Remote effects of ocean thermal condition on seasonal predictability of sea ice area in the Barents and Bering Seas

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1. Warm Arctic-Cold Mid-latitudes patterns

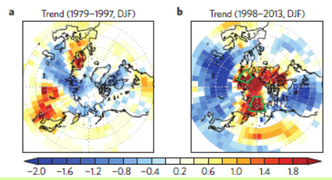


Figure 1. Linear trends in SAT (DJF) in (a) previous and (b) recent decades [Kug et al. 2015].

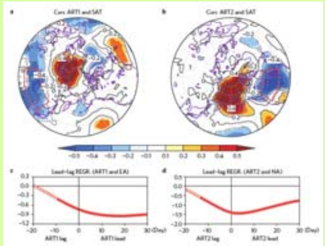


Figure 2. The regression patterns of SAT onto the Arctic-SAT indexes [Kug et al. 2015]

Recently, a number of studies focus on the influence of sea ice change in the Arctic Ocean and its relation to winter climate in the mid-latitude [e.g., Frankignoul et al. 2014].

Along with the recent sea ice decrease, the Eurasia continent and North America have experienced abnormally cold winters in recent years [Inoue et al. 2012; Kug et al. 2015], which is likely to attribute to the atmospheric responses to the reduced sea ice zones in the Barents Sea [Mori et al. 2014] and Bering Sea [Lee et al. 2014].

Therefore, seasonal forecasting of the winter sea ice in these marginal oceans are of great importance in the global context of our country.

We present the appropriate variables for the seasonal forecasting of the sea ice variability in the Barents and Bering Seas in early winter estimated from Canonical Correlation Analysis (CCA). The results are based on Nakanowatari et al. [2014, 2015].

2. Canonical Correlation Analysis

- ✓ CCA is a multivariate statistical technique that measures the linear relationship between predictors (Y(x,t)) and predictand (T(x,t)) [Barnett and Preisendorfer 1987].
- ✓ Predictand
  - —Sea ice concentration (SIC) over the Barents and Bering Seas in early winter (Nov.-Dec.)
- ✓ Predictors
  - —Local ocean temperature at 200 m depth (T200), SST, SAT, and zonal & meridional winds
  - – SLP and geopotential height at 500hPa (Z500) (Northern Hemisphere)
- ✓ SIC and atmosphere-ocean variables were derived from NCEP-CFSR reanalysis data ver. 2 [Saha et al 2014]
  - – 0.5° x 0.5°, 2-monthly mean data (seasonally resolved)
  - – 1980–2014

Observed SIC (Nov.-Dec.)

Detecting High correlation modes between them

2-month mean variables (SAT, SST, etc)

2 year before	....	Aug.-Sep.	Sep.-Oct.	Oct.-Nov.	Nov.-Dec.
Leading months	....	3	2	1	0

SIC is estimated from empirical formula using predictors

Predicted SIC (Nov.-Dec.) | Predicted SIC (Nov.-Dec.) | Predicted SIC (Nov.-Dec.)

3. Forecast skill of SIC evaluated from CCA

Barents Sea / Bering Sea

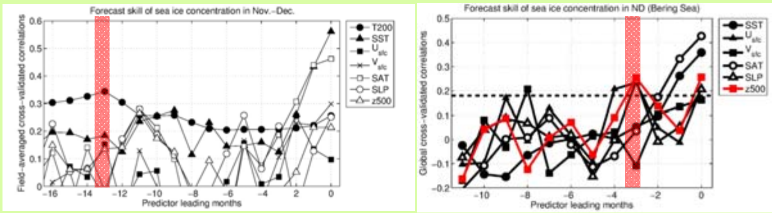


Figure 3. Forecast skill (global cross-validated correlation) of (left) the Barents Sea and (right) Bering Sea in each leading month. The global cross-validated correlation is the field-averaged correlation between the observed and modeled data.

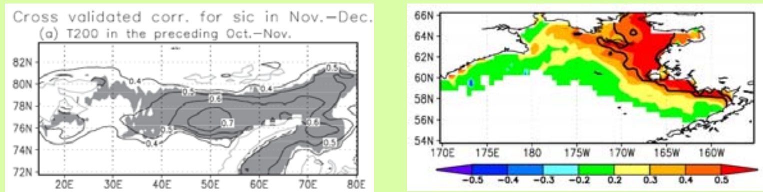
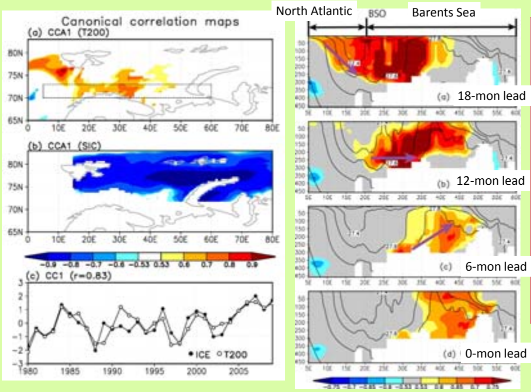


Figure 4. Geographic distribution of CCA skill (cross-validated correlation) for (left) 13-month lead forecasts from T200 and (right) 3-month lead forecasts from z500.

