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Advancing knowledge of Earth's frozen regions

Regional Sea Ice Predictability at Seasonal Time Scales and the Problem of Summer

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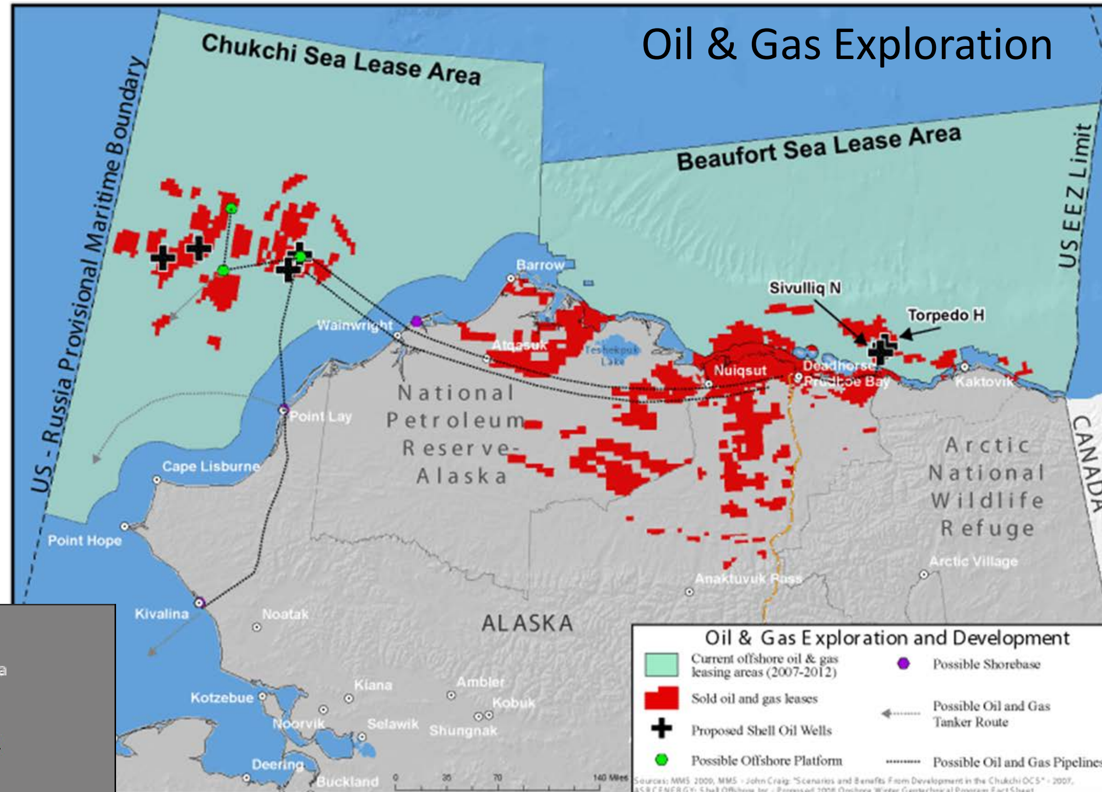
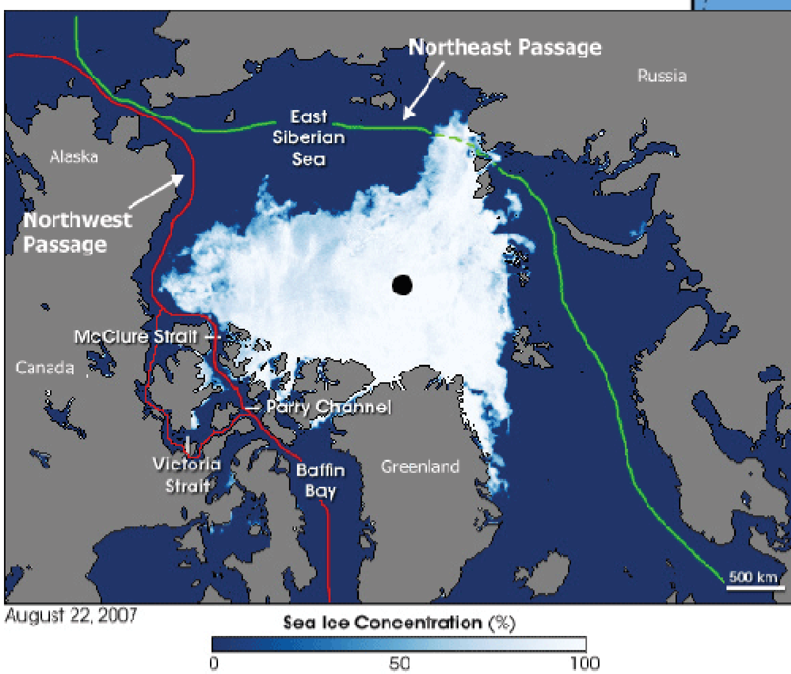
A focus on the Chukchi Sea



