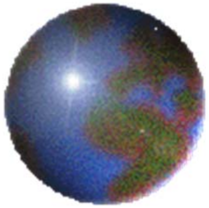

Measurement of Sea Surface Current and Wave Parameters Using X-band Nautical Radar

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Outline

1. Introduction
2. Ocean current measurement
3. Wave information retrieval
4. Conclusion and future work

1. Introduction

1.1 Radar oceanography

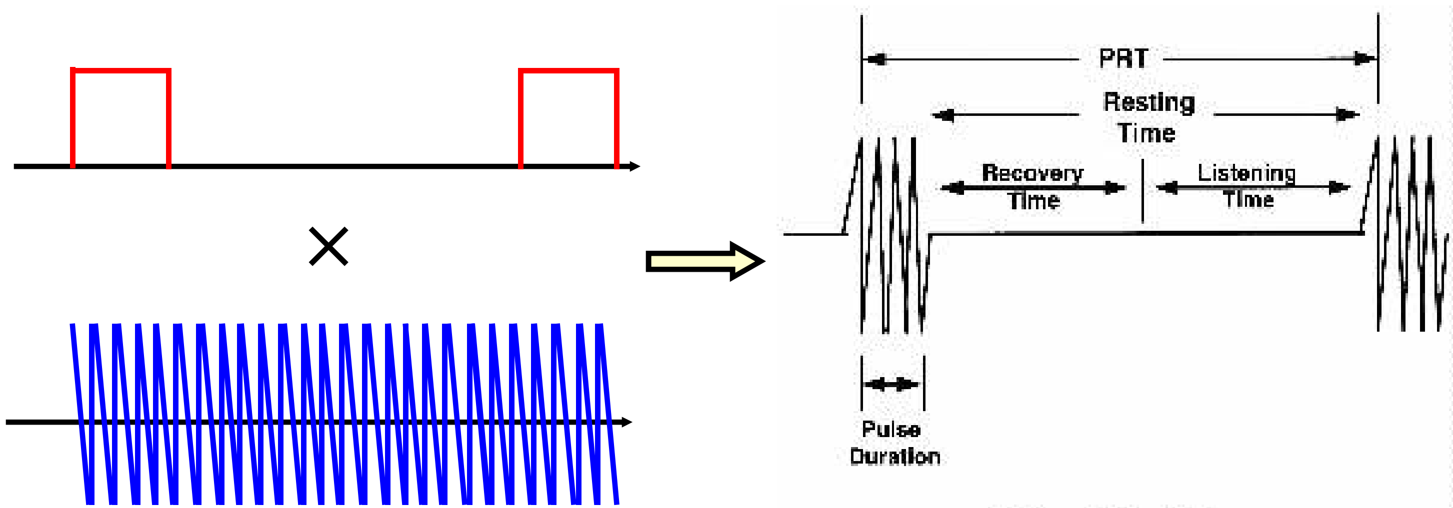
- *Why Remotely Sense the Ocean?*

1. Weather monitoring and forecasting
2. Collision avoidance for marine safety
3. Search and rescue at sea
4. Surveillance and defence
5. Exclusive Economic Zone management

Why Use Radar?

1. Satellite: large area----intermittent
2. *In-situ* Instrumentation (Ship and buoy): ----easy to be destroyed; expensive deployment and retrieval; limited coverage area
3. radar: large area with high resolution; real-time data

1.2 How pulsed nautical radar “sees” the ocean

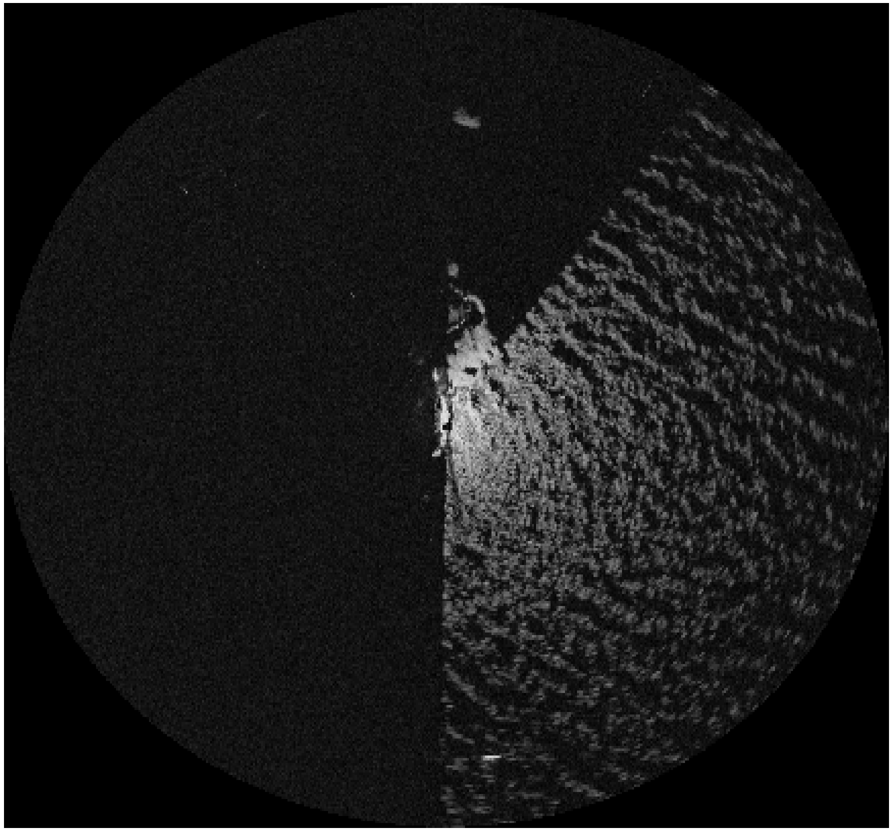


3 or 10 GHz

Radar Pulse Train

Typical Pulsed Radar Image

Image(1)in Segment(1)-----Start Bearing: 1148--Stop Bearing: 1147--Radius: 2.1 NM



