Mooring measurements within polynya or its outflow region:
Sakhalin Polynya in the Sea of Okhotsk
and Cape Darnley Polynya in the Antarctic

Yasushi Fukamachi
Institute of Low Temperature Science, Hokkaido University

Jyozankei Workshop  July 6, 2009
Backgrounds -- Sea-ice thickness --

- Ice thickness governs atmosphere-ocean heat and momentum fluxes
  ice-ocean heat and salt fluxes

- Ice-thickness data (↔ Ice areal data)
  Limited due to difficulties of remote sensing and in situ measurement

- In situ observation methods
  - Drilling
  - Visual observation
  - Video monitoring
  - Submarine sonar profiling
    - Moored upward sonars ⇒ Seasonal variability
  - Laser profilometry
  - Electromagnetic techniques
Measurement Principle of Ice Profiling Sonar

**Measurement:**
- Echo time to ice bottom or ocean surface ⇒ Range
- Pressure, tilt, temperature

**Data Processing:**
1. Remove atmospheric pressure \( P_{btm} - P_{atm} \)
2. Convert pressure to water depth
3. Derive average sound speed using echo time from open-water surface
4. Determine vertical distance to sea-ice bottom \( r \cos \theta \)
5. Derive ice draft \( d = (\text{water depth}) - r \cos \theta \)

Courtesy of ASL Environmental Sciences Inc.
Moorings and Data

- Ice Profiling Sonar (IPS)
  - Range to ice bottom or ocean surface (1 sec.)
  - Pressure, tilt, temperature (30 sec.)
- Acoustic Doppler Current Profiler (ADCP)
  - Ice velocity (20 min.)
  - Bottom tracking
  - Water-velocity profile (20 min.)

IPS draft time series +
ADCP ice-velocity time series ↓

Pseudo spatial draft series (bottom profile)

Birch et al. (2000)
Sakhalin Polynya in the Sea of Okhotsk

(Fukamachi et al., CSR 2009)
Backgrounds -- Sea of Okhotsk --

Feb. 15, 1997

Green: New ice thickness < 0.1 m
Yellow: Young ice 0.1-0.3 m
Red: First-year ice > 0.3 m

- Southernmost seasonal sea-ice zone in northern hemisphere
- High sea-ice production in coastal polynyas
  \[ \Rightarrow \text{Production of Dense Shelf Water (Cold-water source to N. Pacific)} \]
Present Observation

- **Moorings**
  - **Mooring site**
    - Off northern Sakhalin
    - Within Sakhalin polynya
    - ~15 km offshore (33 m deep)
  - **Mooring period**
    - 2002/12/27-2003/6/12
  - **Moored instruments (for both ice and ocean)**
    - Ice profiling sonar
    - ADCP + C-T recorder

- **Automatic weather station**
  - At Chaivo Research Station
    - (~47 km away from mooring site)
  - **Pressure data**
    - ⇒ IPS data processing
  - **Wind data**
    - ⇒ ADCP data processing
Spatial Draft Data Example  -- Thin ice --

Jan. 12, 2003

Courtesy of H. Enomoto and K. Tateyama at Kitami Institute of Technology

Offshore wind ⇒ Offshore ice velocity ⇒ Thin ice

Jan. 11 21:10:01-Jan. 13 1:18:13 (25 km)

Mean: 0.11 m, Std. dev.: 0.11 m, Max.: 2.15 m

Conc.: 97%

Draft values exaggerated ~70 times

0 m

5 m

5 km
Spatial Draft Data Example  -- Thick ice --

Mar. 18, 2003

Onshore wind ⇒ Onshore ice velocity ⇒ Thick ice
Mar. 17 23:54:10-Mar. 19 0:47:49 (25 km)
Mean: 2.63 m, Std. dev.: 2.81 m, Max.: 18.24 m
Conc.: 87%

Draft values exaggerated ~20 times

0 m
20 m

5 km
1. Salinity increase during thin-ice periods till March
2. Temperature very close to freezing point ($T_f$)

Brine rejection in polynya
Heat Loss and Ice Production

Daily-averaged heat loss: Calculated assuming open water
Daily Ice Production: Calculated using observed ice thickness

Difference: Insulting effects of ice during thick-ice periods
Salinity Calculation Within Polynya

Observed salinity is governed by
1. Alongshore advection
2. Onshore-Offshore advection with upwelling or downwelling
3. Brine rejection at surface

