# Radarsat Imagery in Regions of Large Tides and Shallow Water

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# Radarsat Imagery in Regions of Large Tides and Shallow Water

**A report to**

**Defence Research and Development Canada – Ottawa**

**As part of the Global Shoreline Project**

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# EXECUTIVE SUMMARY

This report summarises the investigation of two sets of Radarsat imagery for the purpose of automated coastline extraction. Studies in the Bay of Fundy, Nova Scotia area highlighted potential problems in identification of shoreline in a region with large tides, steep topography, and large expanses of inter-tidal flats. Studies on the Canadian Beaufort Sea coast highlighted problems associated with storm surges.

Under almost all the conditions we investigated there was a sufficient difference in radiometric brightness between land and sea to make the extraction of a shoreline vector relatively easy. Difficulties arose only in estimating the location of the shoreline at the Mean High Water Line (MHWL) from the location of the actual shoreline found.

Automatic geolocation of the imagery proved insufficiently accurate for mapping purposes, although the one Radarsat image received with precision orbital information proved to be the closest to being able to be automatically geocorrected to mapping standards. With a more precisely determined position on orbit, perhaps automatic geocorrection could be employed.

Manual geocorrection proved to be very difficult as well. The shoreline itself cannot be used for image location, since determining the location of the shoreline is the point of the exercise, and without an accurate tidal model and a knowledge of the intertidal bathymetry, it is not possible to relate any found shoreline to the MHWL. Geocorrection of imagery using points further inland is not possible without a digital elevation model of the area.

Steep topography can shadow the true shoreline. Even if the topography is known, the shoreline position may not be visible. In such regions at least two Radarsat images, one ascending and the other descending, will be required.

In regions of very flat topography and large storms, such as the Beaufort coast, changes in water level due to storm surge are the major disturbing factor in the association of measured shoreline to MHWL. Without good meteorological measurements and a storm surge model, the association cannot be made.

A final problem encountered in this study is one of definition of shoreline, i.e. how does one differentiate between those water/land boundaries that are 'shoreline' from those that are 'lakeshore' or 'riverbank'? In the Beaufort region, where the transition from open ocean to solid land may happen gradually over tens of kilometres, where one draws the line is not obvious.

Many of the problems noted here are not exclusively associated with radar imagery. Any satellite imagery will have similar problems. The conclusion is that, in extreme regions such as the two examined here, automated shoreline extraction to the accuracy required for a 1:50000 map may not be currently possible.

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# 1. Introduction

## 1.1 Issues concerning shoreline mapping with large tides and shallow waters

The extraction of vector shorelines from RADARSAT imagery in regions of large tides and shallow water is burdened with complexities on top of those present in simpler cases. These complexities are both radiometric and geospatial.

The radiometric problem is in relating the 'coastline' that the SAR sees to the observable land/water boundary. It is clear from other studies that, for any appreciable water depth, there is usually a radiometric difference between land and water. When the water depth is less than the wavelength of the radiation (millimetres to a few centimetres deep), it is not clear how the penetration depth of the microwave radiation, which is on the order of the wavelength (5cm) might affect the perceived boundary.

Large tides and shallow water can produce large horizontal excursions of the land-sea boundary. In regions with lesser tides, or with steeper bathymetry, the horizontal excursion is usually only a few metres, and therefore the difference between any shoreline determined from a RADARSAT image acquired at a random phase of the tide, and the Mean High Water Line is likely to be less than the accuracy required of a 1:50000 chart. However, in regions such as examined in this chapter, the horizontal excursion can be several hundred metres. Therefore there may be a large difference between the shoreline located from the imagery and the desired MHWL. These excursions may be caused by meteorological conditions as well as by the tide. Storm surges can contribute temporary changes in shoreline of hundreds of metres as well.

## 1.2 Objectives

In this portion of the study we examine RADARSAT imagery from two regions of the Canadian coastline in which the tides are large or the coastal morphology is extremely flat and the shoreline is indistinct. We define a methodology for extracting a vector shoreline from the imagery, and examine the possibility of inferring the MHWL from the imagery. We also investigate the accuracy with which the imagery may be geolocated.