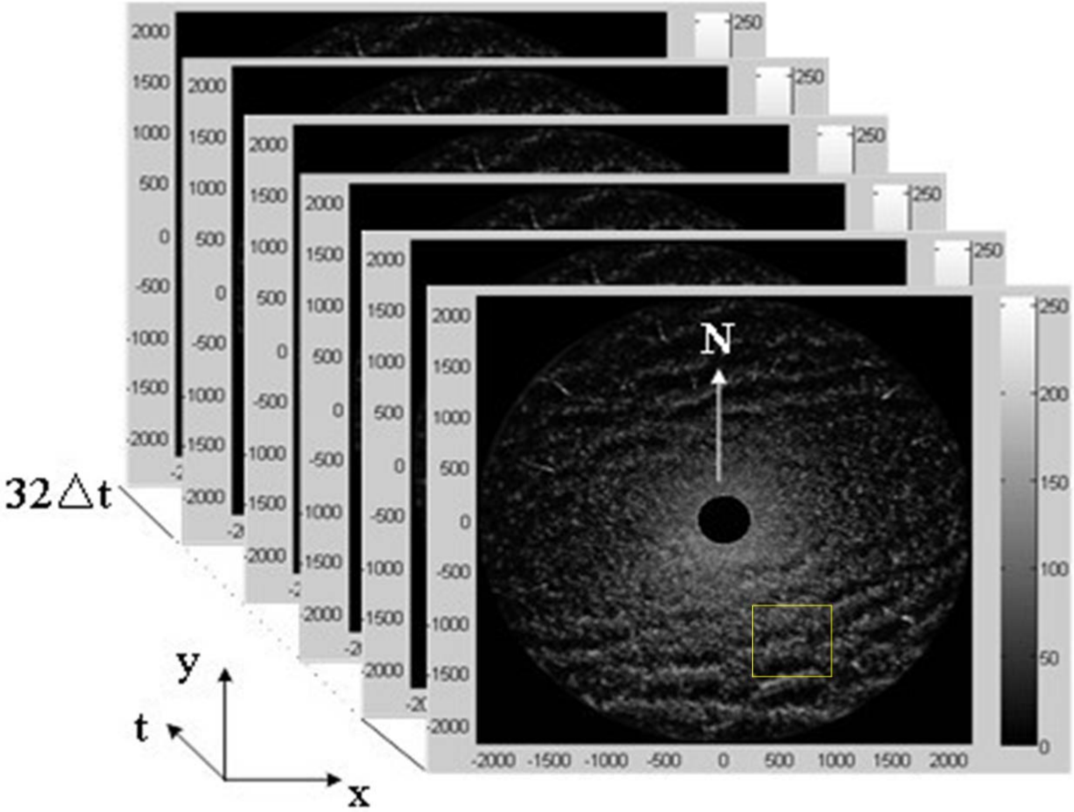
2. *Ocean Current Measurement*

Purpose

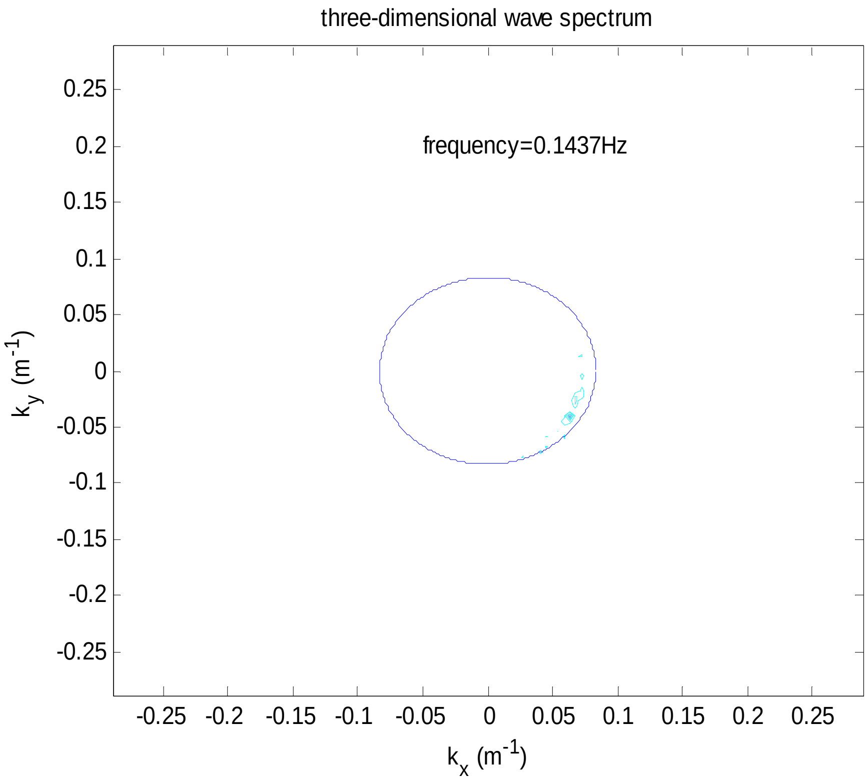
1. Better guidance for ship operation
2. Oil spill tracking and control

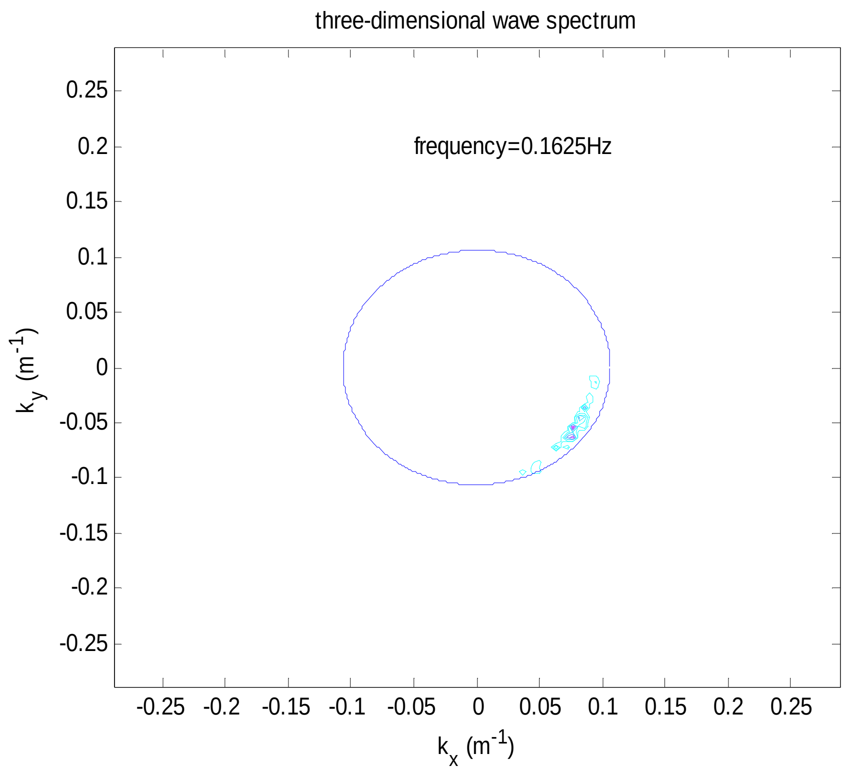
Processing steps

1. Temporal sequence of radar sub images



2. 3-D image spectrum by 3-D FFT on sub images





2.1 Least-squares (Young's) method

.

Minimize $d = \sum_{i=1}^{N_\omega} \sum_{x=1}^{N_x} \sum_{y=1}^{N_y} [\omega_i(k_x, k_y) - \tilde{\omega}_i(k_x, k_y)]^2$

where $\omega_i(k_x, k_y)$:frequency at which spectral energy is located for wave number components (k_x, k_y)

$$\tilde{\omega}_i(k_x, k_y) = \sqrt{gk \tanh(kd)} + k_x U_x + k_y U_y$$

is the value calculated by dispersion relationship with assumed current velocity (U_x, U_y)

2.2 Iterative LS (Senet's) method

.

Minimize $d = \sum_{i=1}^{N_{\omega c}} \sum_{x=1}^{N_x} \sum_{y=1}^{N_y} [\omega_i(k_x, k_y) - S_{ip}(k_x, k_y)]^2$

where the spectral frequency after de-aliasing using higher-order harmonics and FFT periodicity and symmetry is

$$S_{ip}(k_x, k_y) = (p+1)\sqrt{gk/(p+1)} + k_x U_x + k_y U_y$$

and is the value calculated using the dispersion relationship along with the previous current velocity (U_x, U_y).

2.2 NSP (Serafino) method

Normalized Scalar Product

$$V(Ux,Uy)=\frac{<|I_f(k_x,k_y,\omega)|,G(k_x,k_y,\omega,Ux,Uy)>}{\sqrt{P_F P_G}}$$

where $I_f(k_x,k_y,\omega)$ is the spectral energy at (k_x,k_y,ω) after HPF.

The Characteristic Function for the current velocity, $U(U_x,U_y)$, is

$$G(k,\omega,U)=\begin{cases}1, & |\sqrt{gk}+k_xU_x+k_yU_y-\omega_i|\le\frac{1}{2}\Delta\omega\\ 0, & \text{otherwise}\end{cases}$$