Choke point for shipping…



…Bowhead Whale migration route

http://www.thecanadianencyclopedia.ca/en/article/bowhead-whale/

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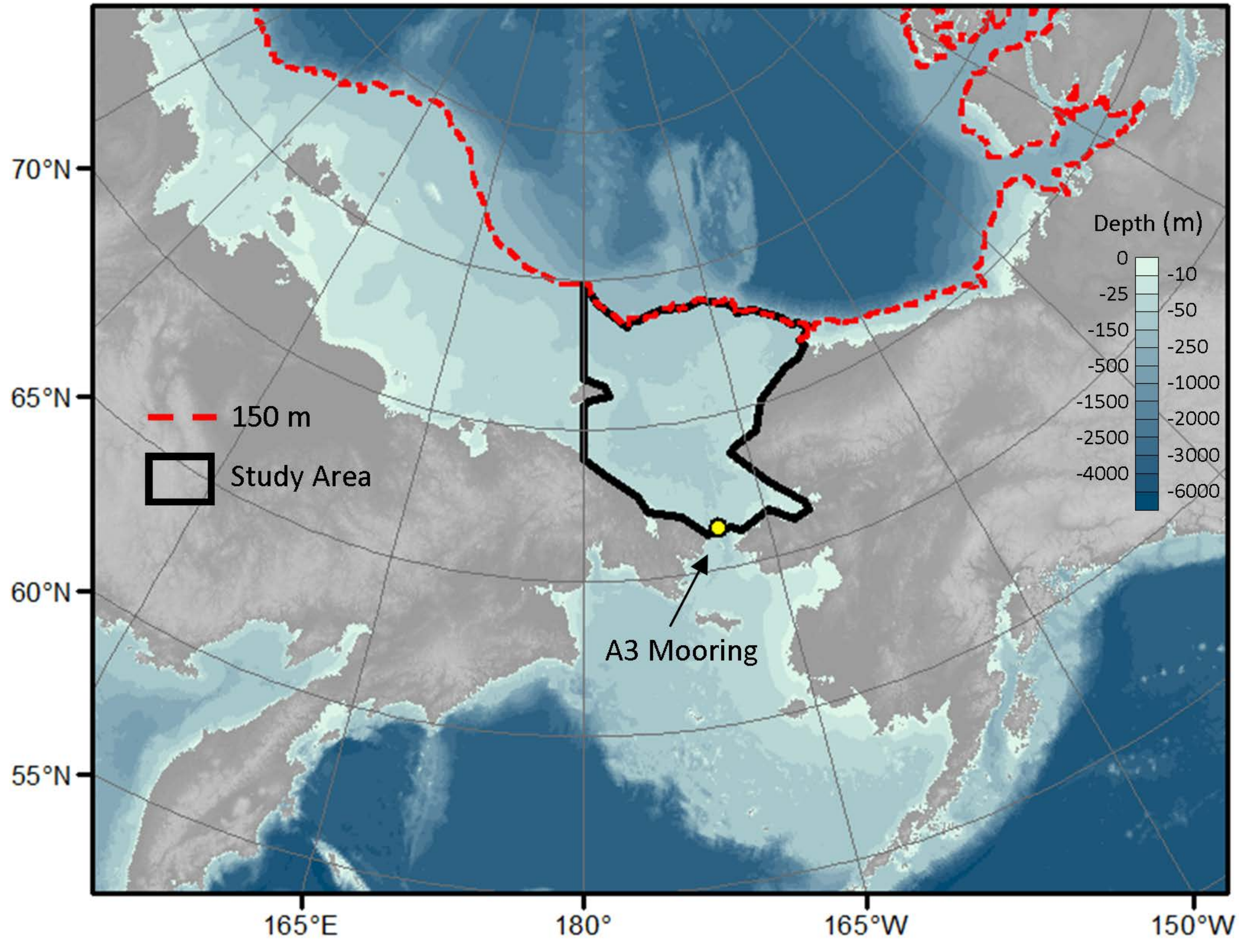
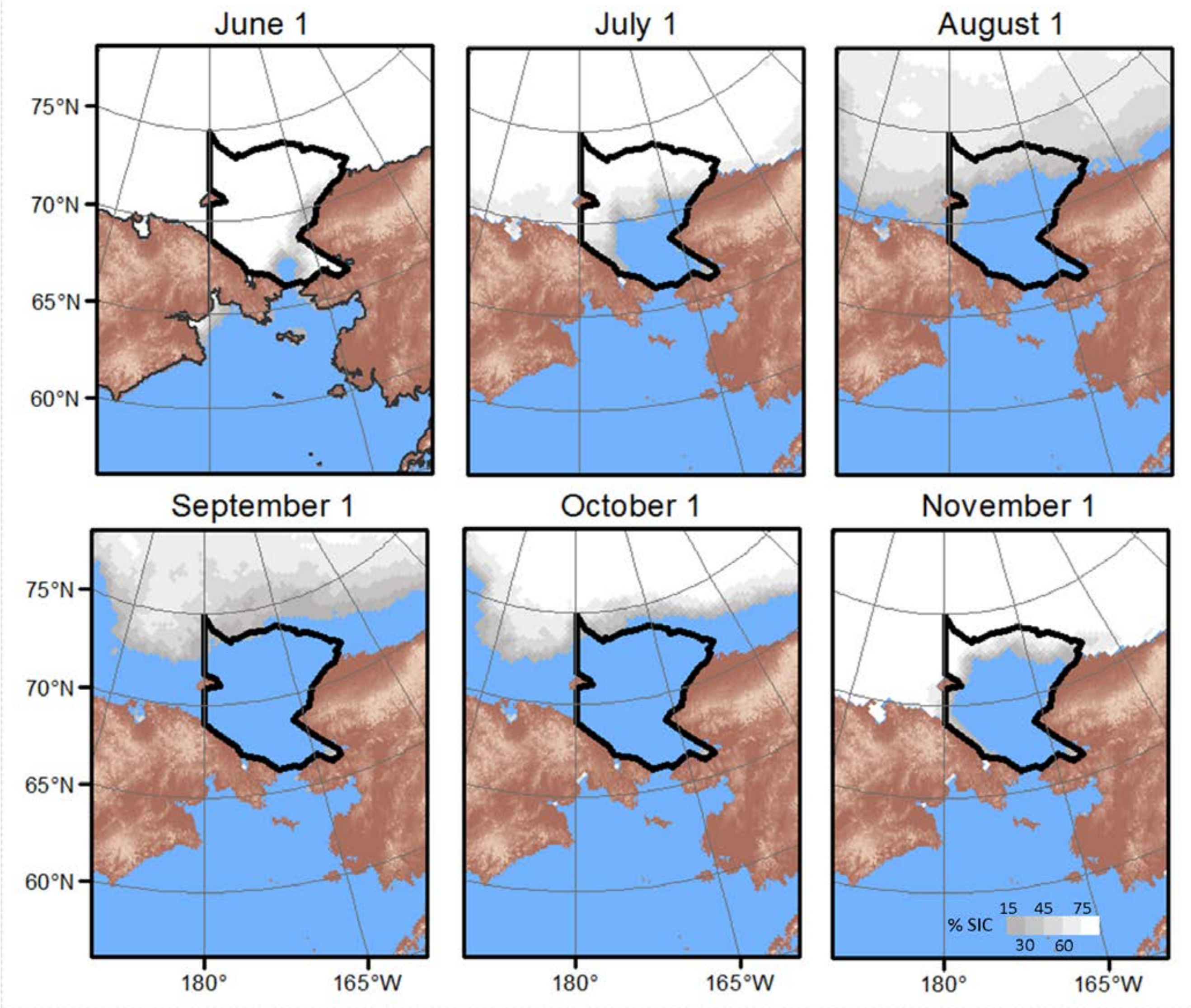
