# Operational Utilization of SAR-derived Winds for Forecast Operations at the Pacific Storm Prediction Centre

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## ABSTRACT

In a collaborative project involving the Meteorological Service of Canada (MSC) and Ottawa-based Vantage Point International (VPI), synthetic aperture radar (SAR)-derived wind products are being generated and utilized in near-real time for use by marine forecasters at the Pacific Storm Prediction Centre (PSPC) in Vancouver. Funded in large part by the Canadian Space Agency (CSA), the Marine ENvironmental moniTORing (MENTOR) project utilizes the SAR and software engineering expertise of VPI, monitoring, modelling and image analysis capabilities within MSC, as well as the meteorological and local area knowledge of Prediction Centre forecasters. The objective is to assess the utility of this imagery, and if appropriate, establish an in-house capability for MSC to generate, manage, and display these products rapidly for operational use. This paper describes milestones and present status of the project, and shows examples of wind images obtained to date. It also touches on the importance of training for operational users, the different purposes for which the data will be used, and the need for a continued supply of high-volume and affordable SAR data over the west coast and elsewhere for various marine applications. The need for further research to address present limitations of this dataset will also be outlined.

**Keywords:** Ocean winds, synthetic aperture radar, marine forecasts, MENTOR.

## 1 INTRODUCTION

MSC's Pacific and Yukon Region (PYR) has operationally utilized satellite imagery since the late 1970's. Milestones included installation of the first Canadian GOES ground station, and development and use of the first meteorological workstation in Canada. Using those tools, operational, real-time satellite products and services were implemented. More recently, images from the Alaska SAR Demonstration website (http://fermi.jhuapl.edu/sar/stormwatch/web_wind/) have been utilized for both research and training purposes. The availability of this data stimulated interest in further pursuing this new source of wind information over coastal waters. This paper discusses a collaborative project to develop the capability for automated, local processing of this data at MSC prediction centres, with output in a user-friendly web-based display.

### 1.1 Scientific Background

Scientific software developed at the Canada Centre for Remote Sensing (CCRS) is the core of the Wind Information Processing (WIPS) component of MENTOR, with re-implementation of some portions to improve speed, portability, and to interface with numerical weather prediction models. This scientific software implements earlier work on SAR wind retrieval from C-band SAR [1], and includes extensions such as support for the European ENVISAT ASAR (Advanced Synthetic Aperture Radar).

High-resolution (*i.e.*, kilometer scale) wind retrieval is based upon the SAR-observed backscatter and the wind geometry (local incidence angle and wind aspect angle), and uses the CMOD-IFR2 C-band (5.3 GHz) scatterometer model function [1] to retrieve the wind speed. This model was developed for VV polarization (vertical on transmit and receive), so extensions that allow for HH polarization data from RADARSAT-1 are required. A co-polarization ratio based upon Kirchoff scattering has been used with success [1]. Wind retrieval requires an estimate of the relative wind direction, which is difficult to automatically retrieve on a routine basis from SAR imagery. A critical component of MENTOR has been the use of high resolution numerical weather prediction (NWP) model wind fields to provide the required wind direction information.

### 1.2 Alaska SAR Demonstration

Since the late 1990's, occasional wind images over BC's coastal waters from the Alaska SAR Demonstration project run by NOAA/NESDIS have been viewed with interest by PYR forecasters. However these products suffered from five shortcomings that limited their operational utility: 1) the windfield products were not provided quickly enough to be used in forecasts; 2) there was no advance warning to the forecasters that the product was available; 3) wind direction was derived from a relatively large scale weather model which did not capture terrain effects near the coastal mountains; 4) only dawn and dusk data could be provided by RADARSAT-1 alone; and 5) coverage of Canadian waters was too sparse for routine exploitation in forecasting. Nevertheless the amazing horizontal resolution of the wind images continued to garner increasing interest amongst staff.

In 2002, the value of these images for describing local variations in wind speeds in coastal straits and inlets with varying synoptic patterns was recognized. With funding from the National Search and Rescue Secretariat's New Initiatives Fund, the third manual for west coast mariners, entitled *Living with Weather along the British Columbia Coast: the Veil of Chaos* [2] was published. In that book, SAR wind images from the Alaska SAR Demo were used to great effect in describing local wind variations, and especially in showing how marine regional forecasts could hardly be expected to represent all winds within a region. The book also effectively demonstrated that observations from single locations could be unrepresentative of winds a short distance away.