2.4 Improved method

1) For Senet (iterative LS): Adaptive termination criterion

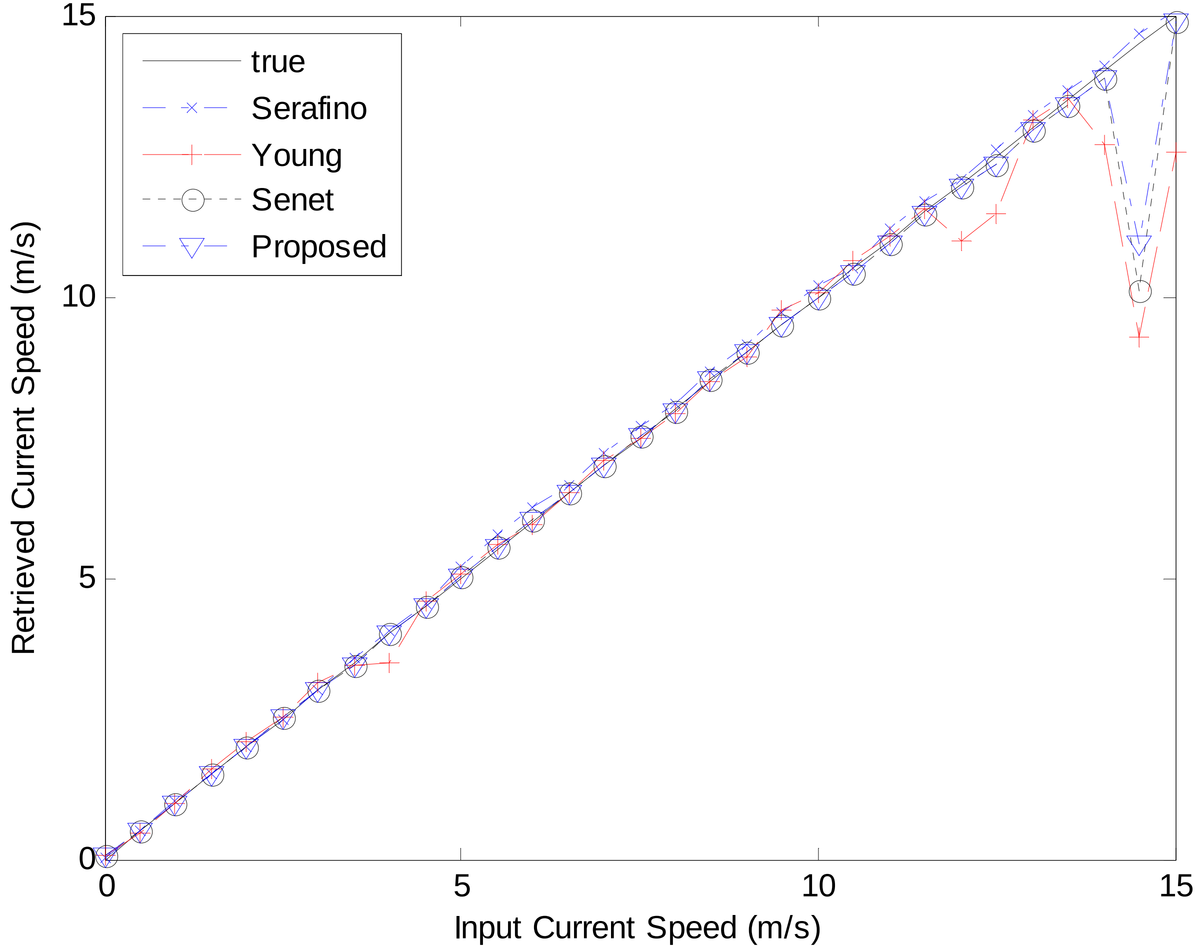
$$|U_{xn} - U_{x(n-1)}| < 0.005 \quad \text{and} \quad |U_{yn} - U_{y(n-1)}| < 0.005$$

Subscripts n denotes present result; (n-1) for previous

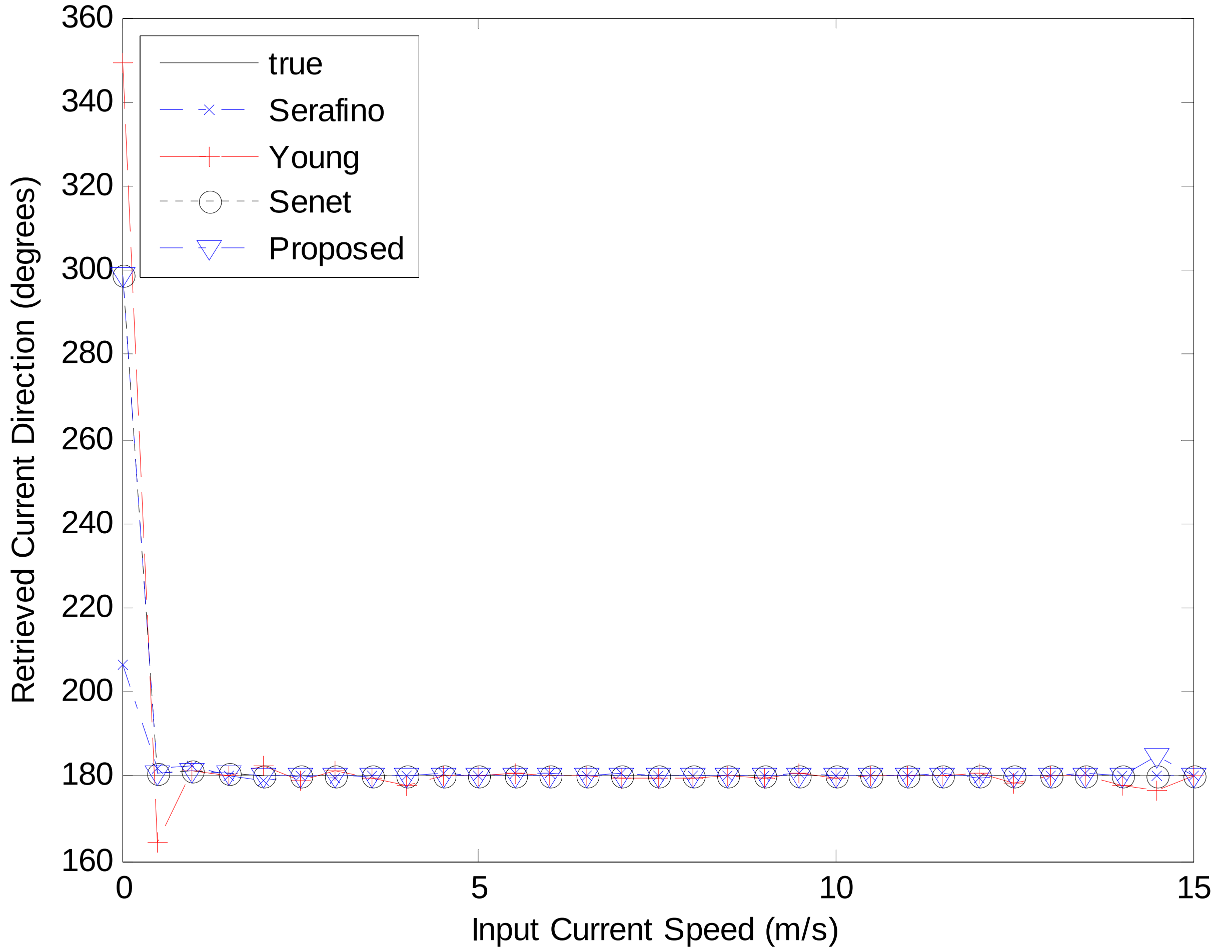
2) For Serafino (NSP): Variable search step

$$SL = \begin{cases} 1, & U_x, U_y \in [-20, \quad 20] \\ 0.1, & U_x \in [U_{x_1} - 1, U_{x_1} + 1], U_y \in [U_{y_1} - 1, U_{y_1} + 1] \\ 0.005, & U_x \in [U_{x_2} - 0.1, U_{x_1} + 0.1], U_y \in [U_{y_1} - 0.1, U_{y_1} + 0.1] \end{cases}$$

