On the Wave Field Analysis by Using SAR Images

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Foreword

Coastal zones are effected by both artificial and natural factors.

In Taiwan, 769 boats were damaged and 228 people were killed in coastal hazards from 1995 to 1998.

It’s necessary for obtaining wave data to understand its character.
Obtaining Ocean Wave Information

Wave information

- Theory
  - Numerical
  - Physical
- Model
  - In-situ methods
- Observation
  - Remote sensing
The Other Common Applications of Satellite Images

- Pollution Monitoring
- Sea-ice Monitoring
- Ship Detection
- Internal Wave Detection
SAR (Synthetic aperture radar) is one of the sensors of satellite ERS-1 and ERS-2, it can

- Provide Spatial information of wave
- Spans large area (100 km x 100 km)
- All weather working during day and night

The objectives of this study to understand the capability of the SAR images in wave field analysis.
SAR Image Processing

2D FFT

Wave Number Spectrum, $S(kx,ky)$

Comparison

Dispersion Relationship

Directional Wave Spectrum, $S(f,\theta)$
The Locations of the SAR Images

05-Feb.-1998 Case[C] [D]

29-Nov.-1999 Case[F] [G]
07-Feb.-2000 Case[I] [J]

26-Nov.-1993 Case[A]
02-Feb.-1998 Case[B]
09-Nov.-1998 Case[E]
29-Nov.-1999 Case[H]
07-Feb.-2000 Case[K]
The example of SAR Spectral Processing

Wavenumber spectrum $S(k_x, k_y)$

Directional spectrum $S(f, \theta)$

The spectrum energy is complex, the primary component waves can’t be derived.
Effect of the Distribution of Image Gray Values

- Sub images that cannot be analyzed have a broader distribution of gray value.
- The coefficient of variation of subscenes that cannot be analyzed is approximately 0.184
Effect of Relationship Between Satellite Travel and Wave Propagation Direction

- The closer wave propagation and satellite travel, the greater difference between in-situ measurements and SAR derived wavelength.
Selection of Subscene Size

This box-plot shows that the average discrepancy of the wavelength derived from a 128 x 128 pixel subscene and the measured is smaller than other sizes subscene.
Sample Average on Nearshore Subscenes

<table>
<thead>
<tr>
<th>SAR subscene in the Northeastern Taiwan Waters [Case G]</th>
<th>Single 128×128 pixel SAR subscenes</th>
<th>Sample averaging of 16 subscenes</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave direction</td>
<td>2°</td>
<td>11°</td>
<td>mild seabed</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1.6m / 1.2%</td>
<td>22.9m / 17.1%</td>
<td></td>
</tr>
<tr>
<td>SAR subscene in the Eastern Taiwan Waters [Case K]</td>
<td>Wavelength</td>
<td>48.8 / 42.1%</td>
<td>steep seabed</td>
</tr>
<tr>
<td>Wave direction</td>
<td>2°</td>
<td>18°</td>
<td></td>
</tr>
<tr>
<td>Wavelength</td>
<td>34.7m / 27.2%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Discrepancy with the measured values is actually greater after the sample averaging of wavenumber spectra from nearshore satellite images.
- Sample averaging of wavenumber spectra is not suitable for analyzing the wave field of nearshore images.
Effect of Non-homogeneous Nearshore Wave Field

- Wave length vs. Water depth
- Distance from land to sea vs. Water depth
- Hualien waters topography vs. Suao waters topography
- Region of Suao SAR sub-image vs. Region of Hualien SAR sub-image
Comparison of SAR and Data Buoy Wave Fields

