qingdao coastal area mainly focus on the seasonal sea breeze analysis. Wu and Long [1] studied the local wind system characteristics based on the statistics of synoptic and weather station measurements. Also research using the local meteorological model, described by Chang and Wu in [2], was carried out. In 2006, there was a test event for the 2008 Olympic Sailing Event; Sheng et al. investigated the three-dimensional structure of the sea breeze using data from buoy, automatic stations, Doppler radar and Lidar in [3]. However, there is no long time series record analysis with the observation of space borne sensors for the wind field properties

in Qingdao coastal area. In order to provide a better climatology of wind for the 2008 Olympic sailing events, wind speed statistical analysis of the historical Augusts from 1999 till 2007 using the QuikSCAT data are investigated in the paper. The temporal and spatial properties of the wind field in August are demonstrated. A case study from August, 20, 2007 for Olympic test event—International 2007 Regatta investigated using ASAR and QuikSCAT data, together with buoy measurements is given. The fine scale two-dimensional wind field retrieved from the ASAR image shows the variability of wind speed in the coastal area due to the seasonal sea-land breeze.

The paper is organized as follows. Part 2 is the data set description for scatterometer and SAR. Part 3 is the introduction of wind vector retrieval algorithm for scatterometer and SAR. In the fourth part, wind climate of the Qingdao coastal area is analyzed, based on QuikSCAT 25 km grid products. In the following part, a case study for 2007 Qingdao International Regatta Sailing Event is demonstrated. Finally, conclusions are given.

2. DATA SOURCE

Active radar can operate independent of weather, day and night, which provides the possibility to observe the area of interesting continuously.

2.1 Scatterometer Data

The scatterometer data used in this research are obtained from the SeaWinds instrument on QuikSCAT launched on June 19, 1999. Level 3 daily and gridded ocean wind vector data (speed and direction) are used for this analysis. The spatial resolution is 0.25 degree. Daily two times (ascending and descending) measurements can be obtained in Qingdao area at early morning and late in the afternoon depending on the orbits. Detailed description of QuikSCAT products can be found at (QuikSCAT Science Data Product User's manual, 2006).

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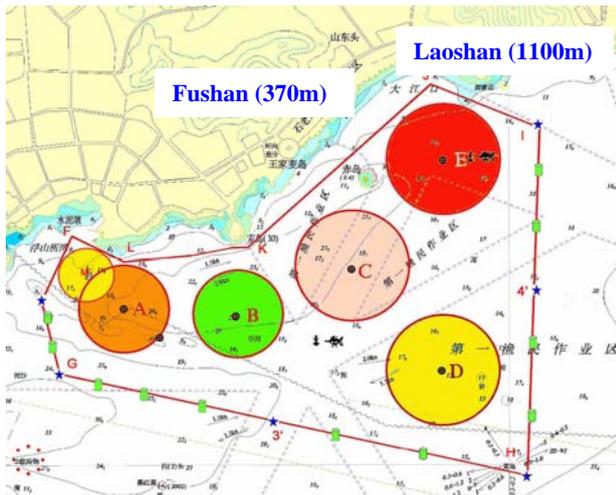


Figure 1. Schematic map for Sailing Events

2.2 Synthetic Aperture Radar (SAR) Data

In the research, data from ASAR onboard ENVISAT launched by ESA in 2002 is selected for high resolution coastal wind field analysis. ASAR operates in different modes, as a conventional Strip map SAR (also known as the image mode, shown in Figure 2) as well Scan SAR mode. When operating in image mode, the antenna array has the flexibility to allow ASAR to alter the swath width by varying the size of the pulsed-Doppler beam and the incidence angle, thus it has a swath width between 56 to 100 km and a resolution about 30 m. For coastal wind field retrieval, the high resolution image mode data is needed.