## 2. Data

One of the experimental sites chosen is in the northern Bay of Fundy on the east coast of Canada, in which six RADARSAT images were acquired in November, 1998. A significant effort was made to provide ground truth for these data. The other site was in the delta of the Mackenzie River on the western arctic coast of Canada. Eight RADARSAT images were acquired in the summer of 1999. Only minimal ground truthing was possible.

### 2.1 Blomidon Peninsula – Bay of Fundy

The Blomidon Peninsula separates Minas Basin from the main body of the Bay of Fundy between the provinces of Nova Scotia and New Brunswick in eastern Canada. It is the eastern end of the North Mountains of Nova Scotia, and is a region of high relief. On the eastern and northern shores, steep cliffs about 100m high plunge directly to beaches or into the ocean itself. On the western side, farmland and forest slope moderately to the sea. In many places there are extremely wide and flat beaches.

The Bay of Fundy is known for its extreme tides. The $M_2$ tide (twice daily, driven by the gravitational attraction of the moon) has a range of over 10m in this region. Large areas along the coast are alternatively exposed and submerged.

A total of six Radarsat images were acquired as detailed in Table 2-1.

**Table 2-1: Radarsat Images - Bay of Fundy**

| ID | Date | Start Time | Beam Mode | Product Type | Orbit Data Type | Pixel Spacing |
|---|---|---|---|---|---|---|
| 1 | 11/14/1998 | 22:21:10.750 | SAR Fine 5 Far Ascending | Path Image | Predicted | 6.25m |
| 2 | 11/18/1998 | 22:04:28.258 | SAR Standard 2 Ascending | Path Image+ | Predicted | 8m |
| 3 | 11/12/1998 | 10:19:20:405 | SAR Fine 4 Near Descending | Path Image | Predicted | 6.25m |
| 4 | 11/21/1998 | 22:16:53:882 | SAR Fine 4 Near Ascending | Path Image | Definitive | 6.25m |
| 5 | 11/22/1998 | 10:27:25.196 | SAR Standard 3 Descending | Path Image+ | Predicted | 8m |
| 6 | 11/28/1998 | 22:11:44.770 | ScanSAR Narrow (W2 S5 S6) Ascending | (SCN) | Predicted | 25m |

These images are shown in Figure 2.1

region, show large horizontal excursions in some areas. The region is also subject to significant storm surges.

The only ground truthing that was possible in this region was a GPS transect made by Atlantic Geoscience Centre personnel (S. Solomon, pers. comm.) along the top of the berm behind a beach.

A total of eight SAR images were processed for the Mackenzie Delta region at the locations shown in Figure 2.2. They cover a region of the Beaufort Sea coast, extending from the Yukon eastward along the Mackenzie Delta and up toward the eastern end of the Kugmallit Bay. The locations of the images are shown in Figure 2.2. Three images are in Kugmallit Bay, two images are in the Olivier Islands, and two more in the Mackenzie Delta. One image is of the northern Yukon Coast. These images are shown in Figure 2.3 and are described in Table 2-2. All images were received in Single Look Complex form. This form is essentially the raw output of the SAR processor at the Gatineau Receiving Station with only the most basic conversion to image form.

**Table 2-2: Radarsat Images – Mackenzie Delta**

| Scene | Day | Time | Beam |
|---|---|---|---|
| Kugmallit Bay 1 | 20 Jul 99 | 15:22:51 | F3F-Desc |
| Kugmallit Bay 2 | 22 Jul 99 | 02:27:11 | F3N-Asc |
| Kugmallit Bay 3 | 15 Aug 99 | 02:27:23 | F3N-Asc |
| Mackenzie Delta 1 | 08 Aug 99 | 02:31:32 | F2F-Asc |
| Mackenzie Delta 2 | 01 Sep 99 | 02:31:35 | F2F-Asc |
| Olivier Islands 1 | 06 Aug 99 | 15:27:19 | F4 Desc |
| Olivier Islands 2 | 30 Aug 99 | 15:27:25 | F4 Desc |
| Northern Yukon Coast | 11 Jul 99 | 02:48:14 | F3F-Asc |

Work in this report concentrates mainly on the Beaufort Sea image set along the Mackenzie Delta coastline.

# 3. Methodology for Shoreline Extraction

## 3.1 Approach

The basic philosophy of processing the Radarsat images was to explore the practicality of using a production environment to extract a precision shoreline from radar imagery. We had not expected to develop new algorithms, but were looking at the geophysical relationship between our measurements and radar imagery.