### 1.3 Ice Centre Demonstration

A very successful pilot project lead by the Canadian Ice Service in 2001 used an operational near-real time data stream aimed primarily at ice forecasting to provide experimental marine wind products for evaluation by marine forecasters [3]. Output from this project was available in three MSC offices: Dartmouth NS, Gander NL, and Thunder Bay ON. Marine forecasters in those offices were enthusiastic and felt the products were of value for learning about wind climatology, and could also be used for local forecasting. These initial products were produced by a Canadian software product called the Ocean Monitoring Workstation which had the same scientific heritage as MENTOR. While improvements were needed in speed of delivery, automation, and presentation, the pilot project was very successful and boosted the credibility of SAR-derived winds.

### 1.4 MENTOR

MENTOR (Marine ENvironmental moniTORing - Ocean Winds) is a CSA supported project under the Earth Observation Application Development Program (EOADP), with management and technical support from Defence R&D Canada, and with contributions from MSC's Coastal and Mountain Meteorology Laboratory (CMML), the Department of Fisheries and Oceans (DFO), Vantage Point International (VPI), and NOAA/NESDIS. The aim of MENTOR is to provide a pre-operational system for SAR-derived wind field measurements to help in marine forecasting activities with a geographical emphasis on the BC coast.

The MENTOR project benefited greatly from previous efforts on both retrieval algorithms for SAR-derived winds, and on pilot demonstrations in a marine forecast environment. Canada, along with the USA, Germany and Norway has been a leader in this field. MENTOR uses scientific software developed by NRCan, and builds on previous work led by the Canada Centre for Remote Sensing and the Canadian Ice Service, with extensions to the toolsets provided by DFO (Dr. William Perrie).

Five operational pilot trials were conducted during this project with the dual aim of satisfying the MSC-PYR forecasters' need for near-real time SAR wind data, and developing the MENTOR software which is composed of the Wind Information Processing System (WIPS) and a Web Portal delivery interface. The accomplishments of each of those five trials are summarized below.

1. Delivery of a sample of RADARSAT-1 windfields to the MSC-PYR forecasters for feedback.
2. Delivery of a higher volume of RADARSAT-1 windfields to the MSC-PYR forecasters. Analysis of the feasibility of including ENVISAT ASAR windfields. Generation and delivery of ENVISAT ASAR windfields.
3. Delivery of a high volume of both ENVISAT ASAR and RADARSAT-1 data to the MSC-PYR forecasters using the MENTOR Web Portal to access the data. Use of the CMC GEM-LAM (Canadian Meteorological Centre Global Environmental Multiscale – Local Area Model) NWP model as a source of wind direction in the windfields. Test of system delivery times for both sensors.
4. Provision of an uninterrupted, high volume stream of data over a prolonged period of time for the MSC-PYR forecasters. Installation and operation of a version of the WIPS software at the MSC-PYR offices in parallel with the Ottawa version.
5. Continued provision of an uninterrupted high volume stream of data over a prolonged period of time for MSC-PYR forecasters. Production of supplementary windfields with the Canadian Ice Services RADARSAT-1 data stream. Implementation of the MENTOR Web Portal at MSC-PYR with operation in parallel with the Ottawa web portal. Integration of buoy measurements into the windfield products for in-situ comparisons.

In total 151 RADARSAT-1 and 158 Envisat ASAR windfields were processed, and all but 16 of these were made available to forecasters in near-real time

The MENTOR project is nearing completion, having accomplished its objectives as defined in the EOADP agreement. In particular, MENTOR has addressed a major weakness identified in the Ice Centre Demonstration project: an ineffective visualization strategy for output. The web portal display developed for MENTOR provides forecasters with an easy-to-use web interface that shows buoy observations, NWP-provided wind directions, and SAR wind speeds, together with an easy means for zooming and roaming over the image domain. It also facilitates comparisons of wind images with the original SAR images in normalized radar cross section format. Wind products are conveniently selected by year, month, day and time, and it is easy to check historical events from past months. Locations and times of future acquisitions are also shown, providing advance notice regarding product arrival times which is very helpful to forecasters. The SAR-derived winds shown in this paper are screen captures from the web portal display.

## 2 MARINE FORECASTING NEEDS AND REQUIREMENTS

Storms approaching the British Columbia Coast can be difficult to accurately forecast, in part because of the relative lack of mid-tropospheric meteorological information upstream for about 7000 km. A network of coastal buoys has been established to provide early warning of strong surface winds, but in many cases this network is not sufficiently dense to provide all the needed information. This has become more apparent with the study of the significant but small-scale variations evident on the SAR wind images, and also from details revealed by mesoscale NWP products.