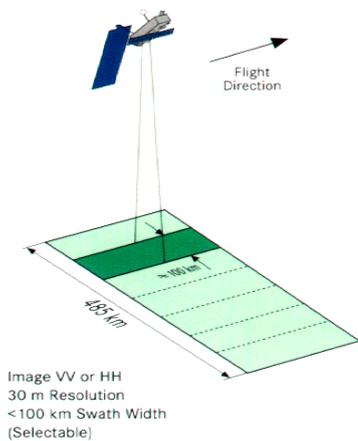


Figure 2. ASAR image mode (© ESA)

3. WIND FIELD RETRIEVAL ALGORITHM

Surface wind vector observations derived from space-borne scatterometer measurements have been available since the launch of the ERS-1 platform. The empirical geophysical model function (GMF) relating the wind speed, direction to the normalized radar cross section (NRCS) provides possibility to derive the wind vector from scatterometer ocean surface measurements by the CMOD4 function described by Stofflen and Anderson (1997). Vachon and Dobson (1996) and Lehner

et al. (1998) extended the CMOD algorithm to investigate wind speed on SAR data. As an improved GMF function, CMOD5 function is developed by ECMWF and KNMI for use with ERS-2 and ASCAT scatterometer (Hersbach *et al.*, 2007). CMOD5 algorithm is used as an extension of CMOD4 for ocean surface measurements in extreme wind conditions (e.g. hurricanes). For SAR images, this is investigated by Reppucci and Lehner (2007).

4. WIND CLIMATE ANALYSIS

Using the QuikSCAT 25 km grid products, the wind climate in Qingdao coastal area is analyzed. The area of Interest (AOI) for wind climate analysis is chosen as 35°N~36.5°N, 120°E~122°E. The analyzed period is nine years spanning from 1999 to 2007.

4.1 Monthly Wind Speed Distribution

In the AOI, all QuikSCAT data in the historical Augusts from 1999 to 2007 are selected to evaluate the monthly wind speed distribution.

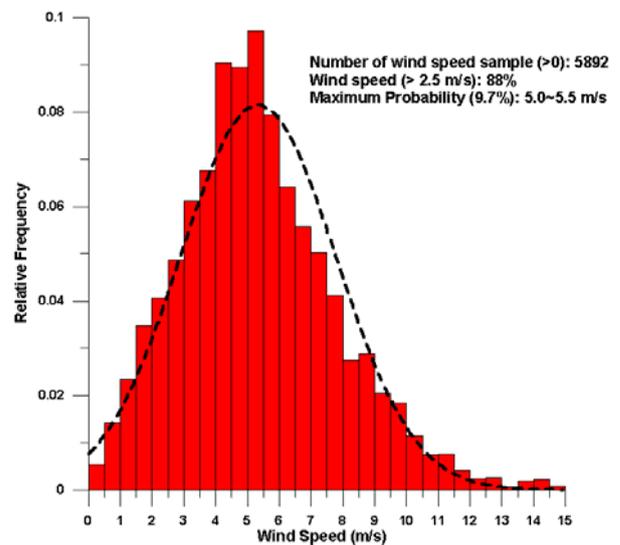


Figure 3. QuikSCAT data Monthly Wind Speed Distribution

The wind speed distribution of August at Qingdao coastal area shows a near Gaussian distribution (dashed line). The bin size for statistics is chosen to be 0.5 m/s. Average wind speed is 5.3 m/s and standard deviation is 2.4 m/s. This shows that maximum probability of wind speed is 5~5.5 m/s, which agrees well with the historical records. Nearly 88% wind speed is larger than 2.5 m/s, which fits the requirements for the sailing competition.

4.2 Wind Speed Spatial Analysis

Usually, QuikSCAT has a twice daily coverage in the AOI depending on the orbit. Figure 4 shows the gridded average wind speed during the investigation period.

However, there is no data coverage near the coast as the resolution is 0.25 degree for the Level 3 product. From the plot, it is observed that the wind field in the AOI is stable and most of the measurements are in the range of 4~6 m/s, which also agrees well with the monthly wind speed distribution statistics.