Our programming system of choice was Easi/Pace Version 6.3, a product of PCI Geomatics, Richmond Hill, Canada. It is a remote sensing imagery processing system that our group has been working with for a decade, and is well suited to a production environment. All processing was done on a Sun Ultra-60 workstation running Solaris 2.6. The following two sections describe the process from the data received on CD-ROM to an extracted shoreline vector.

## 3.2 Imagery post-processing

The first phase of the processing takes the data from the raw form on the CD-ROM received from Radarsat International to the point of being ready for the specific shoreline extraction algorithms to be applied.

### 3.2.1 Preliminary Steps

SAR data for the Bay of Fundy trial were provided on CD-ROM by Radarsat International in several different forms: Path Image, Path Image Plus and ScanSar Narrow. For the Mackenzie Delta trial, data were provided only in Single-Look Complex form.

The first step then is to read the Radarsat image from the CD-ROM onto the hard disk of the host computer. The single look complex (SLC) images in this study contain two 16 bit channels (real and imaginary). The complex number form of these images was not useful for this study, so the data were converted to real numbers through the standard $(\Re, \Im) \rightarrow Re^{i\varphi}$ transform. The other forms of imagery were already in real number form upon transferral from CD-ROM.

The classification procedures used later in the processing are sensitive to the dynamic range of the image. When the full 16 bit values are used, the noise variance is large enough to cause some classification error, while with scaled down 8 bit values, the problem is less severe. Accordingly, at this time in the processing, the data are scaled into an 8 bit range for each channel.

Finally, the imagery was converted from slant range to ground range using the known satellite altitude and the incidence angle of the inner edge of each image. Nearest neighbour resampling was used in this step, and the resulting pixel size was maintained as close to the original as possible

1:50000. Unfortunately, most of the maps at this scale originated from 1958, and were based on the NAD 27 geoid. Even though four decades separated the maps from the imagery, many of the larger lakes still were identifiable, and had close to the same shape. As in the earlier step, these lakes formed the basis of our geo-location.

## 3.3 Image Filtering

Although the border between land and sea is often quite visible and definite when looking at a SAR image as a whole, at the pixel level it is quite indistinct due to the inherent SAR multiplicative speckle noise. We applied a speckle filter to the data to reduce this problem.

A Lee filter is a standard deviation based (sigma) filter that filters data based on the statistics of the image or a portion of it. Unlike a typical low-pass smoothing filter, the Lee filter and other similar sigma filters preserve image sharpness and detail while suppressing noise. The pixel being filtered was replaced by a value calculated using the surrounding pixels in a 5 X 5 region.

To estimate the noise variance, we performed a K-Cluster classification of the images, constraining the clustering to two classes. The variances of these classes were used in a two pass Lee filter, with the first pass using the ocean variance and the second the land variance. The resulting coastline can be seen to be much smoother.

## 3.4 *Shoreline extraction and enhancement*

### 3.4.1 Image Classification (Sea-Land)

Once the images were filtered, a second K-Cluster classification was performed. The resulting images were cleaner, but still exhibited some land pixels classified as sea and vice versa. To remove these we applied a sieve procedure that removed all isolated regions smaller than 400 pixels. This procedure would also remove any islands smaller than about 1 ha in area, but was necessary to remove the remnants of clutter in the imagery.

Finally a sieve was applied to remove any lakes or bodies of water smaller than 2500 pixels (6 ha) encircled by land. This step was cosmetic only and specific to this region, since we are interested only in the land-sea interface.

An overview of the final stages of this process is shown in Figure 3.3.