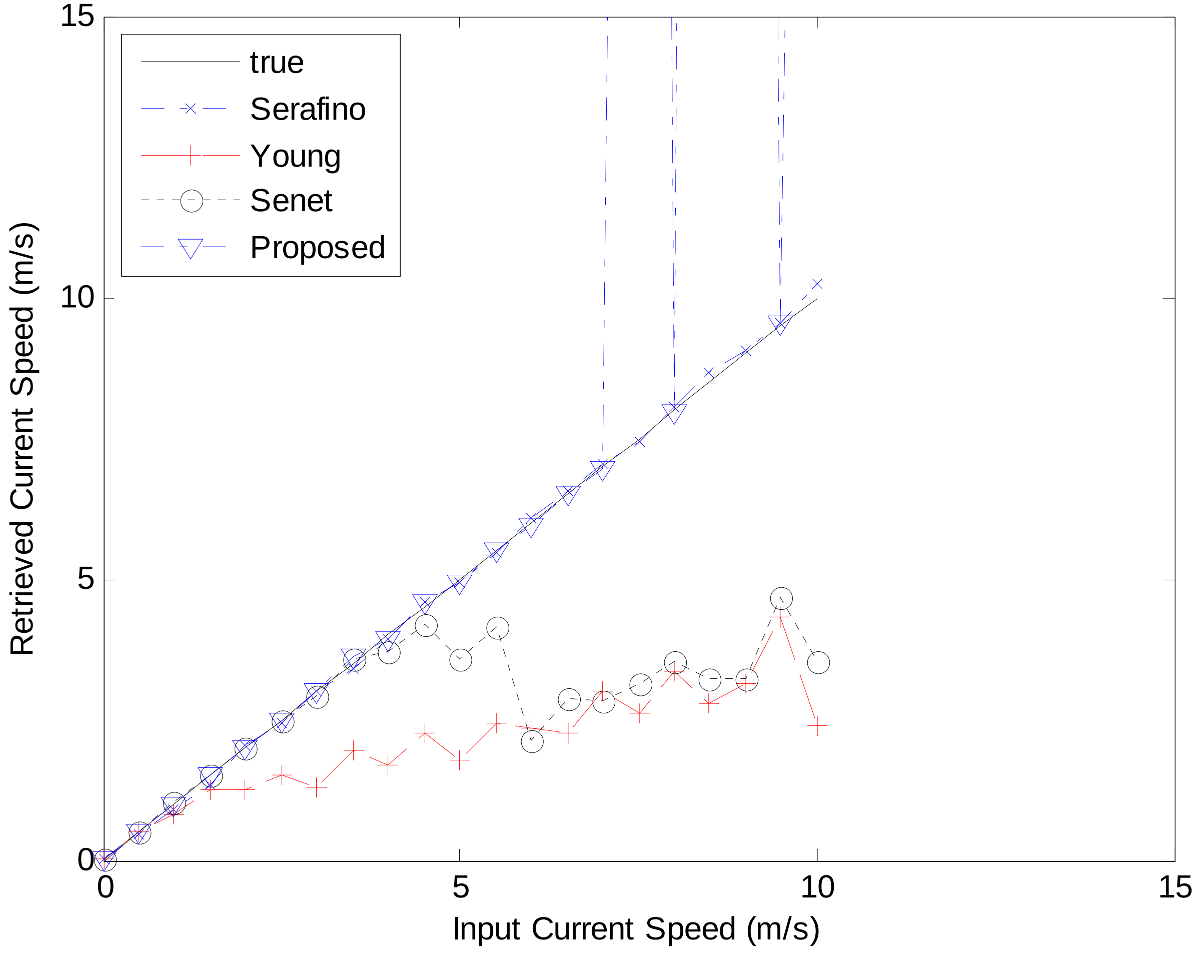
Simulation Results



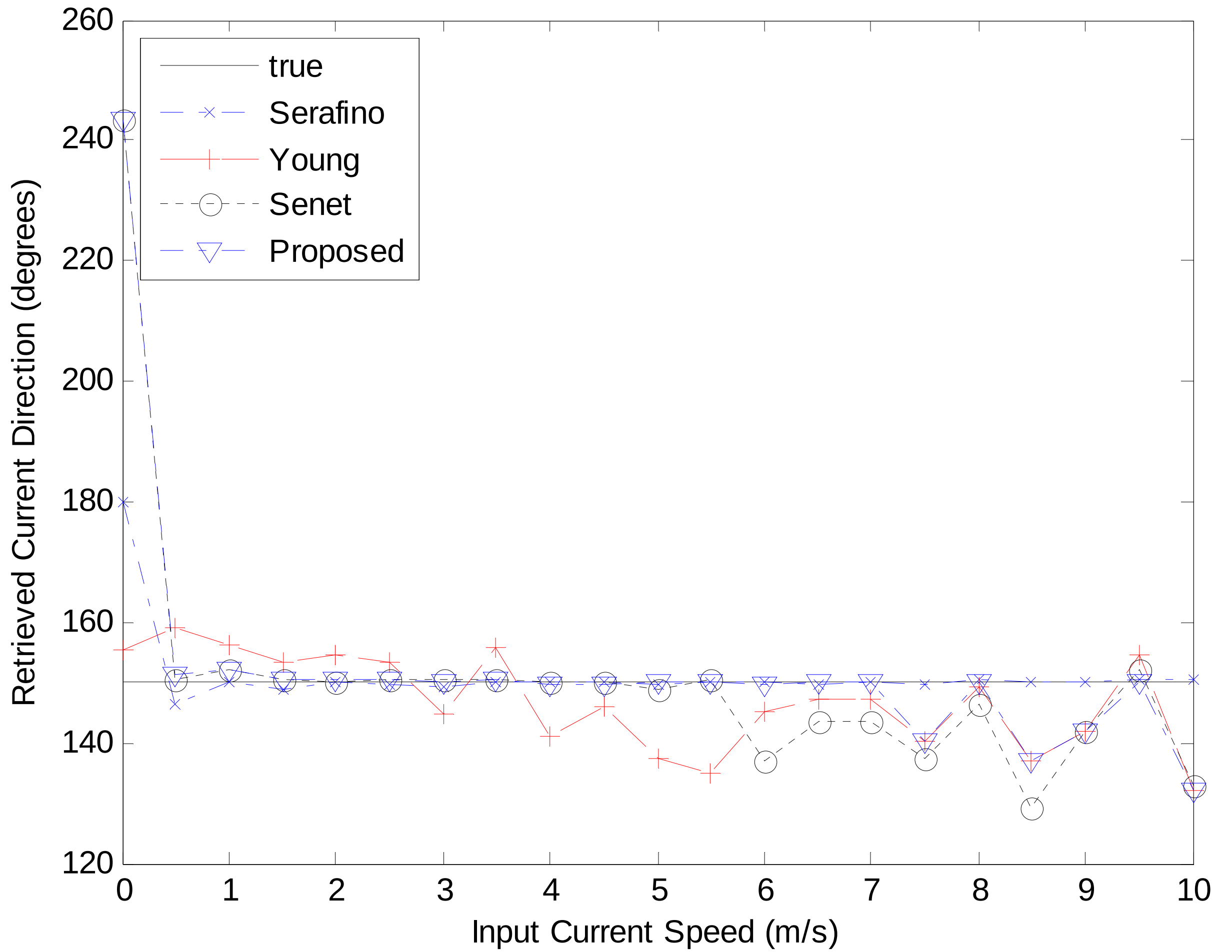
Current speed (wave-current in different direction)



Current direction (wave-current in different direction)

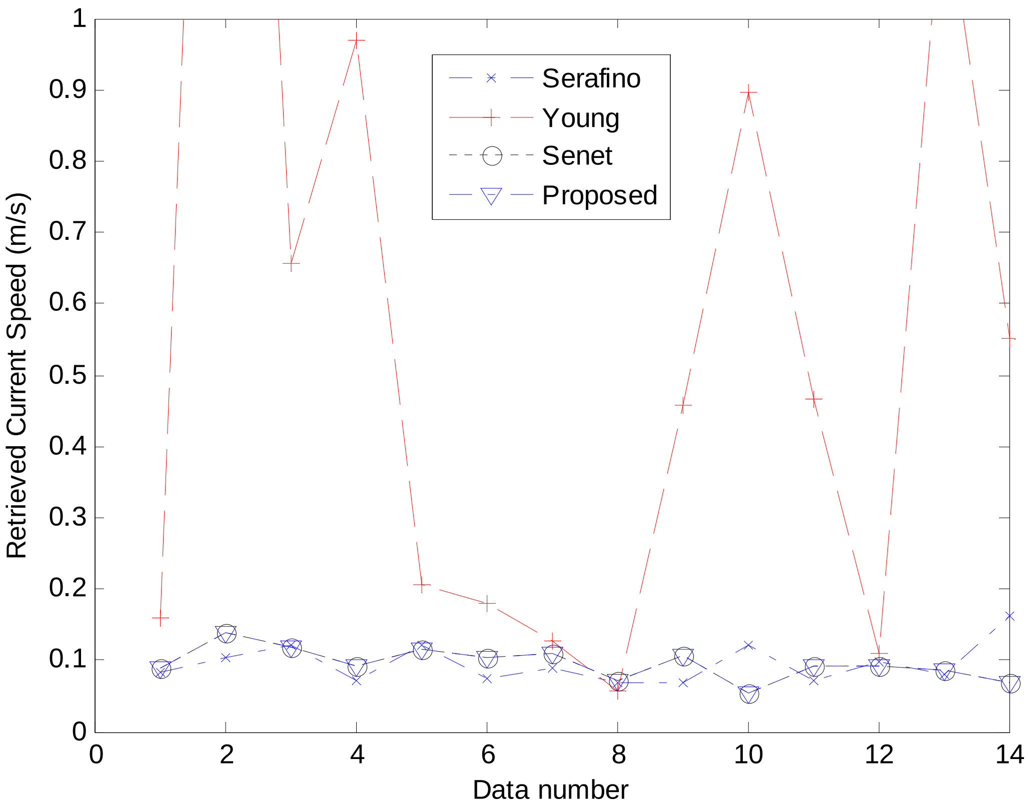


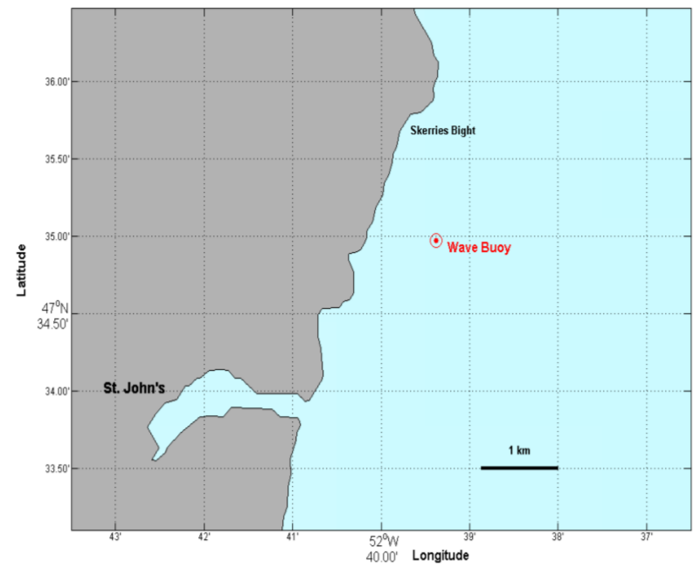
Current speed (wave-current in same direction)