Other satellite data provide important information about temperature and moisture over the Pacific, but in most cases they do not provide explicit surface wind information. In the past, cloud tracking has been used with some success, but this only works well in convective situations where low clouds are clearly visible. It can also be difficult to automate low-cloud tracking algorithms for reliable output. And while Quickscat winds are available, they do not provide the spatial resolution of SAR, nor the coverage over BC's coasts, straits and inlets where most of the marine traffic exists.

Information from high resolution SAR-derived surface wind fields can help forecasters assess the strength of weather systems as they near the coast. This provides an early warning of when such weather systems are not developing as expected. This in turn can form the basis for more timely marine forecasts and warnings.

However the greatest benefit for forecasters is likely the increased understanding gained regarding local wind patterns. In-situ observations, aside from being relatively sparse, are often not optimally located to accurately report winds from all directions. SAR winds enable forecasters to observe and conceptualize patterns, and to recognize when surface wind reports are not representative of the larger region.

This added knowledge provided by SAR winds raises issues about verification of marine warnings based on them, and whether warnings should be issued when the peak winds are relatively local. The mandatory use of the Scribe forecast generation system for marine forecasts within MSC may make it more difficult to describe the local nature of such winds. Since verification scores are currently based solely on surface, in-situ wind reports, if no surface station observes the strong wind, it would not be part of the official record and the warning would be considered a false alarm. Verification scores that don't utilize all the data used in forecasting have little value, so a means to incorporate this dataset into the verification system is needed.

There are several other noteworthy uses of SAR-derived winds besides near-real time use for operational forecasts and warnings. One major focus of MSC is development and validation of mesoscale NWP models. Even though the GEM-LAM wind directions are used in calculating the SAR wind speeds, results from SAR can still be used to validate and confirm the model's wind speeds and patterns. An example is shown in Figure 1. Essentially, SAR winds are confirming many of the patterns seen on the GEM-LAM that are otherwise unverifiable due to their small scale.

The value of SAR winds for education and training has been graphically demonstrated in the previously referenced marine manual [2]. High resolution SAR images can be used to explain numerous coastal wind phenomena.

Lastly, SAR-derived wind images can contribute greatly to our understanding of local wind climatology related to coastal topographic features. For example, before these products became available the offshore extent of strong outflow winds from coastal inlets was poorly known. The area of lighter winds to the north of Vancouver Island in southerly flow patterns, which is described below, is another example. Different flow patterns create different areas of locally enhanced and reduced winds. These need to be systematically studied and catalogued, after a large number of suitable SAR wind images have been collected. This knowledge will become increasingly important as coastal activity increases in the future, including increased recreation and tourism, as well as possible offshore oil and gas exploration.

## 3 USE OF SAR WINDS IN PACIFIC AND YUKON REGION

The need for and utility of SAR winds along the west coast has been outlined. In the next sections, examples will illustrate their potential usefulness to forecasters as well as in research and development. Insights into the importance of training for end users will also be described. The sensitivity of derived winds to an appropriate wind direction will also be illustrated.

### 3.1 Assessment of Wind Images Obtained to Date

Four cases shown below provide examples of SAR wind information made available in PYR through the MENTOR project. They will also serve to illustrate the progress made in provision of these products during the five stages of the project. Note that all these datasets were available to forecasters in near-real time.

#### 3.1.1 Case 1: Strong winds along Northern Vancouver Island on October 25, 2005

This case shows winds over the south and central coast of British Columbia, but focuses on Queen Charlotte Sound immediately north of Vancouver Island (see Figure 1). Prior to availability of the GEM-LAM model estimates for wind direction, MENTOR winds were based on marine buoys using a nearest-neighbour approach. GEM-LAM was running at that time, but was not yet being used to provide wind directions for the MENTOR WIPS processor. Wind shifts between buoys resulted in discontinuities of wind speed as shown in this example. It is noted that in this case, because the wind direction varied only gradually over the area as there were no pressure centres, fronts, or sharp troughs over this domain, a smooth interpolation between the buoy wind directions would have provided good results, at least in the offshore areas.

Of particular interest meteorologically is the area of lighter winds extending northward from the tip of Vancouver Island on both the GEM-LAM modelled output of wind speeds, and the SAR-derived winds. This is a common wind pattern, but there is typically no data in the area to verify the nature and extent of this wind feature. The SAR-derived wind fields frequently show this effect, as well as lee effects associated with other prominent topographic features.