Calculate Salinity assuming
1. Homogeneous water column
2. Constant distance between northern polynya edge and mooring of 140 km
3. Constant initial salinity at northern edge of 32.7
4. Uniform ice thickness within polynya
5. Uniform water velocity within polynya

Observed salinity
≈ Initial salinity + brine rejection within polynya

(Jan 12, 2003)
Northern edge is often located around the base of Shmidt Peninsula
Comparison between Observed and Calculated Salinities

- Calculated salinity agrees well with observed one with $r = 0.71$
- Large salinity increase under thin-ice, large heat loss, and slow southward velocity conditions
Validation of thin-ice thickness based on satellite data

Nihashi et al. (revised)

IPS ice thickness

AVHRR thin-ice thickness

AVHRR thin-ice thickness + AMSR-E data

Thin-ice thickness

IPS ice thickness ↓

AVHRR thin-ice thickness

AMSR-E thin-ice thickness

Thin-ice thickness
Cape Darnley Polynya in the Antarctic

(Preliminary Results)
Region of Observation off Cape Darnley

Mooring sites
M1, M2, and M3: Outflow region (within canyon) from Cape Darnley Polynya

M4: North of Cape Darnley Polynya

Mooring depths:
M1: 2975 m
M2: 1478 m
M3: 2659 m
M4: 1868 m
Mooring Configurations

Benthic layer of 226-306 m
- 3-4 C-T recorders
- 1-2 current meter and/or ADCP

Bottom-water properties and velocity

M2

- 258 m
- C-T Recorder
- Current Meter
- Thermistor
- 150m Cable
- Downward-looking ADCP
- 80m Cable
- Acoustic Release
- Bottom depth: 1478m

M3

- 226 m
- C-T Recorder
- Current Meter
- 200m Rope
- Bottom depth: 2659m

3-4 C-T recorders
1-2 current meter and/or ADCP

⇓⇓ ⇓⇓

Current Meter
C-T Recorder

Velocity and Theta/Salinity: M2 (1478 m)

≈≈ ≈≈
≈≈ ≈≈

≈ 255 m from bottom

≈ 30 m from bottom

● T/S decrease (Velocity increase) after mid-April
Velocity and Theta/Salinity: M1 (2975 m)

- ≈ 255 m from bottom
- ≈ 90 m from bottom
- ≈ 25 m from bottom

● T/S decrease (Velocity increase) after mid-May
  ≈ 1-month delay from M2 ⇒ 2.6 cm/s between M2 & M1
Velocity and Theta/Salinity: M3 (2659 m)

- Strong NNWard (along canyon) flow near the bottom
- 4 to 5-day variability in T/S and velocity
  Low T/S $\Rightarrow$ Large velocity, No phase lag in vertical
Velocity and Theta/Salinity: M4 (1868 m)

- 305 m from bottom
- 105 m from bottom
- 25 m from bottom

T/S decrease after mid-July at the lower two C-T recorders
⇒ Absent from the uppermost CT-recorder
Near-bottom density ($\sigma_2$): M3 & M4

- M3: ≈ 25 m from bottom
- M4: ≈ 25 m from bottom

- Low T/S $\Rightarrow$ High potential density
Neutral density > 28.27
⇒ AABW

Heaviest water mass at M4
Theta-salinity diagram: Vertical variation

Large density variability at M2

Strong stratification at M4
Theta-salinity diagram @M1&2: Temporal variability

Active sea-ice formation in Cape Darnley Polynya from mid-March to October
Sea-ice production estimate in Cape Darnley Polynya during the mooring period

Active sea-ice formation from mid-March to October

Courtesy of T. Tamura
Theta-salinity diagram @M3&4: Temporal variability

Onset of Low T/S

Heavy benthic layer

Active sea-ice formation in Cape Darnley Polynya from mid-March to October
Summary

● Mooring data confirm seasonal AABW production around Cape Darnley Polynya ⇒ Density significantly lighter than in western Ross Sea (Gordon et al., 2009) and slightly lighter than off Mertz Polynya (Williams et al., in preparation)

● Heavy benthic layer thickness
  > 225-250 m in outflow region from Cape Darnley Polynya
  < 300 m north of Cape Darnley Polynya

● Onsets of low T/S event and periods of heavy benthic layer are different among four moorings.

● Heaviest water observed north of Cape Darnley Polynya (M4)
  ↓

● Importance of Mackenzie Polynya and/or Amery Ice Shelf further east as well as Cape Darnley Polynya (Meijers et al., in press; Yabuki et al., 2006)

After Tamura et al. (2008)