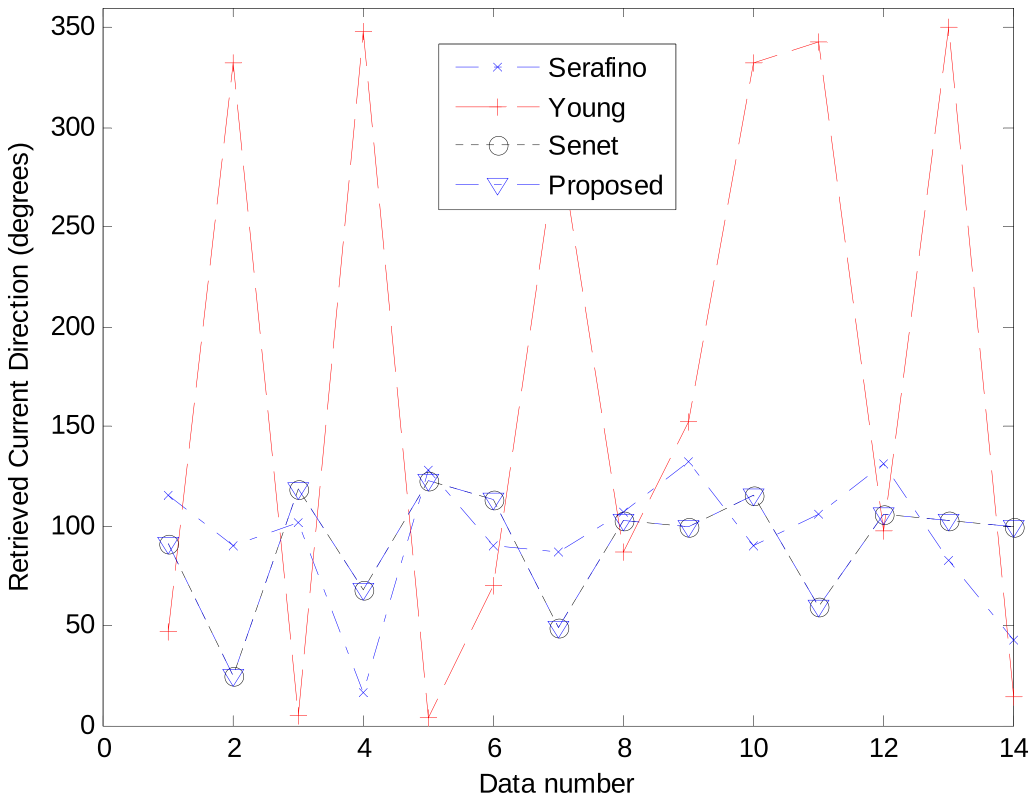
Current direction (wave-current in same direction)

Experimental Results (Skerries Bight)





Current speed from Skerries Bight (Dec 15, 2010)



Current direction from Skerries Bight (Dec 15, 2010)

Summary

• Current extracted from navigation radar images using different methods: Serafino best, but slow; Senet good for low current, but fast; proposed algorithms improve both.

1. **W. Huang**, E. Gill, "Surface Current Measurement under Low Sea State Using Dual Polarized X-band Nautical Radar", *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens. (JSTARS)*, 5(6), pp. 1868-1873, 2012.

2. **W. Huang**, E. Gill, "Simulation Analysis of Sea Surface Current Extraction from Microwave Nautical Radar Images", *IEEE International Conference on Image Processing,* Orlando, Florida, USA, pp. 2673-2676, 2012.

3. **W. Huang**, E. W. Gill, and Z. Zhong, "Enhancement of the Normalized Scalar Product Method for Surface Current Measurement Using Nautical Radar", *Oceans' 12 MTS/IEEE*, Hampton Roads, USA, 2012.

3. *Wave Information Extraction*

Formula

1. Inverting 3-D wave spectrum by filtering image spectrum

Filter as $$E(k_x, k_y, \omega) = k^{-1.2} \int_0^{\omega_N} I_f(k_x, k_y, \sigma)\delta(\sigma - \omega) d\sigma$$

2. 2-D wave spectrum from 3-D wave spectrum

$$E(\omega, \theta) = E(k_x, k_y, \omega) \frac{kdk}{d\omega}$$

3. Non-directional frequency (1-D) wave spectrum by integrating 2-D wave spectrum

$$S(\omega) = \int_0^{2\pi} E(\omega, \theta) d\theta$$

Retrieving wave spectrum from 3-D image spectra (classic algorithm)

1. Band-pass filter (BPF)
2. Modulation transfer function (MTF)

Iterative least-squares-based algorithm

1. Disadvantage in the classic algorithm

- only the fundamental wave components that fall in the pass-band are used for wave analysis.
- designing BPF is complex

2. Solutions: use fundamental and harmonic components without BPF

- base on the modes classification during the iterative least-squares current estimation

3. Algorithm details

- The minimization criterion for LS current estimation:

$$\sum_{i=1}^{N}\left(\left|\omega_i-\omega_{p,r}(\vec{k}_i)\right|^2\right)\rightarrow MIN$$

ω_i - the sampled frequency, $\omega_i \in [0,\omega_N]$

$\omega_{p,r}(\vec{k}_i)$- the pth order of folded wave frequency within $[0,\omega_N]$ calculated using periodicity and Hermitian property from theoretical frequency obtained by Doppler shifted dispersion relation

$$\omega_p(\vec{k})=(p+1)\sqrt{\frac{gk}{p+1}\tanh(\frac{kh}{p+1})}+\vec{k}\cdot\vec{u}_e$$

h -the depth of the ocean; $\vec{u}_e$- current velocity

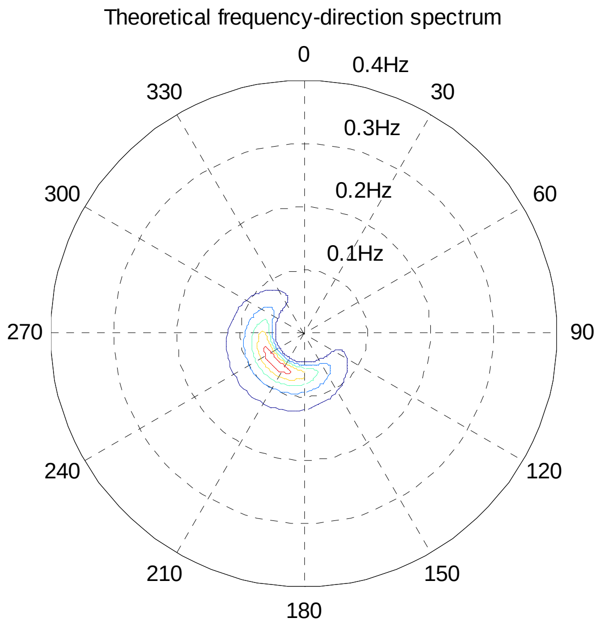
3. Algorithm details (cont.)

- The image spectral sample points with energy higher than a preset threshold will be classified as
  - fundamental wave components (p=0)
  - 1st or higher order harmonic components with mapped frequencies $\omega_{p,r}(\vec{k}_i)$ where p=1,2,…

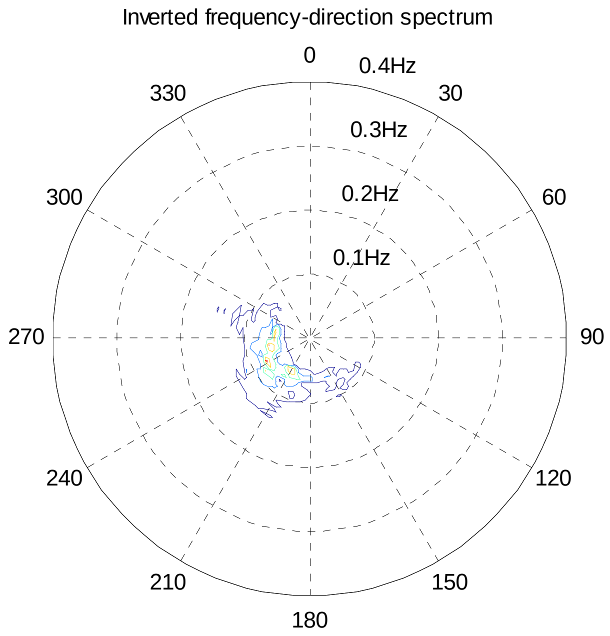
Note: only fundamental and 1st-order harmonic components are used for wave retrieval.