In the Barents Sea, The forecast skill of 13-month leading T200 (ocean temperature at 200 m depth) is the highest (r=0.34), and the forecast skill is relatively high in the eastern region.
In the Bering Sea, the significantly high prediction skill is found at 3 month lead time for Z500 (r=0.25), and the correlation value is higher than 0.5 in the eastern part of the Bering Sea.

4. Source of predictability for T200 (Barents Sea)



- T200 for negative sea ice anomalies exhibit warm anomalies in the sub-surface ocean temperature in the Norwegian Atlantic Slope Current (NwASC).
- Warmer ocean temperature set up in the preceding winter in the BSO is found to be advected along isopycnal surfaces to the Barents Sea within approximately a year
- This result suggests that the preceding winter affects the sea ice area through the reemergence mechanism.

Figure 5. (left) CCA mode 1 for 13-month leading T200 predictor experiment. (right) Lag correlation maps (colors) of 2-monthly mean ocean temperature along the zonal section (70–73N shown in left panel) with T200 canonical correlation time series (CCA1) at lag (a) 18 months to (d) 0 months.

4. Source of predictability for Z500 (Bering Sea)

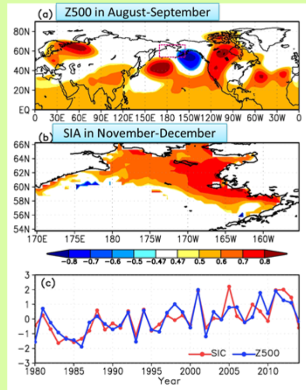


Figure 6. Canonical correlation maps of (a) Z500 in August–September and (b) SIA in November–December (Heavy ice scenario). (c) Canonical correlation time series of the SIA (red) and the Z500 (blue).

- Low pressure anomaly over the Gulf of Alaska and high pressure anomaly over the North America and western subarctic North Pacific is related to heavy SIA anomaly (The anomalies area is opposite in light sea ice case)
- Year-to-year variability is dominant with weak positive trend
- The time series is highly correlated with **Pacific Transition pattern** in September (R=0.73)

PT pattern (positive) In summer (AS) ← Large convection over the western subtropics

Northwesterly wind over the Gulf of Alaska

SST decreases

Low temperature anomaly is advected to the Bering Sea → Bering SIA increase → Warm winter in North America

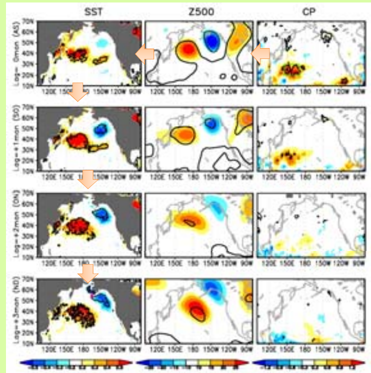


Figure 7. Lead-lag regression maps (colors) of the 2-monthly mean SST (left), Z500 (middle) and convective precipitation (mm/day) onto the Z500 canonical correlation time series (CCA mode 1) at 0-month (top) to 3-month (bottom) lag times.

6. Schematic view for severe winter scenario

Nakanowatari et al. [2014]

Nakanowatari et al. [2015]

- The interannual variability of sea ice areas in the Barents and Bering Seas can be skillfully predicted by using ocean temperature data at the stage of 3 months to 1 year ahead.
- The usage of ocean temperature data can improve the long-term prediction skill of winter climate in the Northern Hemisphere

References

Nakanowatari T, Sato K and Inoue J 2014 Predictability of the Barents Sea ice in early winter: Remote effects of oceanic and atmospheric thermal conditions from the North Atlantic *J. Climate* **27** 8884–8901.
Nakanowatari T, Inoue J, Sato K and Kikuchi T 2015 Summertime atmosphere-ocean preconditionings for the Bering Sea ice retreat and the following severe winters in North America *Environ. Res. Lett.* **10** 094023.