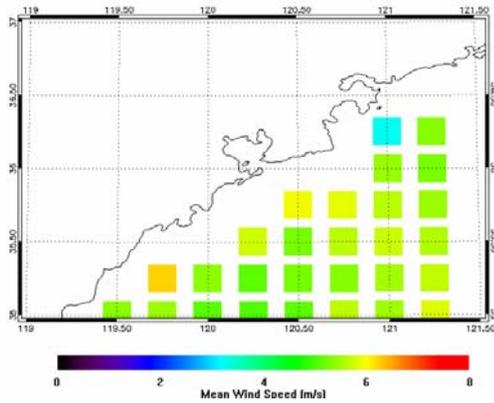


Figure 4. QuikSCAT data Grid Average Wind Speed

4.3 DAILY MEAN WIND SPEED

The 2008 Olympic Games will open on August 8. The sailing events are scheduled for August 16 to 21, 2008. Based on QuikSCAT data, the daily mean wind speed can be calculated in the Augusts from 1999 to 2007. The statistic results are shown in Figure 5. It can be found, that during August 16 to 22, there are five days when the daily mean wind speed is larger than the monthly mean wind speed (5.3 m/s). Figure 6 shows the daily mean wind speed difference to the monthly mean wind speed. During this period, the average difference is 3.4 m/s. Thus it can be concluded there is a high possibility during the period to have the larger mean wind speed around 6 m/s.

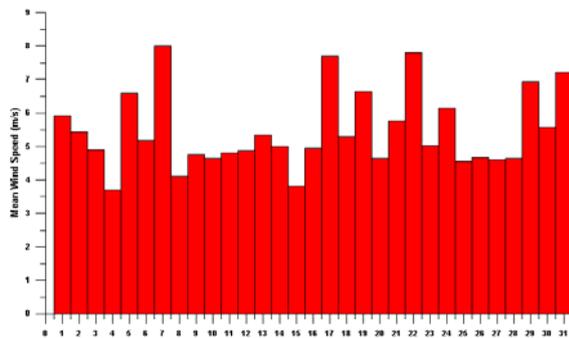


Figure 5. Daily Mean Wind Speed

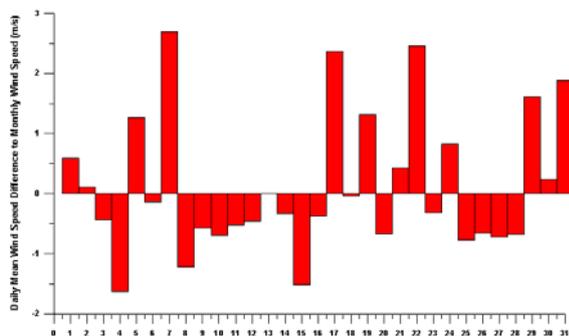


Figure 6. Daily Mean Wind Speed Difference to the Monthly Mean Wind Speed

5. CASE STUDY FOR 2007 TEST EVENT

5.1 ASAR Retrieved Wind Field Analysis

The 2007 Qingdao International Regatta was held at the Qingdao International Marina Olympic Sailing Center from August 9th - 24th, 2007 with a sailing competition in Fushan Bay from August 15th - 23rd. Using available satellite data and in situ observations, wind field features during the period are analyzed as follows.

The background wind field is derived from the QuikSCAT data (Level 2, 12.5 km resolution) obtained at around 17:00 local time as represented in Figure 7. It is observed that the QuikSCAT cannot provide the wind field close to the coast. The wind direction information from QuikSCAT is used as the first guess information for ASAR wind direction retrieval.