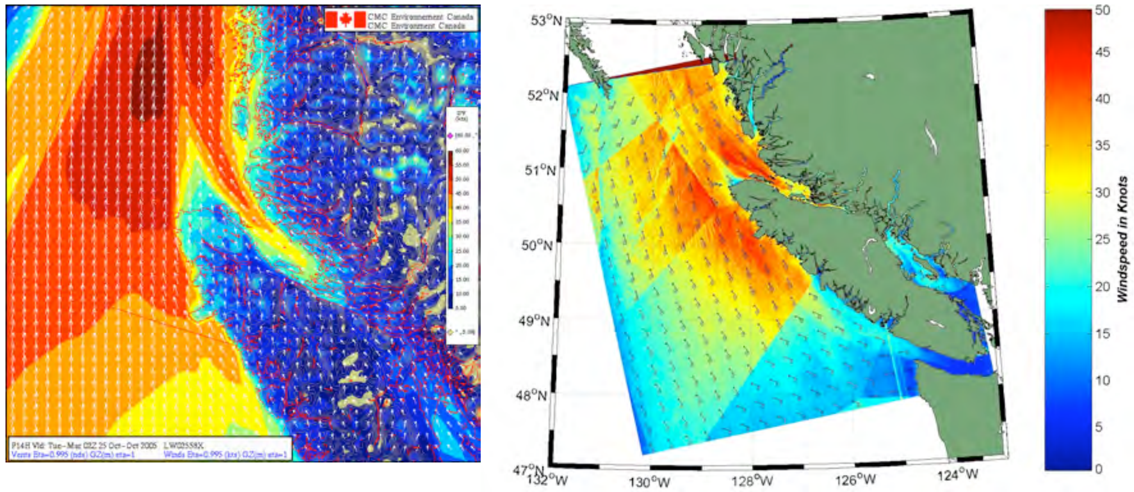


**Figure 1.** Left-side image shows output of surface winds from the GEM-LAM mesoscale model valid 02Z October 25, 2005 with colouring similar but not identical to that for SAR winds. Right-side image shows corresponding SAR-derived wind speeds for the same valid time, using directions from buoys only**.**

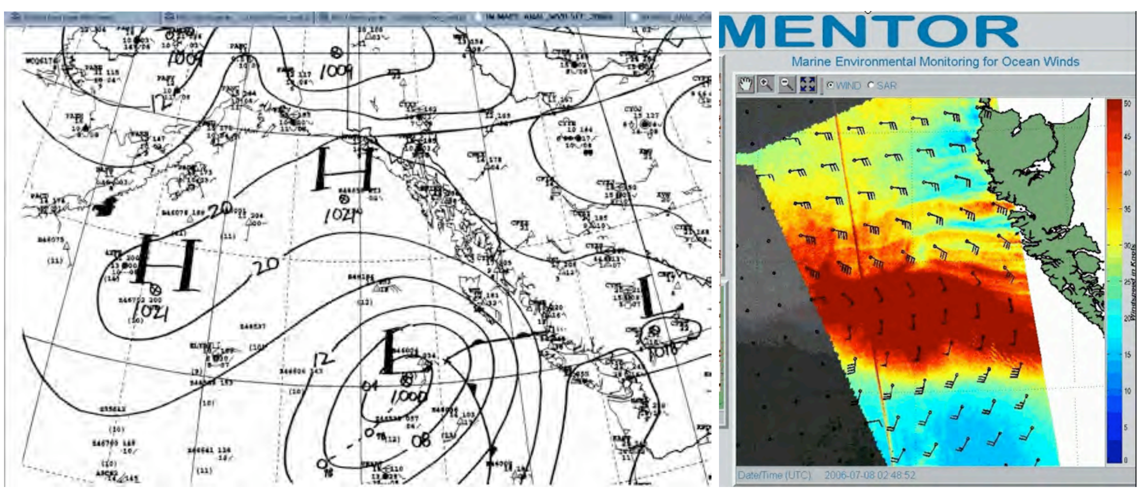


**Figure 2.** Surface analysis valid 00Z July 8, 2006 (at left) and wind image based on RADARSAT-1 SCW (ascending) at 02:48Z (at right). Speeds from SAR are colour coded, and are also shown on the wind barbs. Wind directions are from GEM-LAM.

### 3.1.2 Case 2: Warm Front off Queen Charlotte Islands on July 8, 2006

The Pacific Storm Prediction Centre's surface analysis for 00Z July 8, 2006 (see Figure 2) shows a 1000 hPa low approaching the Queen Charlotte Islands. While buoy 46004 (near 51N 136W) and the observation from Sandspit show 15 and 25 kt winds respectively, no surface observation reveals the strong band of southerlies associated with the warm front. Actual winds in the band were likely marginal storm force, slightly lower than the 50 kt indicated on the corresponding RADARSAT-1 wind product from three hours later. SAR winds provided valuable information about how quickly winds decreased to the south of the front, probably a result of stability in the warm sector, and how narrow the band of very strong winds actually was.

