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A Case Study of Polar Low Detection Using ERS-2 Wave Mode Image

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Abstract: An empirical approach for detecting polar lows is developed based on satellite data from two sensors: Synthetic aperture radar (SAR) wave mode image on board ERS-2 satellite and AVHRR image on board the National Oceanic and Atmospheric Administration (NOAA) family of polar orbiting platforms (i. e. POES). This approach is primarily based on 10m wind field and wave height besides the latitudinal position. Based on these criteria, the polar low systems could potentially be detected using CWAVE algorithm [7] for practical applications. A probable approach for this purpose is discussed in this study through an example.

Keywords: AVHRR, Cyclone, mesoscale, SAR image, Severe Storm, Polar Low.

INTRODUCTION

A Polar Low (PL) is a mesoscale, short-lived atmospheric low pressure system (depression) that is found over the ocean areas towards pole in both northern and southern hemisphere [1]. The systems usually have a horizontal length scale of less than 1,000 km and a life span of less than couple of days. They are part of the larger class of mesoscale weather systems, but are fairly intense maritime cyclones those form pole ward of the main baroclinic zone [2]. They are also termed as comma cloud, meso-cyclone, polar mesoscale vortex, Arctic hurricane, Arctic low, and cold air depression [3]. These days, the term is usually reserved for the more-vigorous systems that have near-surface winds of at least 17 ms^{-1}.

The PL systems in polar areas are often difficult to detect using conventional weather instruments and are a hazard to high-latitude operations, such as shipping, gas and oil platforms [4]. One of the best examples could be the direct impact on the increased economic activity in the Arctic region. The study of polar lows over the Arctic has become especially important due to the significant sea ice decrease in the Arctic Ocean in recent years [5]. The occurrence of these systems can lead to the increase of marine production. Therefore, one of the most important tasks for science now is an early detection and prediction of polar lows, investigation of their characteristics and tracking their movements.

Polar lows were first identified on the meteorological satellite imagery that became available in the 1960s, which revealed many mesoscale cloud vortices at high latitudes. The most active polar lows are usually found over certain ice-free maritime areas in or near the Arctic during winter, viz the Norwegian Sea, Barents Sea, Sea of Japan, and Gulf of Alaska. Polar lows dissipate rapidly when they make landfall. Antarctic systems tend to be weaker than their northern counterparts since the air-sea temperature differences around the continent are generally smaller. However, vigorous systems of such types can also be found over the Southern Ocean.

Only the use of satellite data helps in obtaining enough and regular information about the polar lows. On the other hand, the current meteorological observational network has several limitations in detecting cyclones in general, and especially small mesoscale cyclones. There is a strong need for new and improved and feasible methods like that of satellite remote sensing; in order to detect and monitor the mesoscale systems like polar lows. In the present study, ERS-2 wave mode images as well as AVHRR images have been empirically exploited for detection of these systems. They have been identified on the ERS-2 images by analyzing the image features.

The details of the data used in this study and the adopted methodology, both are described in the next section. The results obtained from this study and concluding remarks follow subsequently.

DATA AND METHODOLOGY

The SAR images used in this study are the wave mode ERS-2 images, with a size of 10 by 5 km acquired for every 200 km along the satellite track. It may be noted that ERS-2 satellite orbits the earth once in about 100 minutes and is able to cover the whole globe in about 35 days. The C-band radar in the satellite operates with vertical polarization in transmission process and receives and provides a spatial resolution of about 10 m in azimuth direction and 20 m in

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range direction. The required SAR wave mode single look complex (SLC) images, which are not available as standard products, were reprocessed at German Aerospace Center from raw data, provided by the European Space Agency [6]. ERS-2 images are quite useful for several studies. For example, our previous study uses them for validating and developing a new algorithm for their classification [8]. A number of SAR missions are crucial for continuous SAR research. European radar satellites ERS-1, ERS-2, ENVISAT, TerraSAR-X and TanDEM-X provided valuable SAR images for this study. All of the SAR satellites provide wave mode SAR imagettes similar to the ones used in this paper.