<table>
<thead>
<tr>
<th>Case</th>
<th>SAR image analysis</th>
<th>Field measurements</th>
<th>Discrepancy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wave length (m)</td>
<td>Wave length (m)</td>
<td>of wave length (m / %)</td>
</tr>
<tr>
<td></td>
<td>Wave direction (°)</td>
<td>Wave direction (°)</td>
<td>of wave direction (°)</td>
</tr>
<tr>
<td></td>
<td>Wave period (sec)</td>
<td>Wave period (sec)</td>
<td>of wave period (sec)</td>
</tr>
<tr>
<td>A</td>
<td>137.2</td>
<td>132.0</td>
<td>5.2 / 3.9</td>
</tr>
<tr>
<td>B</td>
<td>–</td>
<td>96.5</td>
<td>–</td>
</tr>
<tr>
<td>C</td>
<td>–</td>
<td>87.0</td>
<td>–</td>
</tr>
<tr>
<td>D</td>
<td>–</td>
<td>104.6</td>
<td>–</td>
</tr>
<tr>
<td>E</td>
<td>–</td>
<td>200.8</td>
<td>–</td>
</tr>
<tr>
<td>F</td>
<td>144.8</td>
<td>129.3</td>
<td>15.5 / 12.0</td>
</tr>
<tr>
<td>G</td>
<td>132.4</td>
<td>134.0</td>
<td>1.6 / 1.2</td>
</tr>
<tr>
<td>H</td>
<td>169.6</td>
<td>147.7</td>
<td>21.9 / 14.8</td>
</tr>
<tr>
<td>I</td>
<td>162.5</td>
<td>115.1</td>
<td>47.4 / 41.2</td>
</tr>
<tr>
<td>J</td>
<td>132.0</td>
<td>118.0</td>
<td>14.0 / 11.9</td>
</tr>
<tr>
<td>K</td>
<td>162.4</td>
<td>127.7</td>
<td>34.7 / 27.2</td>
</tr>
</tbody>
</table>

- Not all nearshore images can be used to perform wave field analysis.
- The average wavelength discrepancy of the seven analyzed subscenes is about 16%, while the averaging wave direction discrepancy is about 12°.
Conclusions

- Not every SAR image can be used to analyze the directional wave spectra.

- The following notes should be taken into consideration when nearshore SAR images are analyzed:
  - Each $128 \times 128$ pixel subscene is suggested to be used in the nearshore images.
  - Unless the variation of water depth in the subscene is small, the use of sample averaging to reduce FFT random error possibly causing even greater error.
Conclusions

- The results from 11 case studies show that the discrepancy of wavelength and wave direction between nearshore SAR derivation and measured by data buoys was larger than those in deep waters. The differences are average approximately 16% and 12° in wavelength and wave direction analysis, respectively.

- The non-homogeneous wave field within a subscene is a major effect on SAR spectral analysis. The water depth variation must be taken into consideration when attempting to derive the nearshore wave field from satellite images.
Thank you for your attention
SAR Image Processing

**Wavenumber spectrum ⇒ wavelength & wave direction**

The 2D FFT is used to derive the spectra from SAR images. The wavenumber spectrum is the wavenumber square of absolute value of the FFT coefficient

\[
F(k_x, k_y) = \frac{1}{N} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cdot \exp\left[-i2\pi\left(k_x x + k_y y\right)/N\right]
\]

\[
S(k_x, k_y) = |F(k_x, k_y)|^2
\]

**Directional spectrum ⇒ wave frequency (wave period)**

The wavenumber domain should be equal to obtain the relationship of wavenumber spectrum and directional spectrum

\[
\bar{\eta}^2 = \iint S(f, \theta) df d\theta = \iint S(k, \theta) dk d\theta
\]

\[
dk = \frac{4\pi \sqrt{gk \tanh(kh)}}{gkt \tanh(kh) + kgh \text{sech}^2(kh)}
\]

\[
df = \frac{df}{dk} = \frac{gk \tanh(kh) + kgh \text{sech}^2(kh)}{4\pi \sqrt{gk \tanh(kh)}}
\]

\[
S(f, \theta) = S(k, \theta) \frac{dk}{df}
\]
The coefficient of variation of subscenes that cannot be analyzed is approximately 0.184, while the coefficient of kurtosis is 5.4.
Conclusions

- Not every SAR images can be used to analyze the directional wave spectra.
  - The higher average value of an image’s gray value the harder it is to distinguish the wave direction and wavelength from image analysis.
  - The closer flight direction of satellite to the wave prorogation direction, the greater error between SAR and in-situ measurement.
  - The ERS SAR images in the eastern Taiwan are more likely to determine of primary waves than the images in the western Taiwan.