Simulation Results

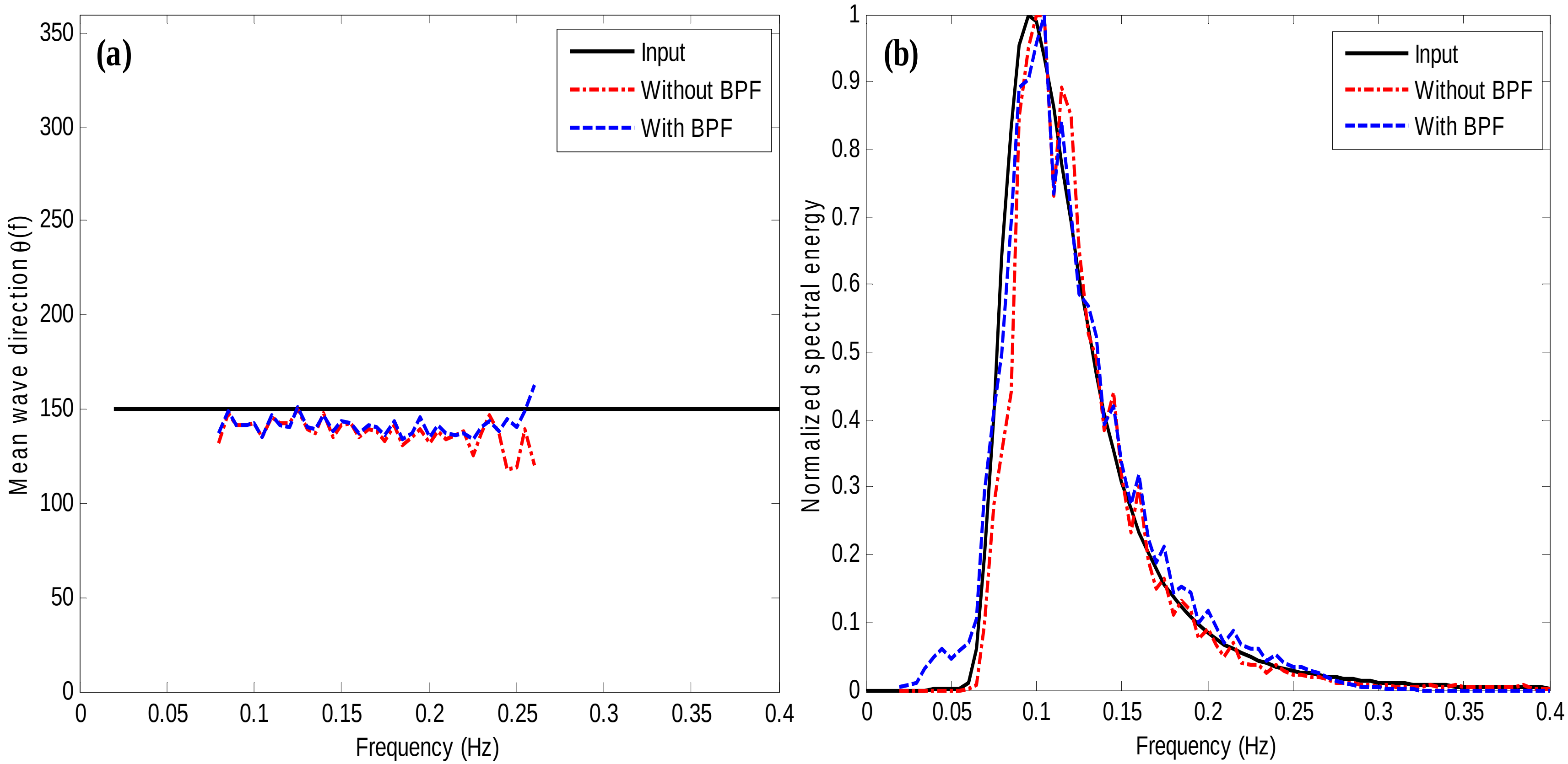
1. 2-D directional frequency spectrum



Input



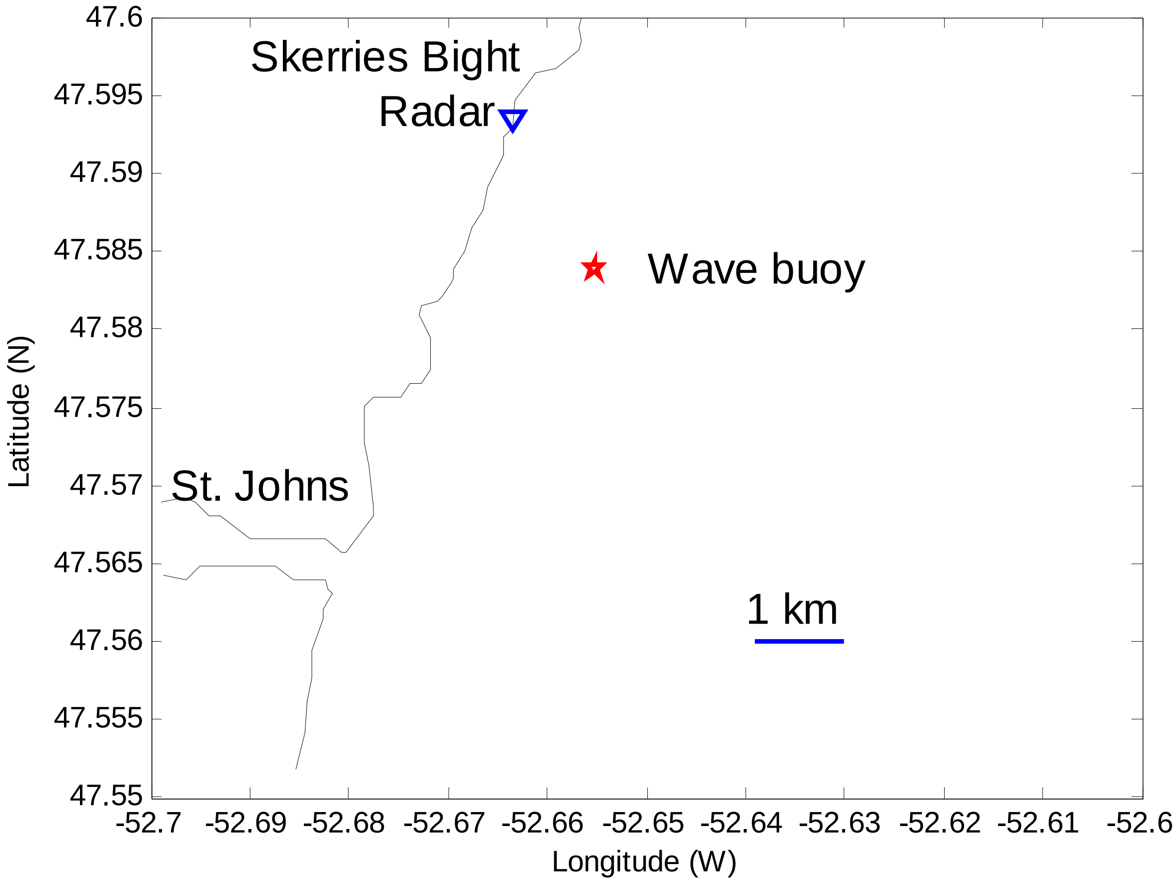
Inverted

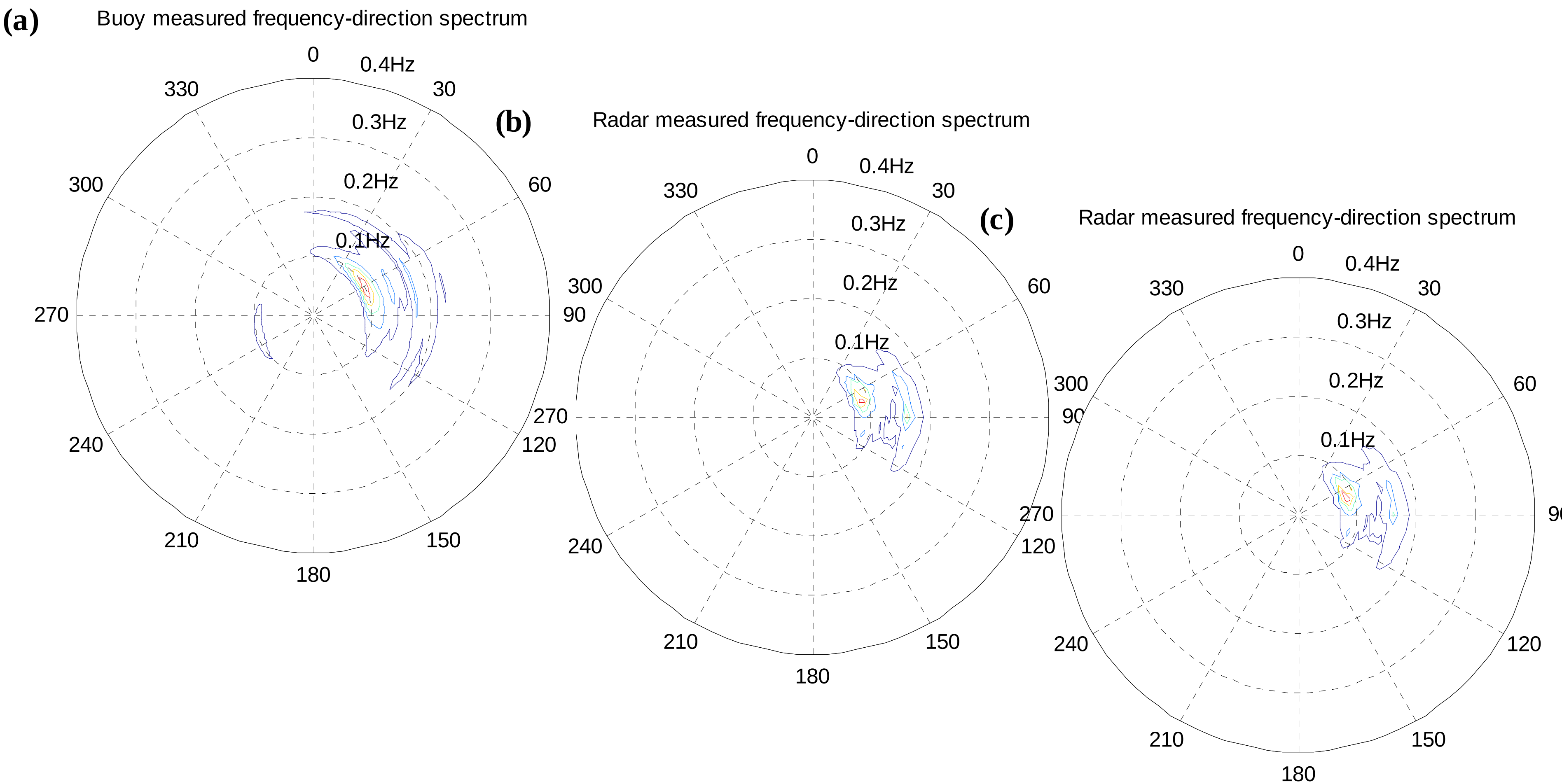


(a) **(b)**

Comparison of retrieved and input: (a) mean wave direction spectra; (b) 1-D wave spectra.

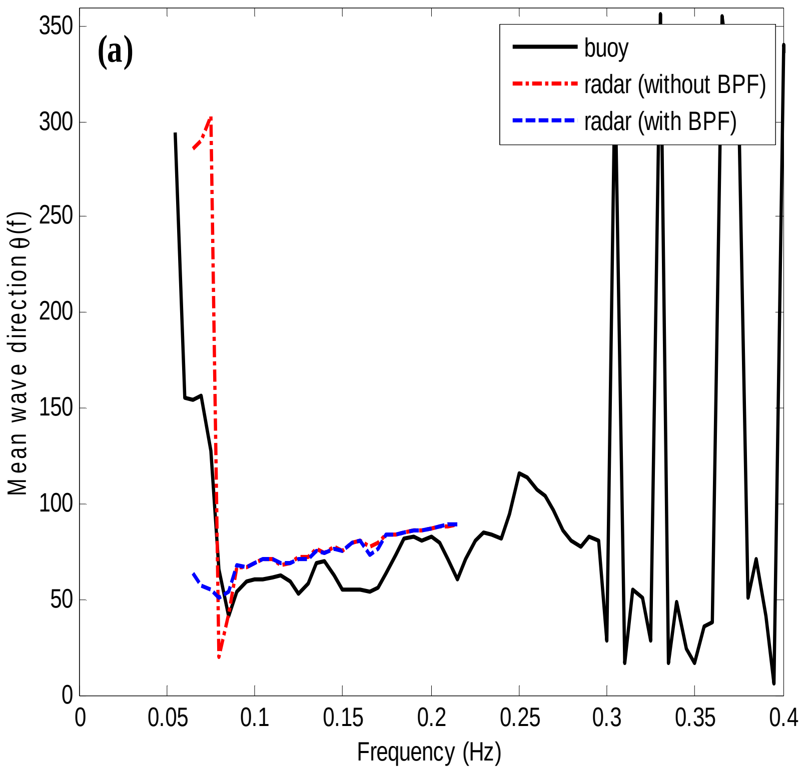
Results from Skerries Bight Data



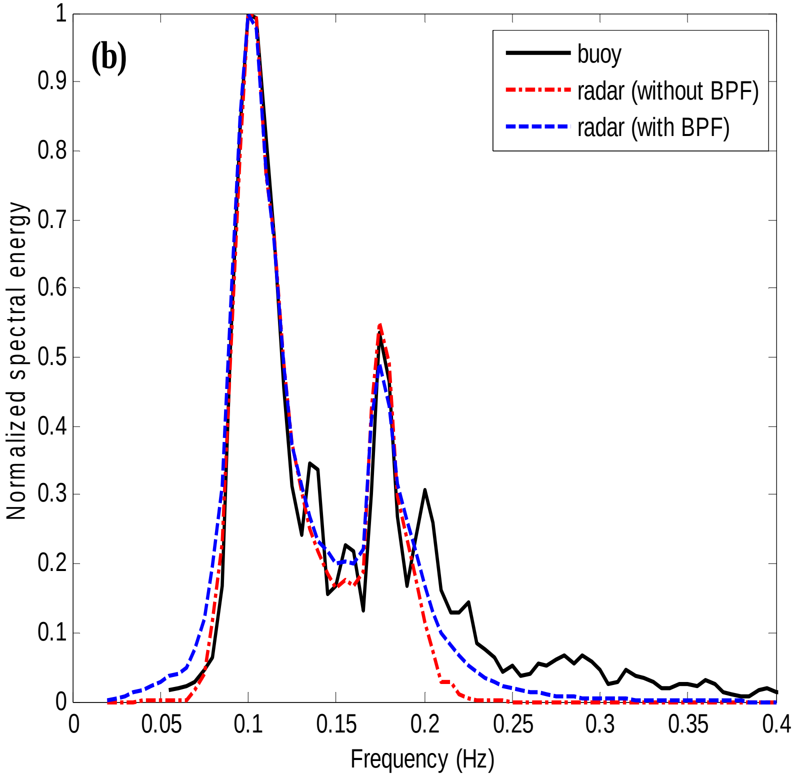


2-D wave spectra from Skerries Bight (Dec 15, 2010):

(a) Buoy; (b) without BPF; (c) with BPF.



(a)



(b)

Comparison of buoy and radar results: (a) mean wave direction spectra; (b) 1-D wave spectra.

Summary

• Wave information extracted from navigation radar images.

1. **W. Huang**, E. Gill, J. An, “Iterative Least-squares-based Wave Measurement Using X-band Nautical Radar”, *IET Radar Sonar Navig.*, 2014. (in press)

2. **W. Huang**, E. Gill, “An Alternative Algorithm for Wave Information Extraction from X-band Nautical Radar Images”, *IET International Radar Conference,* Xi'an, Shanxi, China, pp. 900--904, 2013.

3. J. An, **W. Huang**, E. W. Gill, “Enhanced Algorithm for Wave Information Extraction from X-band Nautical Radar Images”, *Oceans’ 12 MTS/IEEE*, Hampton Roads, USA, 2012.

4. Conclusion and Future Work

Summary

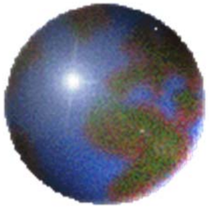
- Current and wave information extracted from navigation radar images.
- Iterative LS-based algorithm provides close performance as classic method.
- Further research work to improve Senet’s current method for ship-borne radar data.
- Further research work for wave retrieval using wavelet method (ongoing).