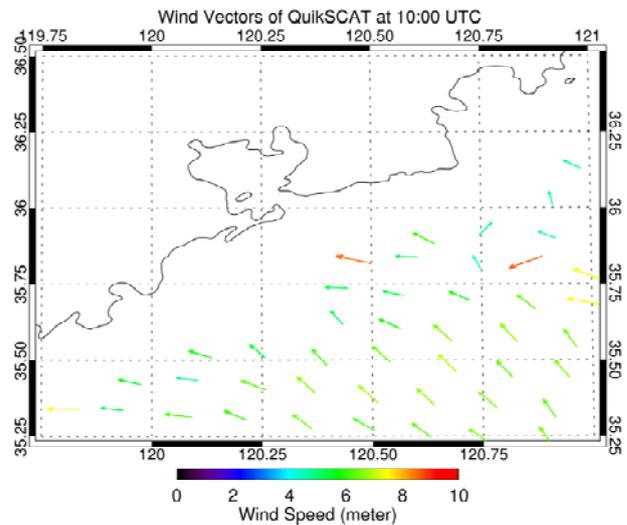


Figure 7. Wind Field over Qingdao Coastal Area derived from QuikSCAT acquired on Aug.20, 2007 at around 10:00 UTC

An ASAR image was acquired on August 20, 2007 at 13:46 UTC (Beijing time 22:46). Wind field derived from SAR data is demonstrated in Figure 8.

In the competition area (drawn as a yellow square represented in Figure 8), wind speed is fairly low, about 3-4 m/s and direction is south-easterly. One reason for the low wind speed is that the SAR image was obtained late at night. Qingdao coastal area has variable wind field in summer time during one day because of the change of sea-land breeze. The sea breeze usually develops into its highest value at 17:00 local time and then wind speed decreases quickly and the minimum wind speed is reached between 20:00-22:00. The tendency of the whole wind field imaged by SAR is that wind speed gradually increases from eastern to western coastal area. The maximum wind speed is reached around 8 m/s in the area located in 35.5°N, 120°E.

As shown in Figure 1, there are three buoys in the competition area. One of them, located in 36.01°N, 120.45°E is used to compare to the ASAR retrieved wind field. Figure 9 shows the buoy measurements on August 20, 2007. The buoy measurement provides average wind speed and average wind direction every ten minutes.

In-situ measurements show that wind speed at 21:50 (local time) is 2.6 m/s and wind direction is 311° clockwise, relative to north. The retrieved wind speed is 2.7 m/s and wind direction is 306°, which is in agreement with the buoy measurement. Figure 10 shows the buoy measurements during August 19 to 21, 2007. The black line shows the measurements in every ten minutes taken from the buoy and red dash line is the three hours running average. On the three days in-situ measurements, the land-sea breeze phenomenon with amplitude of about 1-2 m/s can be observed.

5.2 Coastal Upwelling Observation

There are some low backscatter areas in the ASAR image as observed in Figure 8. The most distinct is the area in the south and east coast of Laoshan Mountain. It is well known that low normalized radar cross section values can be caused by different atmospheric and oceanic phenomena. Low wind speeds and heavy rain (such as in hurricane, Reppucci and Lehner, 2007) are the major atmospheric factors for the low backscatter signatures in SAR images. Natural and man-made surfactants (e.g. oil slicks) and sea ice can be detected as well as the low backscatter features in SAR images. There are two key mechanisms for upwelling pattern imaged by SAR. First one is upward cooler water significantly changes the marine boundary layers and decreases the wind stress which causes the low backscatter pattern in SAR images. Upward water also brings the biogenic slicks which are effective to damping the Bragg waves in ocean surface (Clemente-Colón and Yan, 2000). The surrounding wind speed of the dark area is about 4-5 m/s. The local meteorological measurement doesn't show any records of heavy rain.

