Sea Ice Thickness Observation Using Ship-Borne EM and Passive Microwave Radiometer

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Contents

- Purpose and background

- Sea ice thickness algorithm
  1) Version 1: Video – AMR
  2) Version 2: EM – SSM/I
  3) Version 3: EM – MMRS
Purpose
Estimation of sea-ice thickness using satellite-borne passive microwave radiometer (PMW)
Collecting in-situ sea-ice thickness ➔ Algorithm
History of sea-ice thickness measurements
Sea-ice thickness algorithm for AMR, SSM/I

- Version.1 Algorithm -
アプローチ
- 砕氷船・衛星によって取得された氷厚の実証データを用いて既存の海氷分類パラメータの氷厚識別性能を検討し、その改良版として新規開発パラメータを追加して氷厚推定式を求める。
DATA

マイクロ波放射計：
1) AMR：Airborne microwave radiometer (Feb. 1997)
2) SSM/I：Satellite borne microwave radiometer (1987-1999)

<table>
<thead>
<tr>
<th></th>
<th>チャンネル (GHz)</th>
<th>偏波</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMR</td>
<td>6.9 10.65</td>
<td>垂直, 水平</td>
</tr>
<tr>
<td></td>
<td>18.7 23.8 36.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>89.0</td>
<td></td>
</tr>
<tr>
<td>SSM/I</td>
<td>19.35 22.235</td>
<td>垂直, 水平</td>
</tr>
<tr>
<td></td>
<td>37.0 85.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.5km</td>
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</tbody>
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氷厚実証データ：
1) 船舶観測：砕氷船「そうや」 (1996-1998)
   北海道大学低温科学研究所、運輸省船舶技術研究所
2) 衛星画像：ADEOS AVNIR (Jan.-Mar. 1997)
   11 scenes
Thick ice

Thin ice

Nilas
Sea-ice thickness estimation algorithm ver.1

(Tateyama et al., 2002)

密接度: 80%以上（NASA薄氷アルゴリズムで計算）
Validation of sea-ice thickness algorithm for SSM/I
- Version.2 Algorithm -
Ship observation (1)
Downward-looking video

Not suitable for deformed thick ice
Ship observation (2)
Electromagnetic induction device (EM)
Ship observation (2)
Electromagnetic induction device (EM)

$$\sigma a \rightarrow Z_E, Z_S + Z_I = Z_E - Z_L$$
Accuracy of EM measurements

1. On the ice
- Kovacs et al. (1991)
  "within 10% for undeformed ice from 0.7 to 5m thickness"
- Worby (1999):
  Undeformed FY ice between 0.6 – 0.8m thick
  "within 10% of drill-hole data"
  Deformed Ice
  "within 30-40% of drill-hole data"

2. From Ship
Haas (1999) "not better than ±0.2m"
Previous EM method using the simple 3-layer model

\[ Z_E = 10.30 - \ln(\sigma_a - 18.00) / 0.6500 \]

1\textsuperscript{st}: fresh snow 0mS/m

2\textsuperscript{nd}: sea ice 52mS/m

3\textsuperscript{rd}: seawater 2482mS/m
New multi-layer model  Tateyama et al. [2006]

\[ Z_E = 11.22 - \ln(\sigma_a - 14.47) / 0.6049 + dZ_E \]

**Ship hull offset**

\[ dZ_E = c_1 \cdot Z_L + c_2 \]

*Healy and Xuelong:*

\[ c_1 = 0.275, \quad c_2 = -0.184 \]

*Soya:*

\[ c_1 = 0.141, \quad c_2 = 0.936 \]
Within 7% error for all season and location
EM Total ice thickness accuracy (snow + ice)

< 4m: <7% error
> 4m: 30-40% error
Past EM observations

- Sea of Okhotsk
  - JCG P/V Soya
    - 2004-2009

- Arctic
  - USCG R/V Healy
    - 2004-2005
  - JSDF AGB Shirase
    - 2000-2009

- Antarctic
  - P&O Aurora Australis
    - Antarctic Sea
      - 2003, 2007
  - PRIC XueLong
    - Arctic Sea
      - 2003, 2008