Acknowledgement

1. ***Rutter Inc.*** ***for providing radar and buoy filed data.***

2. ***RDC*** ***Ignite grant support.***

3. ***NSERC*** ***Discovery grant support.***



Thank you!
Any questions?

Highlights of Memorial University

- Largest university in North Atlantic area of Canada

1.4 campuses (Canada and UK)

2.> 100 majors

3.17,000 students

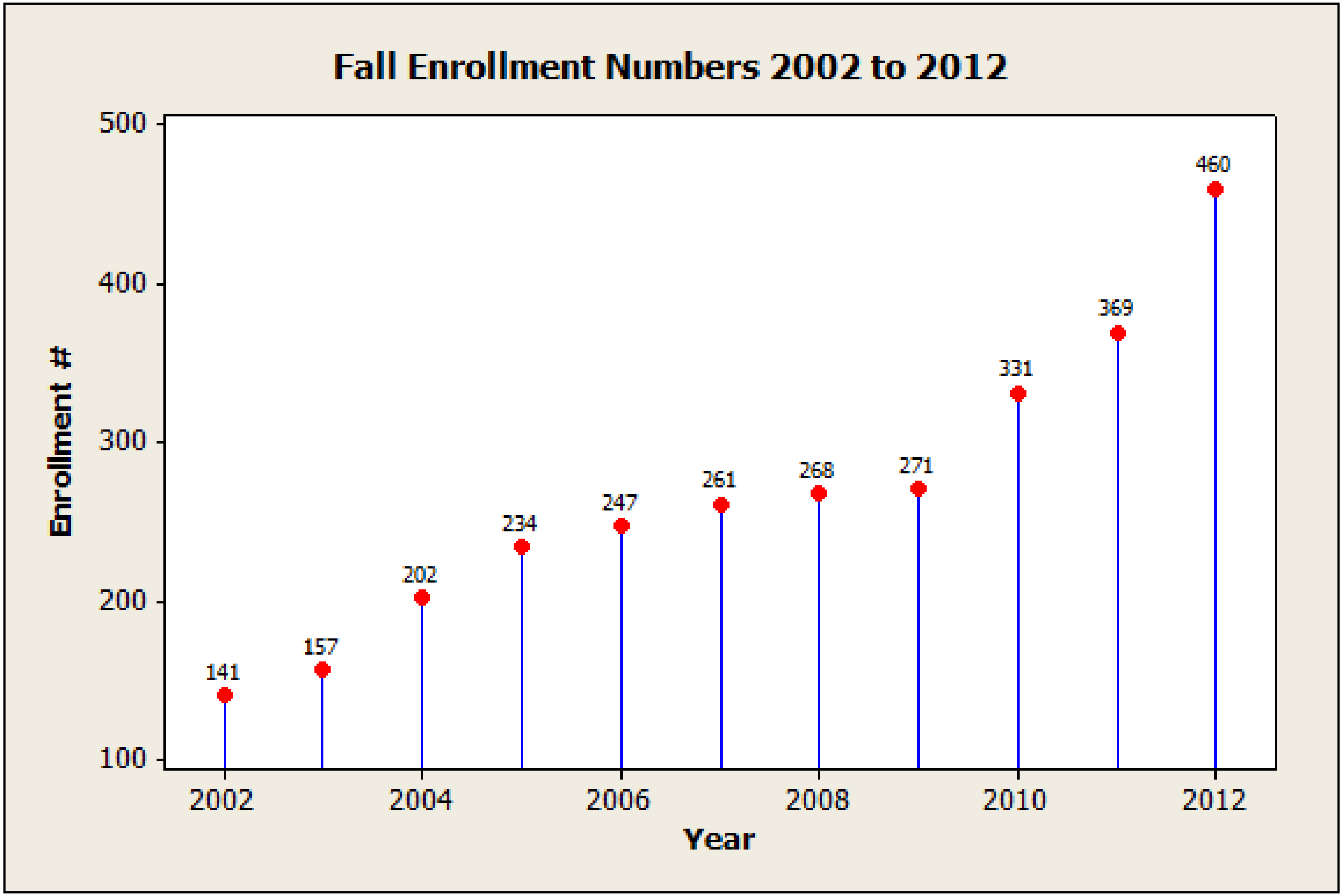
- Lowest tuition in Canada

•Located in the city of St. John's , Newfoundland, Canada

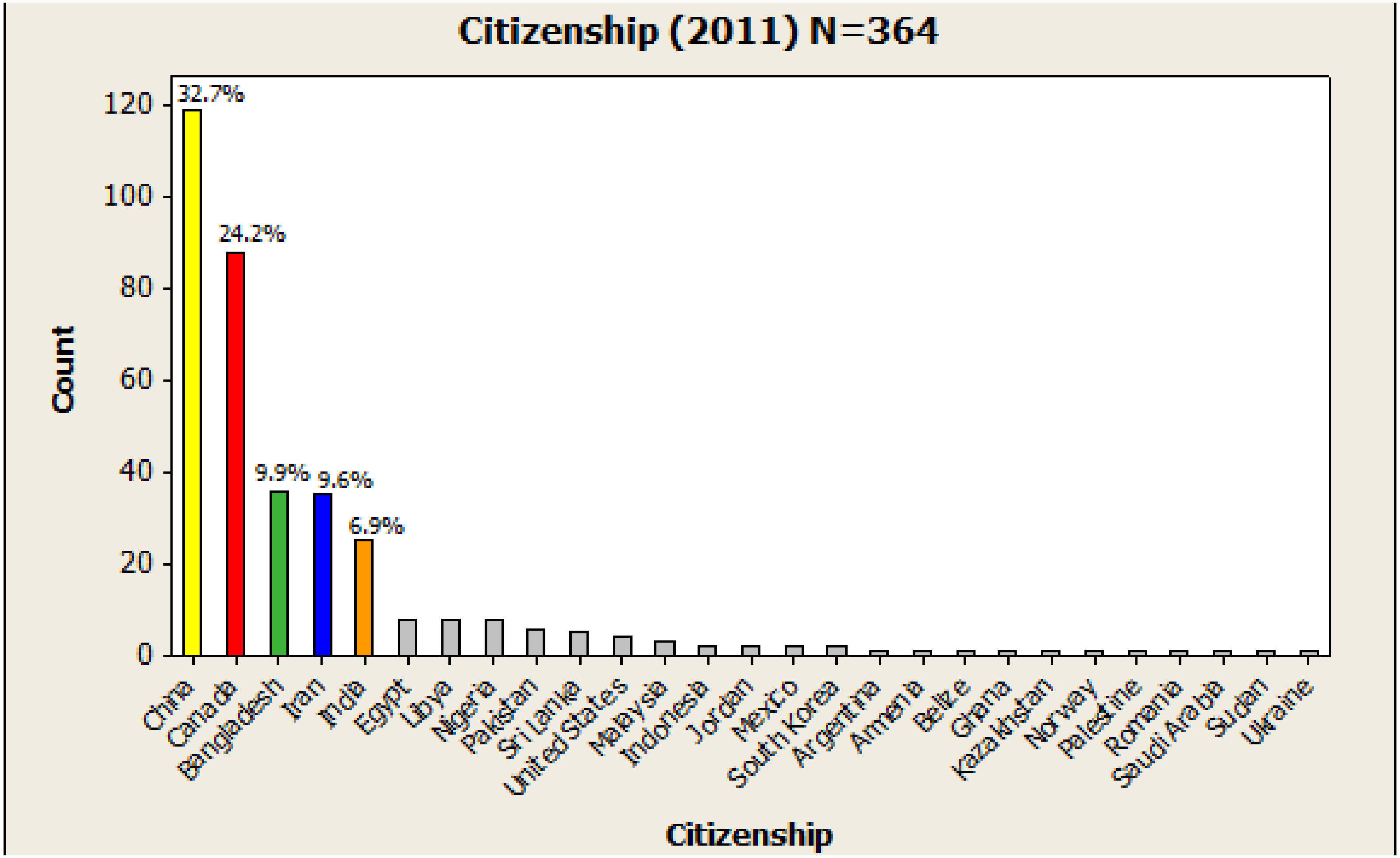
1.safest city in Canada (most East point in North America)

2.beautiful oceanic environment: iceberg, whale, lobster…

Engineering Graduate Students Enrollment Trends



Citizenship of Engineering Graduate Students



Welcome to Memorial University

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