Four AVHRR SST images (NOAA-15, 16, 17 and 18) acquired on August 20th, 2007 over the Qingdao coastal area are shown in Figure 11. The four images indicate the fully cloud free

weather situation. The NOAA-17 SST image (b) closest in time to ASAR image is acquired at 12:55 UTC. The NOAA-15 SST image (a) is acquired before the ASAR image at 08:49 UTC and the NOAA-18 (c) and NOAA-16 (d) are acquired after the ASAR image at 17:37 UTC and 21:24 UTC, respectively. The low backscatter regions in the ASAR image corresponding to the SST are marked as black squares in Figure 10. It is observed that the SST changes significantly in Laoshan coastal area during the day. SST is low at around 23°C~24°C at 08:49 UTC and then increases greatly to around 29°C at 12:55 UTC observed in NOAA-17 SST image, which is the closest to the ASAR image acquired time. At around 17 UTC, the SST decreases again and reaches to about 18 °C observed from NOAA-16 SST image at 05:24 UTC. From four images, the development of colder SST regions at Laoshan eastern and southern coastal area are captured clearly NOAA AVHRR data. Thus it is concluded that the low backscatter regions in the ASAR image is caused by the coastal upwelling confirmed by the lower SST and favourable southerly wind direction.

The AVHRR SST image acquired on August 20, 2007 at 12:55 UTC, closest to the time of ASAR image acquired (at 13:42 UTC) shows the SST in Laoshan coastal area is around 27°~28°C, which is higher than SST retrieved from the AVHRR acquired before and after. As it is explained in the previous part, decreased wind stress due to the low sea surface temperature and the biogenic slicks damping the surface Bragg waves are the main mechanism for the upwelling pattern in SAR images (low backscatter). In this case, the SST retrieved from AVHRR data closest to the ASAR image time is not low compared to other images, it can be concluded the low backscatter pattern in the ASAR image is main due to the surface Bragg waves are damped effectively by biogenic slicks brought by the upward water.

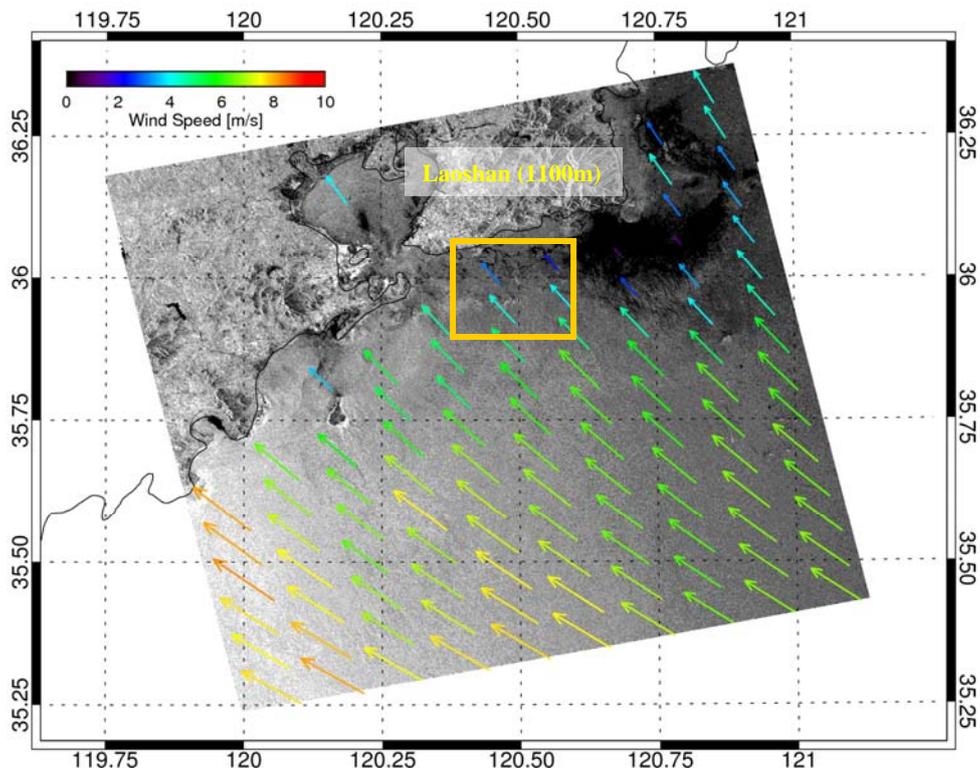


Figure 8. ASAR Imagery (acquired on Aug. 20, 2007 at 13:46 UTC) and retrieved Wind field