### 3.1.3 Case 3: Qualicum Winds on July 17, 2006

Winds usually flow from the northwest or southeast over the Strait of Georgia, constrained by the orography. Sometimes, however, strong southwesterly winds occur over Qualicum Beach on Vancouver Island, and eastward towards Texada Island. The prediction of these so-called "Qualicum Winds" has always been a challenge to marine forecasts, since they usually occur at strengths that are hazardous to small craft and to some commercial activities (*e.g.* log towing).

Qualicum Winds occur because of the specific orography of Vancouver Island, under a particular pressure and stability regime. Verifying these events can be a challenge because of their localized nature, and the fact that the winds sometimes don't extend across observing sites. So the confirmation of these events by SAR winds is very valuable.

The example of Qualicum Winds shown in Figure 3 is particularly interesting because the wind product showed it well despite a wind direction error of about 110 degrees from the GEM-LAM. The model actually predicted the southwesterly Qualicum winds for several hours, but brought northwesterlies down the strait too quickly, so by the time of the satellite pass, the model winds were already northwesterly. Nevertheless, the resulting wind speeds were judged to be quite reasonable. The GEM-LAM model winds were from north-northwest, actual winds were from southwest, and the satellite radar was "looking" to the east-southeast. Consequently the magnitude of the angle between the satellite view and the observed wind was roughly equal to the angle between satellite view and predicted direction. The result was a good wind speed estimate.

### 3.1.4 Case 4: Local Winds over Southern Strait of Georgia on Nov. 27, 2006

This final case study shows a localized area of strong and gusty winds over the southern Strait of Georgia, just south of Vancouver. Although the winds were light and the seas almost flat calm to the west of Vancouver, a meteorologist observing the event described what she saw as "a frothing, boiling line of high winds and waves" which could be seen off to the southwest from shore. She indicated that "the line was so sharp that it looked for all the world like an incoming tsunami that wasn't moving." It persisted for several hours. No stations in the area except East Point recorded the occurrence (wind 29G35 kt, direction not available). The MENTOR image captured this event very well (see Figure 4), and there was no other dataset that provided information about what was taking place just southwest of Vancouver, other than the SAR-derived winds.

It should be noted that observed winds from buoys are now included on the MENTOR wind images. These winds, plotted in white, graphically depict actual measured wind directions (and speeds) against wind directions from the GEM-LAM. Observations are taken closest to the time of the satellite acquisition. This provides valuable information to forecasters regarding the quality of the derived winds, since wind direction is a primary source of error in wind speed from SAR.

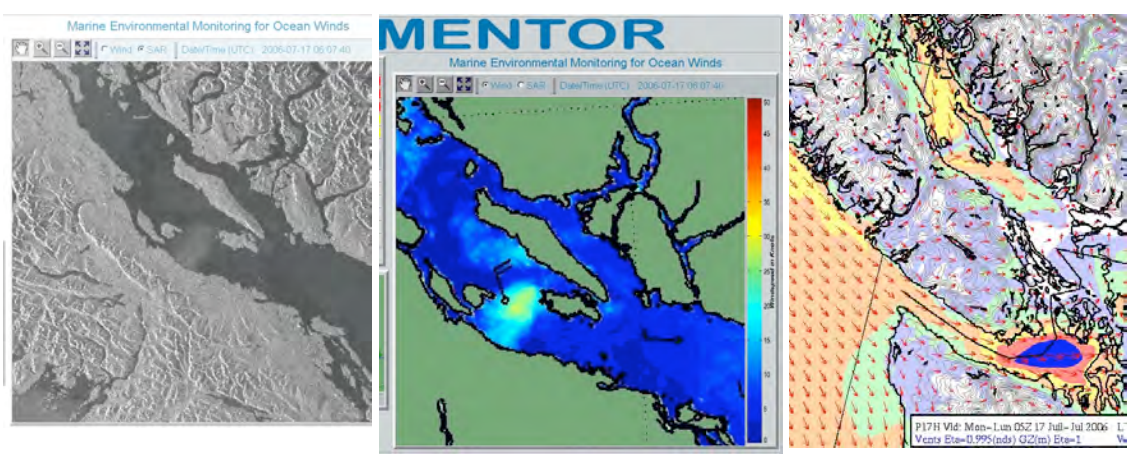


**Figure 3.** Southwesterly "Qualicum Winds" extending down to the sea surface just northeast of Qualicum Beach on Vancouver Island can be seen on this Envisat ASAR (ascending) image on the left from 06:07Z July 17, 2006. The middle image shows the derived MENTOR wind image, indicating a correct 20 kt wind speed, but incorrect northwesterly wind direction which was acquired from the GEM-LAM model. The image on the right is GEM-LAM output from one hour earlier (05Z), at which time a southwesterly wind was still predicted by the model.