Another type of image used in this study is 'Advanced Very High Resolution Radiometer (AVHRR) image'. The AVHRR is a radiation detection imager. There are several versions of AVHRR. The latest version of AVHRR uses 6 detectors that collect different bands of wavelengths in the visible-near infrared region and three thermal infrared channels and each channel has a spatial resolution of 1.09 km. The latest version of the radiometer has two one-micrometer wide channels between 10.3 and 12.5 micrometers. The global area coverage data are derived from an on board sample averaging of the full resolution AVHRR data yielding 1.1-km by 4-km resolution. The temporal coverage of the AVHRR data is different for different satellites. AVHRR instrument measures various environmental parameters. AVHRR data provide a global, long-term, consistent time series with high spectral and spatial resolution suitable for albedo and surface temperature measurements. Such measurements are necessary for studies involving climate, sea ice distribution and movement, ice sheet coastal configuration, locating temperature fronts [9] and bio-oceanography studies like chlorophyll enhancement [10] etc. It is quite noticeable that the AVHRR instrument is used for a wide range of applications in polar and climate research.

Polar lows can have a wide range of cloud signatures in satellite imagery, but two broad categories of cloud forms have been identified. The first is the 'spiral' signature consisting of a number of cloud bands wrapped around the center of the low. Some polar lows have the appearance (in satellite imagery) of tropical cyclones, with deep thunderstorm clouds surrounding a cloud-free 'eye', which has given rise to the use of the term 'Arctic hurricane' to describe some of the more active lows. These systems are commonly deep within the polar air. The second is a 'comma-shaped' signature that is found more frequently with systems closer to the polar front.

According to the features described above, an empirical criterion was developed in order to detect a Polar Low system. The criterion includes two conditions:

i. wind speed at 10 m (U10) $\geq$ 15 ms-1, significant wave height (Hs) $\geq$ 5 ms-1 and the latitutinal position > 60° N

ii. A series of SAR images could reflect a rotation feature of wind field.

Significant wave height, wave period and wind speed could be directly retrieved from SAR wave mode images using the empirical algorithm CWAVE [7]. More detailed information about CWAVE algorithm can be found in the article [7].

RESULTS AND DISCUSSION

A case study is presented here as an example of detection of PL systems using SAR wave mode images with the validation of AVHRR image. The methodology discussed in previous section is adopted in this study. In this process, a system is detected on 17 September 1998. In order to serve the desired objective, the associated description is given in this section.

A series of images on 17 September 1998 (e. g. Fig. **1**) are found that correspond to the first condition of our criteria mentioned above. The images have a time separation of 30 seconds, which correspond to a horizontal distance of roughly 200 km. From the red line drawn in the image, the wind direction rotation along the flight path can be easily seen. This feature fulfills the second condition of our criteria. Therefore, the empirical criteria mentioned in data and methodology section are satisfied and consequently, the possibility of detection of a PL system is evident on the date considered in this study.

The CWAVE algorithm [7] is primarily for the retrieval of wind. It may be noted that the algorithm was empirically developed mainly for the retrieval of integral ocean wave parameters from synthetic aperture radar data. It was later applied and referred by several studies including our earlier works [8]. The wind speeds retrieved using this algorithm from the three images shown in Fig. (**1**) are given by, 16.6 m/s, 16.8 m/s and 17.0 m/s, respectively. The corresponding significant wave heights are found to be 5.4 m/s, 5.6 m/s and 5.8 m/s, respectively. The latitudinal location of all of these three images is greater than 60° N. The red lines in the Fig. (**1**) represent the SAR streaks which are parallel to the mean wind direction. These three red lines indicate that the wind fields of the three images are rotated. Therefore, according to the criteria defined in previous section, the location and existence of a PL system can be determined in these three images.

The red quadrilateral or rectangle region in Fig. (**2**) illustrates the location of significant wave height and wind speed in the maps from ERA-40 data corresponding to the three images of Fig. (**1**). The average wind speed is found to be 16.8 m/s and the corresponding average significant wave height is 5.6 m/s. These results aree well with the SAR retrieved results from CWAVE algorithm. Fig. (**3**) shows AVHRR image at 17:22 on September 15, 1998. The red framed square is corresponding to the three wave images of Fig. (**1**). The comma cloud in the AVHRR image proves that there exists a Polar Low in the location of SAR image. It indicates that the detection of polar lows from SAR images is possible.

For the PL system detection and analysis, several approaches can be found in literature. The first approach is associated with deep insight into the mechanisms responsible for PL genesis and elaboration of the theory of generation and evolution of such systems [11,12]. The second is PL modeling. While the first modeling results were unsuccessful