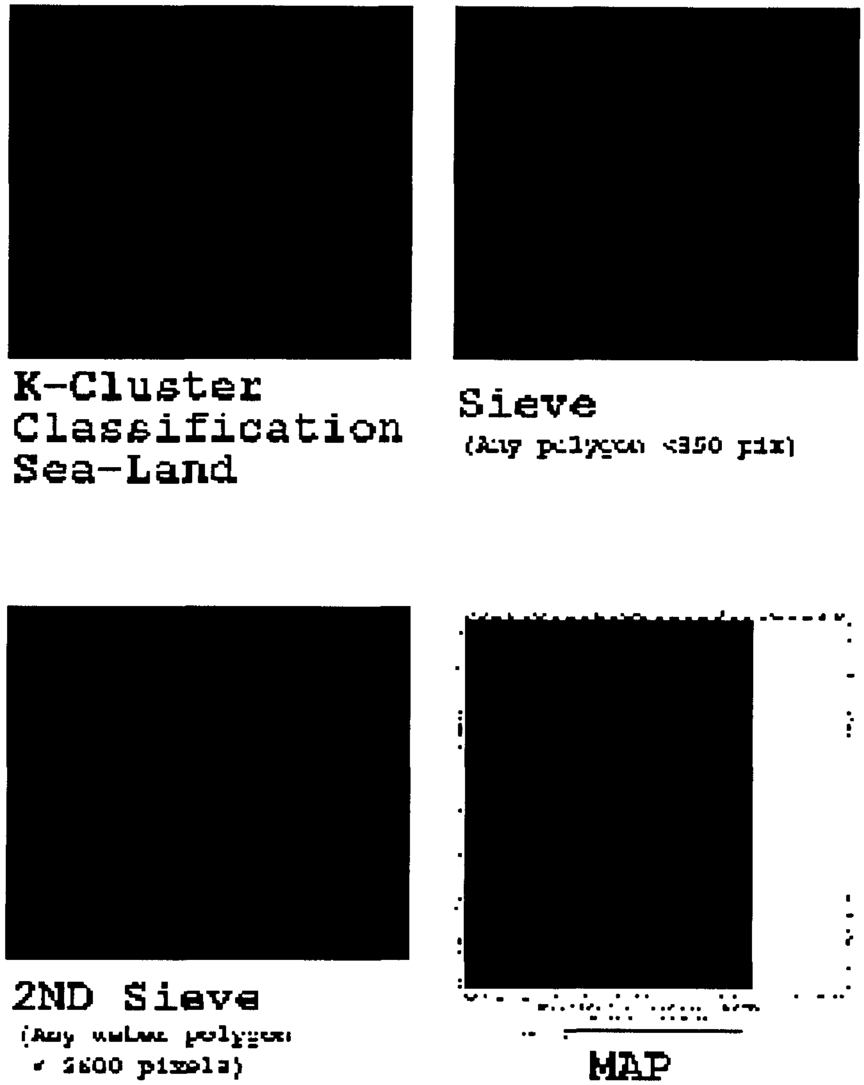


**Figure 3.3: Final Stages of Shoreline Extraction**

### 3.4.2 Shoreline Vectorization

The final stage in the procedure was to convert the two level bitmapped image into a vector shoreline. This was accomplished by using a contour routine that followed the boundary between the pixels classified as land and those classified as water. In the application of this procedure, it was critical not to include the edge of the image in the contouring area, since the procedure would falsely consider the edge of the image to be a boundary between land and sea.

on descending passes (blue in Figure 4.4, green in Figure 4.5), the cliff face is imaged, but in when viewed from the west on ascending passes it is not. At lower tides the entire beach is visible on the descending pass (green, Figure 4.5), but in the radar shadow of the cliffs except for the extreme outer edge on ascending passes (both red and green in Figure 4.4, and red, which together with the green descending pass makes a yellow line, in Figure 4.5). Without the detailed knowledge of the backshore topography, and both ascending and descending passes, the actual shoreline location would not be possible to determine.

At Cape Split, the northwestern tip of the peninsula, there are west-facing cliffs dropping straight into the sea. These are imaged clearly in all ascending passes, but are shadowed in both descending passes.

The Scot's Bay side if the Blomidon Peninsula gently slopes to the west down to the water's edge. There is a pebble berm between the beach and the backshore. The beach itself is a very level mudflat that is exposed at lower tides. A stream enters the mid-point of the Bay through a slightly elevated delta. Two of the three low tide images (red and green, Figure 4.5) show a definite boundary between the mudflat and the water, but the other (red, Figure 4.4) does not. The image of the stream delta is visible however. The difference between these images is that the sea surface in the first two cases is sufficiently rough to cause backscatter of the radar signal. In the third case it is not. In all cases, the smooth wet surface of the mudflat acts as an almost specular reflector of the radar signal, and therefore returns no signal to the satellite.

## 4.2 Kugmallit Bay

The three Kugmallit Bay images show few differences between them. All were imaged in Fine 3 or Fine 3 Far mode, and at similar tidal heights.