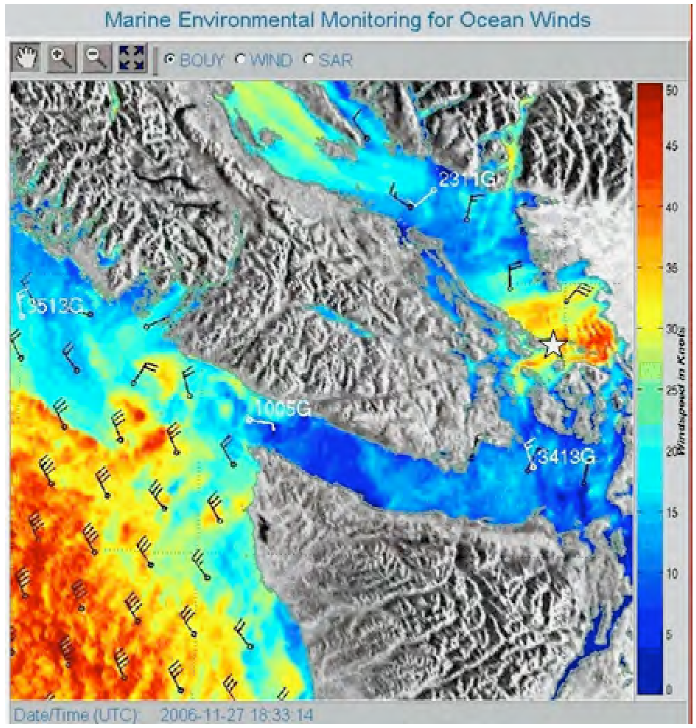


**Figure 4.** Envisat ASAR (descending) at 18:33Z on November 27, 2006.shows an area of squalls over the Strait of Georgia, south of Greater Vancouver. The location of the East Point automatic station is indicated with a star. Black wind barbs indicate wind direction from GEM-LAM, and wind speed from SAR. Also note the white wind barbs, which indicate actual winds from buoy reports corresponding to the SAR pass time.

### 3.2 Forecasters' Assessments of MENTOR Winds

In general, comments from operational marine forecasters were very positive. A large number of detailed assessments were conducted against observed winds, particularly during the March and July 2006 observing periods. Nowhere in those studies were SAR-derived winds proven to have major errors, and several of the cases resulted in marine forecasters confirming or modifying conceptual models regarding how the wind flows through local straits and inlets. A major caveat, however, is that very few of the winds during those periods were in the gale or storm categories.

Observations from the much stormier October-November period are still being studied. A preliminary assessment of those winds shows that errors appear to be a bit larger in some cases (i.e. more noticeable), but in most cases the speeds, and especially the patterns appear to be reasonably accurate. However, mean errors are thought to be a little higher in this period of stronger winds, and with a positive bias.

The only concerns expressed by forecasters related to their ability to discern true wind speeds and patterns from those which are artifacts of processing. Of the latter, all except features which are due to wind direction errors are easy to explain through basic training. As mentioned, the plotting of observed buoy wind data on the MENTOR output goes a long way to helping forecasters know when and where they can rely on the output, and when to be more cautious in accepting the indicated wind speeds.

### 3.3 Training Requirements

Training of operational forecasters regarding use of the products, as well as Informatics Branch staff in operating and running the WIPS and web portal software were important components of the MENTOR project.  Even for meteorologists skilled in the use and interpretation of satellite imagery for weather forecasting, proper use of SAR images requires a significant amount of additional training and experience. Aside from the radar science component, an understanding of the relationship of the SAR product with the

NWP model providing the wind directions is needed, and error characteristics that arise from inaccurate wind directions must be understood.

In the 18 months since VPI provided a full-day training session to operational forecasters in the Pacific Storm Prediction Centre, many staff turnovers have occurred. Presently, roughly half of the operational staff producing marine forecasters have not taken the training. Also, we've learned a great deal from the approximately 300 images received during the MENTOR project, and this information also must be passed on to new forecasters. Clearly it is of paramount importance to provide more training to forecasters utilizing this dataset, and to actively discuss and report on cases where SAR winds provided special insights into meteorological conditions.