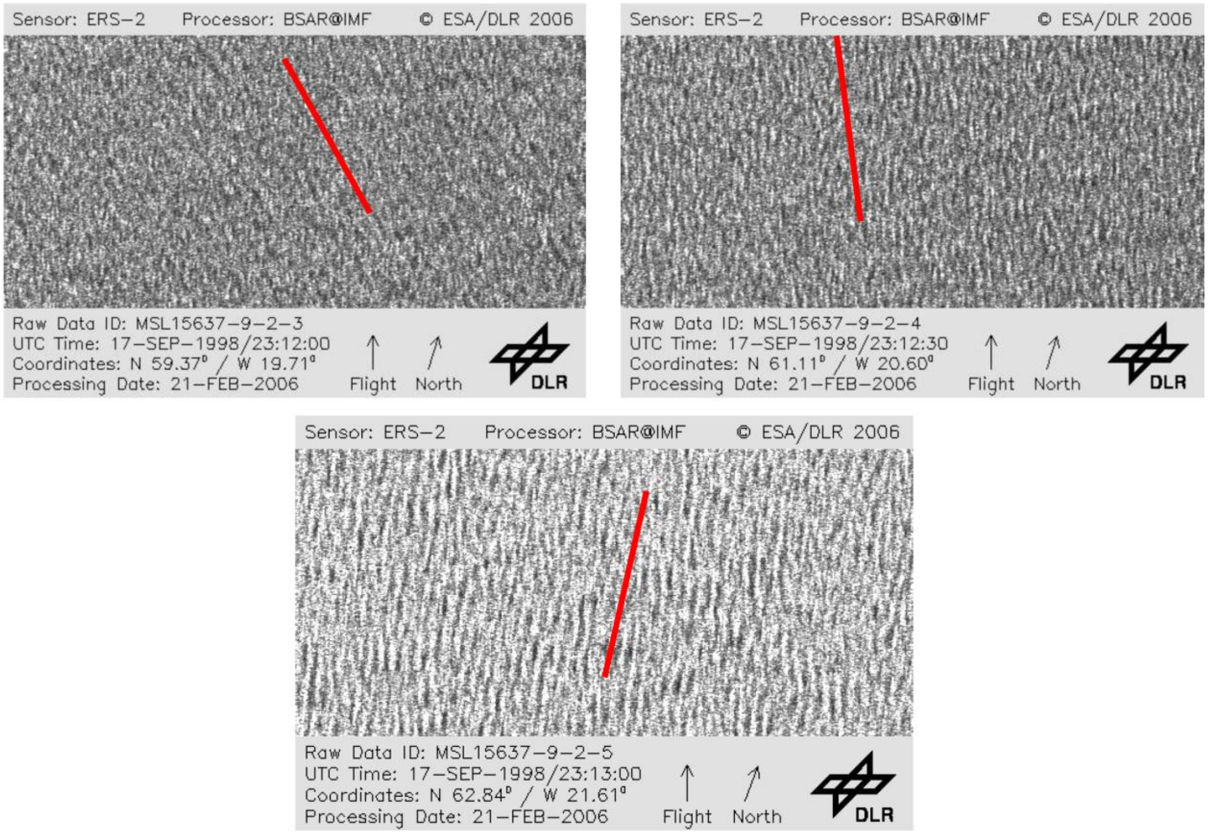

Fig. (1). Three continuous wave mode images as a time series, the red line represents the SAR streaks which are parallel to the mean wind direction.

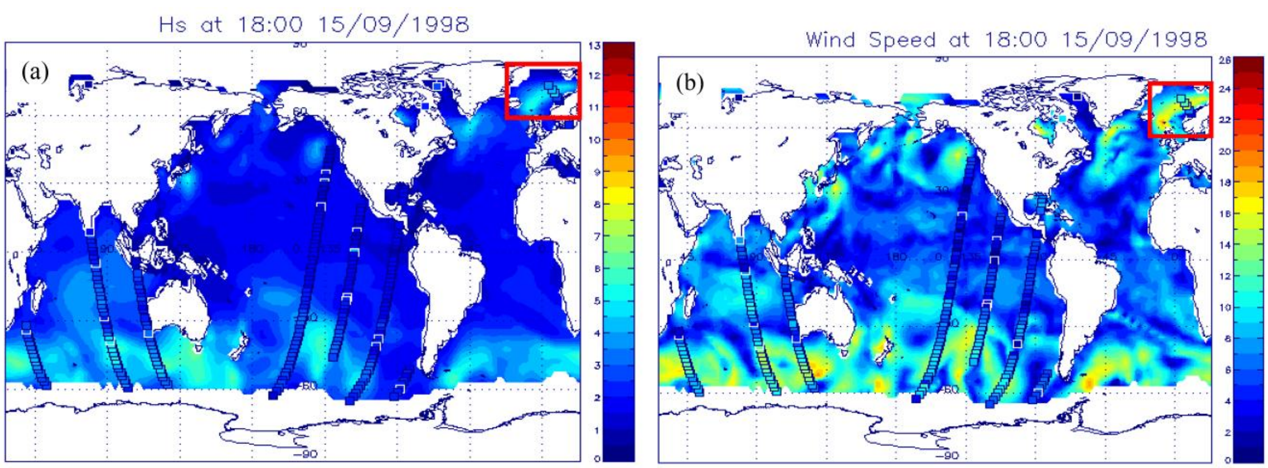

Fig. (2). The maps from ERA - 40 corresponding to the three images from figure 1 at 18:00 on September 15, 1998: (**a**) wave height and (**b**) wind speed. The rectangles with red boundary illustrate the signature of significant wave height and wind speed in (**a**) and (**b**) respectively.