Figure 4.6 shows an image map in which the three dates are shown as different colours. The images show that the shoreline is essentially the same for all three images. In the interior of Figure 4.6 there are a few coloured features that are small lakes or ponds that are present in one of the images but not in others.

Out of the three Beaufort Sea scenes, this one shows the smallest differences in shoreline positions between Radarsat images. It might be well explained by the fact that they were respectively (Aug 15, Jul 20 and Jul 22) at mid tide, high tide (but low amplitude) and mid tide (small amplitude). Heights of the tide at Tuktoyaktuk were predicted to be about 56 cm, 52 cm and 44 cm for the three dates respectively. So these little differences were not enough to account for differences at the map resolution.

The image of an Island of Kugmallit Bay from the north-western section was enlarged (Figure 4.7) so that coastlines differences at this resolution might be noticeable at that scale (1000m each square)

| Going | Down | | Up |
| --- | --- | --- | --- |
| Height | 56cm | 52cm | 44cm |
| Range Hi-Low | 32cm | 21cm | 8cm |
| Coast Colour | Cyan | Purple | Yellow |
| Wind | 5-10Km/h N | 40Km/h E | 25km/h NW |

There is no obvious relationship between tidal height and coastline position. The cyan coastline seems further offshore from the other lines but the tide models shows that this is the highest tide. The lowest tide corresponds to the most onshore coastline, but this is also the date of the strongest onshore winds. Therefore we are probably seeing the effect of a storm surge or wind set-up.

## 4.3 Delta Islands

To the southwest of Kugmallit Bay are a group of islands in the centre of the Mackenzie Delta. These islands were imaged twice, both with Fine 2 Far ascending passes on 08 august and 01 September 1999. The filtered images are shown in the next few pages, with the associated coastlines drawn in red. Lee filtering and coastline extractions were also applied for this scene set, and the resulted shoreline and filtered images appeared in the next few pages. The 08 August 1999 in Figure 4.8 and the 01 September 1999 image is shown in Figure 4.9.

The 01 September image was put in the red and blue channels and the 08 August one in the green channel. The dominant colour in this image is magenta, indicating regions that were above the water line on 01 September but underwater on 08 August. Based purely on tidal information, this situation ought to be reversed, since the tidal level was higher in the September image. The winds both days were equally strong, but in the August image, were easterly, along the general direction of the Beaufort Sea coastline. In the September image, they were onshore. We may conclude that the regional ocean circulation in response to this wind, causing an offshore Ekman transport, and a set-down of the water level is more important than a local wind set-up and a small tidal difference.

## 4.4 Olivier Islands

The third set of pictures analysed was of the Olivier Islands to the southwest of the Delta Islands region. This set consists of two Fine 4 descending SAR images, one on 06 August (Figure 4.11) and the other on 30 August (Figure 4.12). The main coastlines have been drawn in red. Some differences are noticeable in the centre of the image, where some smaller islands appear in one image (30 Aug.) and disappear on the other.

This difference image of the Olivier Islands set shows substantial agreement between coastlines. Scattered green patches over the largest island are possibly meltwater patches that existed early in the month, but have evaporated by late August. The magenta regions bordering the coastline, and the few magenta islands are likely extremely flat areas, mudbanks perhaps, that the small tidal difference of 7cm is sufficient to cover.

# 5. Accuracy of Geolocation

The only ground truth provided to us for this region was a 1994 airphoto of Tent Island provided by S. Solomon of the Atlantic Geoscience Centre, Natural Resources Canada, Dartmouth, NS. He provided a precise geolocation of this photo using a DGPS tracked all-terrain vehicle driving along identifiable landmarks. This airphoto was geocorrected to a NAD83 geoid. The imagery in this report has been corrected to NAD27, since that was the basis for the paper charts used to collect ground control points. Consequently, to compare the two, the radar imagery was reprojected from NAD27 to NAD83.

Figure 5.1 is the resulting image map in which this air photo has been placed in the green channel, with the 01 September image and the 08 August image in the red and blue channels respectively. The area shows the coastline of a section of 925m by 925m near 503000m E 7707700m N (NAD27) situated in the middle of the Delta Islands scene. It can be seen that the airphoto and the radar images overlay within approximately one radar pixel of each other. The differences between the radar images is greater than the difference between the airphoto and the radar.