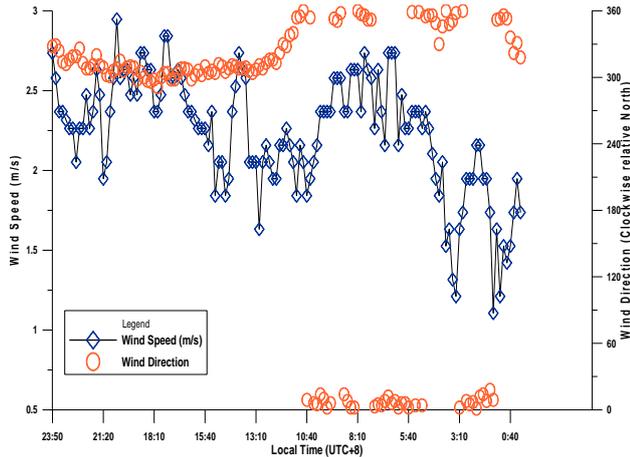


Figure 9. Buoy measurements (wind speed and direction) on August 20, 2007

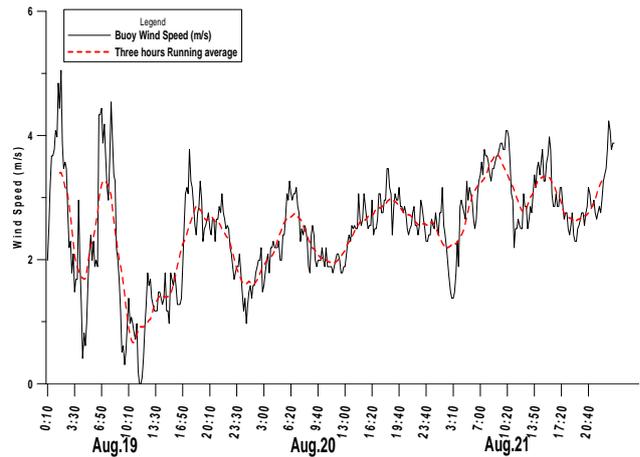


Figure 10. Buoy measurements (wind speed) during August 19 to 21, 2007

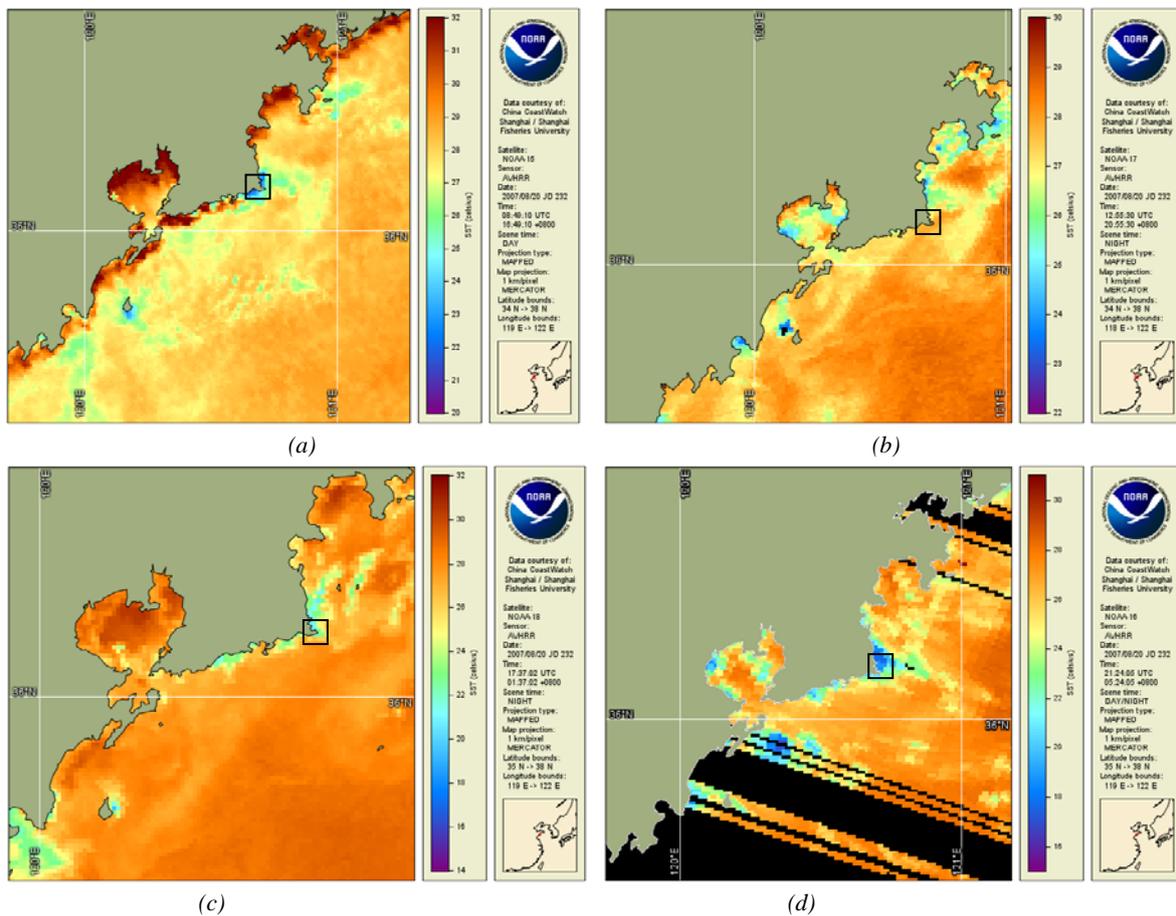


Figure 11. AVHRR NOAA SST image acquired on August 20, 2007 over Qingdao coastal area (a) NOAA-15 (08:49 UTC), (b) NOAA-17 (12:55 UTC), (c) NOAA-18 (17:33 UTC) and (d) NOAA-16 (21:24 UTC)

6. SUMMARY

Using Scatterometer and SAR, the wind climate properties are demonstrated in this paper. Together with the *in-situ* buoy

measurements, a case study for the 2007 regatta sailing test event is analyzed as well. The main conclusions are summarized as following.

- 1) Monthly wind speed distribution investigation shows that the coastal wind in Qingdao area has nearly 90% of the investigated cases the wind speed is above 2.5 m/s, i.e., fulfilling the official requirements for the sailing game.
- 2) The spatial distribution of wind speeds in the competition area is relatively homogenous ranging from 4 m/s to 6 m/s as shown in Fig. 4.
- 3) Daily average wind speed analysis indicates that in the period of August 16-22; mean wind speed can be expected to be about 0.8 m/s higher than the long term average of 5.3 m/s. It is thus a suitable period for sailing competitions.
- 4) Scatterometer data (QuikSCAT) turned to be efficient for a general wind field analysis. But there is a gap with regard to detailed wind field information close to the coast. Wind field retrieved from SAR image provides the fine resolution coastal wind information, which could be very helpful for the Olympic sailing event meteorological service.
- 5) Together with the AVHRR SST image, it is concluded that the low backscatter area in the ASAR image is generated by the coastal upwelling.

It is expected that the background wind climate analysis and case study investigation can make us understand Qingdao coastal area wind field properties well and contribute the meteorological forecast and *in-situ* measurements service for 2008 Olympic Sailing Events.

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