since the models developed for this purpose did not have enough sophistication for the consideration of a resolution that is high enough in order to resolve such small systems. The latest generation of models having resolution of 50 km and higher with good representations of physical processes has had more success in simulating some polar mesoscale weather systems [13, 14]. Nevertheless, forecasting PL systems still a challenging task [14, 15]. Further, there are several observational studies based mostly on the analysis of satellite data. The most informative studies include the comprehensive joint analysis of satellite data from various instruments, providing the most complete information about PL development [16]. Comparing all these approaches above, one obvious advantage of the approaches described in this study is that our method can easily be put into practical application. Therefore, the PL detection can be more effective with the approach discussed in the present study.

CONCLUDING REMARKS

The PL systems are usually accompanied with high wind speeds and severe precipitations and consequently, they

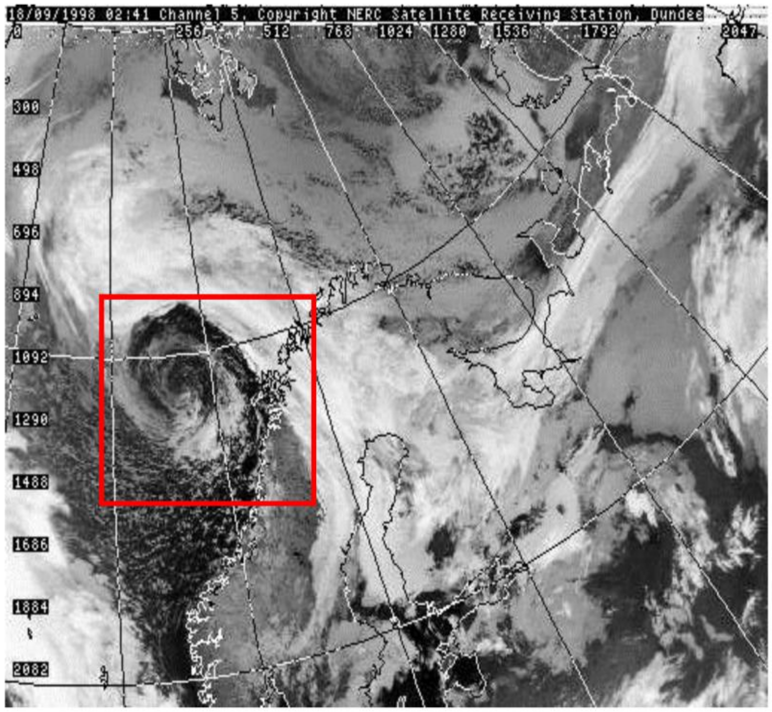

Fig. (3). AVHRR image at 17:22 September 15, 1998. The red framed rectangle is corresponding to the three wave images of Fig. (1).

could lead to destructions. Especially in Arctic area, PL systems are a typical threat to oil and gas exploration, shipping and fisheries. Since the possibility of these systems becoming stronger in future due to the global warming [5] is large, detecting and forecasting of these mesoscale systems could make significant benefit to people in the polar region. In view of this, the present study adopted a new method in order to detect Polar Lows using ERS-2 wave mode SAR image. Primarily two criteria were defined based on 10m wind field and wave height besides the location. Based on these adopted criteria, the present study is able to show the possible approach to practically detect PL systems with the help of CWAVE algorithm [7].

In future, multi-sensor data will be analysed using different remote sensing instruments such as Special Sensor Microwave Imager (SSM/I) and Advanced Microwave Scanning Radiometer–Earth Observing System (AMSR-E) by taking advantage of the unique features of each satellite data,. Their low spatial resolution is a shortcoming to use them as unique information to detect PL systems. However, by using multi-sensor satellite data, such analysis could provide a better information regarding the development of such systems with greater frequency since the temporal resolution of the said data sets is usually very high.

CONFLICT OF INTEREST

The authors confirms that this article content has no conflict of interest.

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