# 6. Lessons Learned Towards Operational Mapping

There are many lessons we can learn from these image sets about the suitability of Radarsat imagery for the operational mapping of the global shoreline. These fall into the categories of shoreline detection, shoreline location and shoreline interpretation.

## 6.1 Shoreline Detection

For the most part in these image sets, raw detection of the land-sea boundary was not difficult. Through the use of a K-clustering classification method, we have been able to extract a shoreline vector in all the Mackenzie Delta imagery. This method relies on there being an intensity or textural difference between land and sea. Only in one of the Blomidon images was the actual shoreline invisible to radar. That was a case of a very calm sea. Offering no significant backscatter, and a smooth, wet mudflat, also offering no backscatter. The experience of other researchers (H. Greidanus, TNOFEL, the Hague, Netherlands, pers. comm.) is that use of these differences, especially for exposed coastlines is unreliable, since wind and wave effects can give the ocean surface a similar backscatter to the shoreline. Perhaps we were just fortunate in these images.

## 6.2 Shoreline Location

Geolocation proved to be a significant problem. Automatic geolocation, using the orbital parameters supplied with the imagery was insufficiently accurate for even the coarsest shoreline vector creation, at least using the routines provided with Easi-Pace software. The one image provided with a precision orbit, rather than a predicted one, was much closer to the ground truth data. We may assume from this that the accuracy of the position of a pixel on the ground can be no more accurate than the accuracy of the position of the satellite in its orbit, and therefore very precise knowledge of the satellite orbit is a requirement.

Although manual geocorrection of imagery is not really feasible for an operational procedure, we found that it is not useful in coastal regions where there are significant elevations near the coast. One cannot use the coastline itself for geolocation, since that is the feature we are trying to locate, and, in regions of large tide, it moves. One cannot use features on land behind the shore without knowing their elevation, due to the standard problems of layover. Hence, manual geocorrection is not possible without an elevation map or model for the image.

Coastal regions of significant topography proved to cause problems as well. In the Blomidon imagery, east facing cliff faces and the beach below were hidden from the radar on ascending passes, and west facing cliffs were hidden on descending passes. In regions such as these, it is a requirement to image in both directions to be sure there is no topographic shadowing of significant coastal features.

## 6.3 Shoreline Interpretation

What is the shoreline? The general goal of identifying the Mean High Water Line is elusive in these image sets. In the Blomidon set, it was possible to locate a high water line by imaging at a time near high water. To do so in an operational sense would require knowledge of the tides in the vicinity of the area to be imaged, and the acquisition of two images, ascending and descending, in that region at a time approximating high tide.

In the Mackenzie set, although the tides were smaller, the land behind the shoreline was much flatter. Indeed, it seemed that the tide was less critical to the location of the shoreline than was the wind direction. Storm surge probably caused more deviation in the observed position of the water/land boundary than did the tide. To relate the observed shoreline to the MHWL would require knowledge of the coastal topography and an operational storm surge model for the region together with a record of the meteorological conditions in the days around the time of image acquisition.

In this region as well, the transition from land to sea was very gradual, a change over many kilometres from land separated by channels in the river to islands in the ocean. It is not clear where the formal boundary between land (with river) and sea (with islands) ought to be drawn. While it is relatively easy to draw a vector map of the boundary between land and water, it is less clear what is ocean and what is not.

# 7. Conclusions

In this chapter we have shown that it is possible to extract a shoreline vector from Radarsat imagery with little problem. In most places along the world's shorelines, where tides are sufficiently small that their horizontal excursion is on the order of tens of metres or less, this technique should be adequate for estimating the location of the mean high water line. In regions like the ones explored in this chapter however, the relevance of this shoreline vector as a representation of the Mean High Water Line is doubtful. The situation is confused in regions of high topography, requiring imagery from both ascending and descending passes to resolve the ambiguity. In all cases, absolute geolocation is not possible without detailed knowledge of local ground control points, and in regions of significant topography, a digital elevation model, unless the satellite orbit is determined precisely.

Questions arise in these regions of large horizontal excursion of the tide about the location of the MHWL with respect to the observed shoreline. If there is no detailed and accurate tidal information available for the region, then enough imagery must be taken to empirically determine the maximum extent of the tide. In some regions with particularly flat nearshore terrain, a storm surge model may be required to remove the effects of meteorology on the observed waterline.

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