# 4 OPPORTUNITIES AND BARRIERS

In this section, opportunities and present barriers to full operational utilization of SAR wind data are described. These include both technical-scientific as well as policy issues that impact our use of this dataset for meeting the stated needs and requirements.

## 4.1 Opportunities for National Utilization of SAR Data

The increasing availability of SAR datasets from a growing list of current and future SAR satellites provides a great opportunity to obtain and share them amongst multiple users and government departments. Although needs for wind data account for the largest volume of required imagery, the datasets can also be used for oil detection (*e.g.* I-STOP project), ice detection, and vessel surveillance (national sovereignty and security, fisheries regulation).

From a policy perspective, financial assistance and other incentives from the Canadian Space Agency for use of this data by private industry as well as government departments needs to be heeded. Previous restrictions on obtaining the data are falling away as it becomes more readily available and more reasonably priced.

This SAR wind data provides information for much finer scale forecasts, which could best be disseminated one-on-one, or by using map-based approaches rather than present text-based forecasts. It is also a valuable tool for consultants, and can provide unique information not available from any other source for use case studies and scientific papers.

## 4.2 Barriers to Overcome

The following sections identify two barriers that must be overcome if the full potential of SAR data for meteorological use is to be achieved.

### 4.2.1 Eliminating Restrictions to Data Access

Unlike traditional satellite images such as those from geostationary satellites, or even from NOAA's polar orbiters, SAR data is more difficult to acquire and utilize in an automated, operational basis. This is due to the fact that there are presently two, significantly different satellites with their own characteristics to take into account. For example, RADARSAT-1 uses HH (horizontal on transmit and receive) polarization, whereas the Envisat ASAR data we have been utilizing has VV (vertical on transmit and receive) polarization (HH is optionally available). There are many other variables, including antenna technology, various swath widths and resolutions. New satellites, such as Japan's ALOS PALSAR (L-band) pose new challenges, as well as exciting opportunities.

Cost is another factor that restricts data flow, and is consequently a barrier to use. Hopefully, as the volume of SAR acquisitions dramatically increases, the cost will decrease accordingly. The promise of freer access to future RADARSAT data, at least to Canadian government departments, is encouraging.

Proper and efficient utilization of a complex dataset such as SAR, originating from multiple sources and requiring ancillary inputs such as NWP wind directions and surface buoy observations, will be a challenge to establish and manage. Nevertheless, bold decisions need to be taken to ensure that this dataset is properly accessed and developed for use in weather forecasts and warnings. The National Laboratories that have been set up in Canada to assist with science and technology transfer to prediction centres are well situated to advance the use of SAR winds.

A steady and reliable stream of SAR data is needed for use by operational forecasters in prediction centres, as well as by CMC for data assimilation purposes. It is also important that data be available more frequently, preferably at least four times per day. Lower frequency will not provide for monitoring of changes in real time. To accomplish this, both RADARSAT-1 which provides data at roughly 6AM and 6PM local time, and Envisat ASAR which passes over at approximately noon and midnight, are needed. As additional SAR satellites become available in the future, it will be important to supplement the data with even more frequent observations.

### 4.2.2 Reduction of Errors Related to Wind Direction Uncertainties

The greatest limiting factor affecting forecasters' use of these products is their ability to discern between true wind features and those produced by errors in wind direction. Showing the buoy winds overlaid on the SAR wind is very helpful in providing evidence for when the indicated wind speeds are most reliable. Training is another key to addressing this issue. However if the number of cases with wind directional errors could be reduced, then the average errors in SAR wind speeds could also be significantly reduced and confidence in the product would grow.

Investigation should be done into whether a measure of stability (such as differential sea-air temperature), perhaps as a function of wind speed, can be used to improve predictions of surface wind directions from NWP models. Other options for changing wind direction input to the SAR wind processor should also be considered. In some cases, simple interpolation between buoys would work well (such as with the Oct. 25, 2005 case shown in Figure 1). Other times, choosing an alternate forecast hour from the model would handle cases when features are moved too quickly or too slowly (as in the case shown in Figure 5). The ability to select a different forecast model would sometimes yield improvement (e.g. GEM Regional). Other, manual corrections to wind directions input by means of a wind direction editor could also be expected to greatly improve the product in cases where wind directions from the NWP model are poor. Integration of this functionality into an operational meteorological workstation such as the new Ninjo workstation would make it possible for wind direction adjustments to be made at the forecast desk.