5 ice breakers
21 observations
SSM/I TB vs. EM thickness from all Soya cruises

For 19V and 19H:
\[ y = 14.98x + 225.03 \]
\[ R^2 = 0.2514 \]

For 37V and 37H:
\[ y = 11.017x + 235.66 \]
\[ R^2 = 0.4329 \]

For 85V and 85H:
\[ y = 1.5732x + 244.76 \]
\[ R^2 = 0.0572 \]

For 85V and 85H (alternate dataset):
\[ y = 13.337x + 219.48 \]
\[ R^2 = 0.2087 \]

EM thickness [m]
SSM/I Brightness temp. [K]
Sea-ice thickness estimation algorithm ver.2 (Wako et al., 2007)

PR: Polarization Ratio >> PR37 is the highest
BR: Brightness temperature Ratio >> BR37H85H is the highest

\[ H = -5.3733 \cdot PR19 + 0.8388 \cdot BR - 0.0691 \]
Black cross: ver.1 algorithm (from visible sea-ice thickness observation)
Blue square: ver.2 algorithm (from SEM)
Validation of sea-ice thickness algorithm for SSM/I and AMSR-E

- Version.3 Algorithm -
# Microwave Miliwave Radiometer System (MMRS)

<table>
<thead>
<tr>
<th></th>
<th>Ship-borne</th>
<th>Ground-based, Heliborne</th>
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<tbody>
<tr>
<td>MMRS1-1</td>
<td>36V, 36H, CCD-cam, Radiation thermometer</td>
<td>MMRS2</td>
</tr>
<tr>
<td>MMRS1-2</td>
<td>18V, 23V, 36V</td>
<td>36GHz , CCD-cam</td>
</tr>
</tbody>
</table>
MMRS2A
6GHz-VH
18GHz-V
36GHz-VH
Summary of sea-ice obs. using PMW

YEAR 2006 2007 2008 2009 2010
AREA
OKHOTSK 36V 18V 23V 36V 36VH
ARCTIC 6VH 18V 36VH
ANTARCTIC 36VH 18V 23V 36V 36VH

36GHz V-pol and H-pol
18GHz V-pol
23GHz V-pol
36GHz V-pol
6GHz V-pol and H-pol
18GHz V-pol
36GHz V-pol and H-pol

pol: polarization
Data analysis

EM: Sea-ice thickness
Ice concentration
+ GPS

PMR: Brightness temp.
Surface temp.

Sea-ice thickness
Ice conc. = 100%
Ship speed >= 3knots

Parameterization
Polarization Ratio

Sea-ice thickness Algorithm
Observation area 1: Antarctic Sea off Syowa Station

December 2006

February 2007
Observation area 2: Sea of Okhotsk off Hokkaido

February 2008
Results
RESULTS: DEC 2006

(b) Ice concentration (%)

EM thickness [m]

Loose  Pack  Land fast

Ice concentration [%]

(c) Brightness/Surface temperature [K]

Latitude [°]

66.8  67.2  67.6  68.0  68.4  68.8  69.2

TB 36GHz-V
TB 36GHz-H
Radiation thermometer
Brightness Temperatures vs. EM thickness

- <1.2m: High correlation between 36GHz-H and EM thickness
- >1.2m: Lower correlation than <1.2m
Ice thickness estimation from PR36

Polarization Ratio (PR36)

$$PR36 = \frac{(36V - 36H)}{(36 + 36H)}$$

$$H [m] = 2.44 \times \exp(-1 \times (PR36 - 0.0076)/0.0464)$$
Comparison thicknesses Between EM and PR36

Histogram

Overestimate

Underestimate

Average

EM      0.99m
PR36  1.04m

R = 0.83
RMS error = 0.35m
Ice thickness algorithm

Version.1

Version.3
Sea-ice thickness fluctuation in Okhotsk Sea [1987-2009]

Red color: Thick ice (maybe thick snow)
Tentative Arctic sea-ice thickness