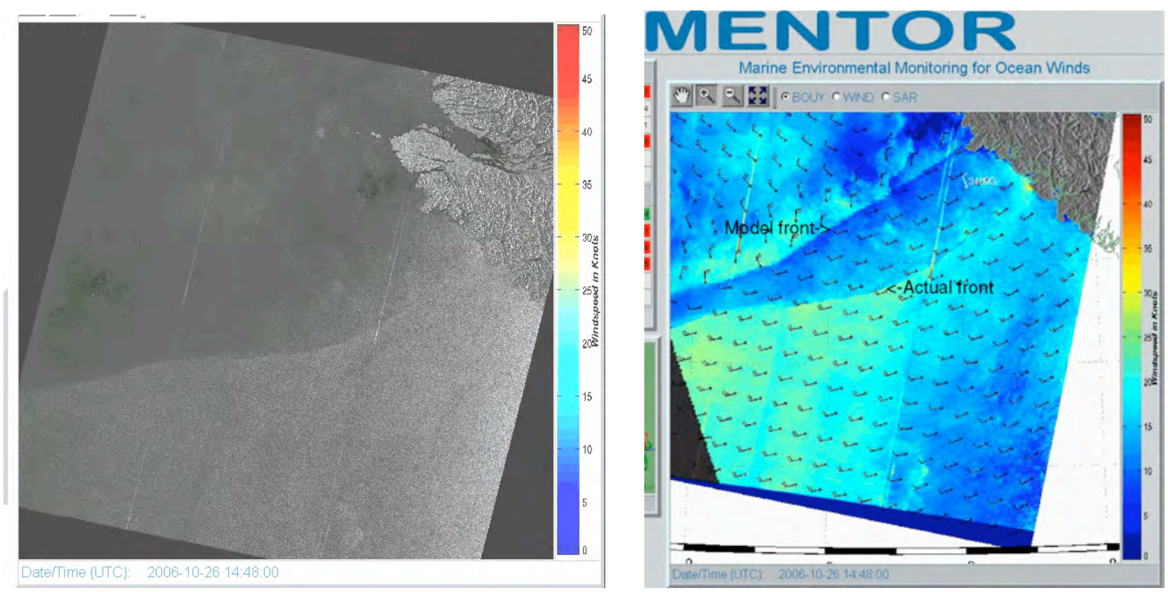


**Figure 5.** RADARSAT-1 SCW (descending) image on left for 14:48Z on October 26, 2006 clearly shows actual cold frontal position extending southwest from just north of Estevan Point on Vancouver Island. The GEM-LAM model for 15Z, however, still had the front further to the north, near Quatsino Sound and the Brooks Peninsula, as shown by the wind barbs on the SAR wind image. The impact of the wind direction error also shows up clearly on this image as a band of wind speeds that are much too light. This 60 nm error could have been greatly reduced by using the NWP forecast for 2 hours later, or by manually adjusting the winds in the region between the predicted and actual locations of the front.

## 5 THE WAY AHEAD

This final section suggests ways in which the operational and scientific utilization of SARderived wind data can be advanced.

### 5.1 Begin Operational Utilization

Use of this data must be instituted on at least a quasi-operational basis. Though still a developmental dataset, it must be made available routinely, regularly, in near-real time, and with sufficient frequency to warrant regular inspection and use. It should be made available to forecasters in all regions in which it can provide valuable and unique information. To make this possible, continuity of funding must be achieved. Only if the data is available routinely will operational forecasters regularly refer to this information. CMC has the same requirement for routine availability, for data assimilation into numerical models.

### 5.2 Maintain Dialogue between Operational Users and Scientific Community

Dialogue between operational users and the scientific community was greatly increased by the MENTOR project. This interaction must continue, and may be facilitated through the network of National Labs in high impact weather forecasting. It can also be furthered through meetings and presentations at conferences and workshops, where the achievements of SAR winds can be showcased and discussed.

### 5.3. Further Research

Results from the MENTOR project have established the utility of SAR winds for operational use, but they have also pointed to avenues for further research by identifying the present limitations to the dataset.

Wind direction editors are already being developed for SAR data [4]. Within the next few years, the capability for a forecaster to choose wind direction methods at a meteorological workstation will be developed, where an assortment of observed and predicted fields can be overlaid. It should be noted that NWP guidance was far from perfect when introduced for use in forecast centres, but it was accepted because, when interpreted carefully, it provided information not otherwise available. Similarly, SAR-derived winds can now contribute to analyses and forecasts when carefully applied, and their benefits will continue to increase as techniques are developed to improve accuracy and reliability.

The partnerships established between the private sector, government and academic researchers, and service-oriented end users has proven valuable in the MENTOR project. Continued collaboration between these groups can be expected to lead to further advances in the utilization of SAR-derived winds.

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