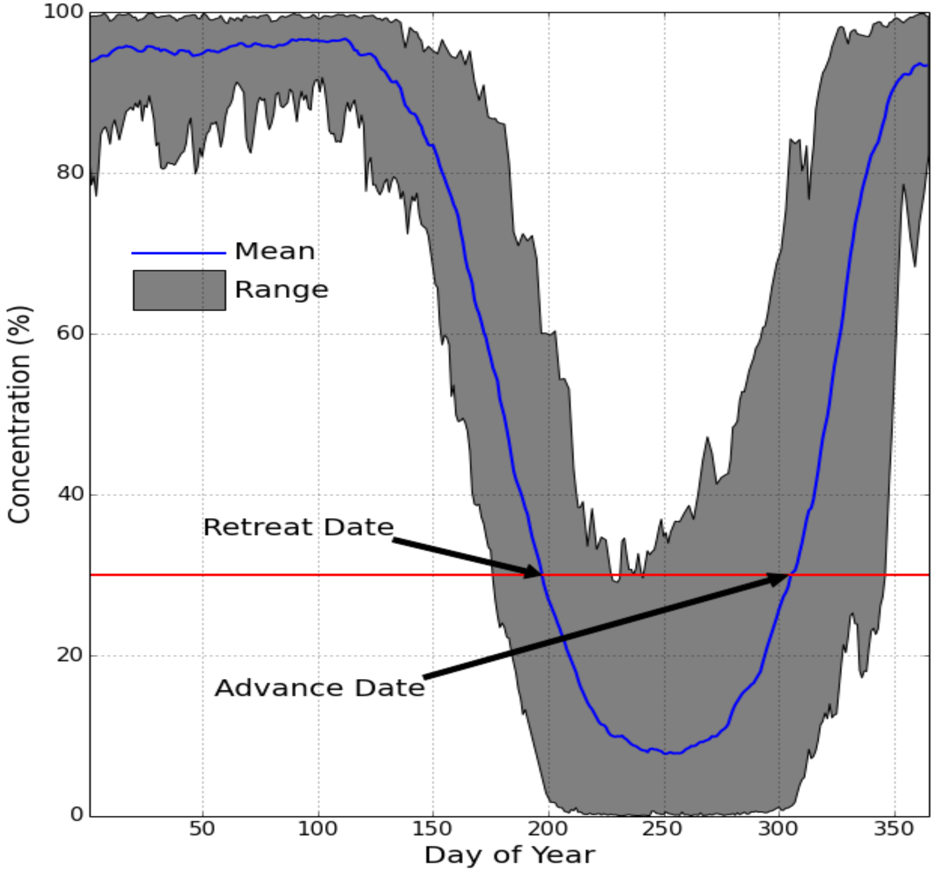
Chukchi Sea study area



Average retreat and advance (1979-2014)



Variability in retreat and advance dates

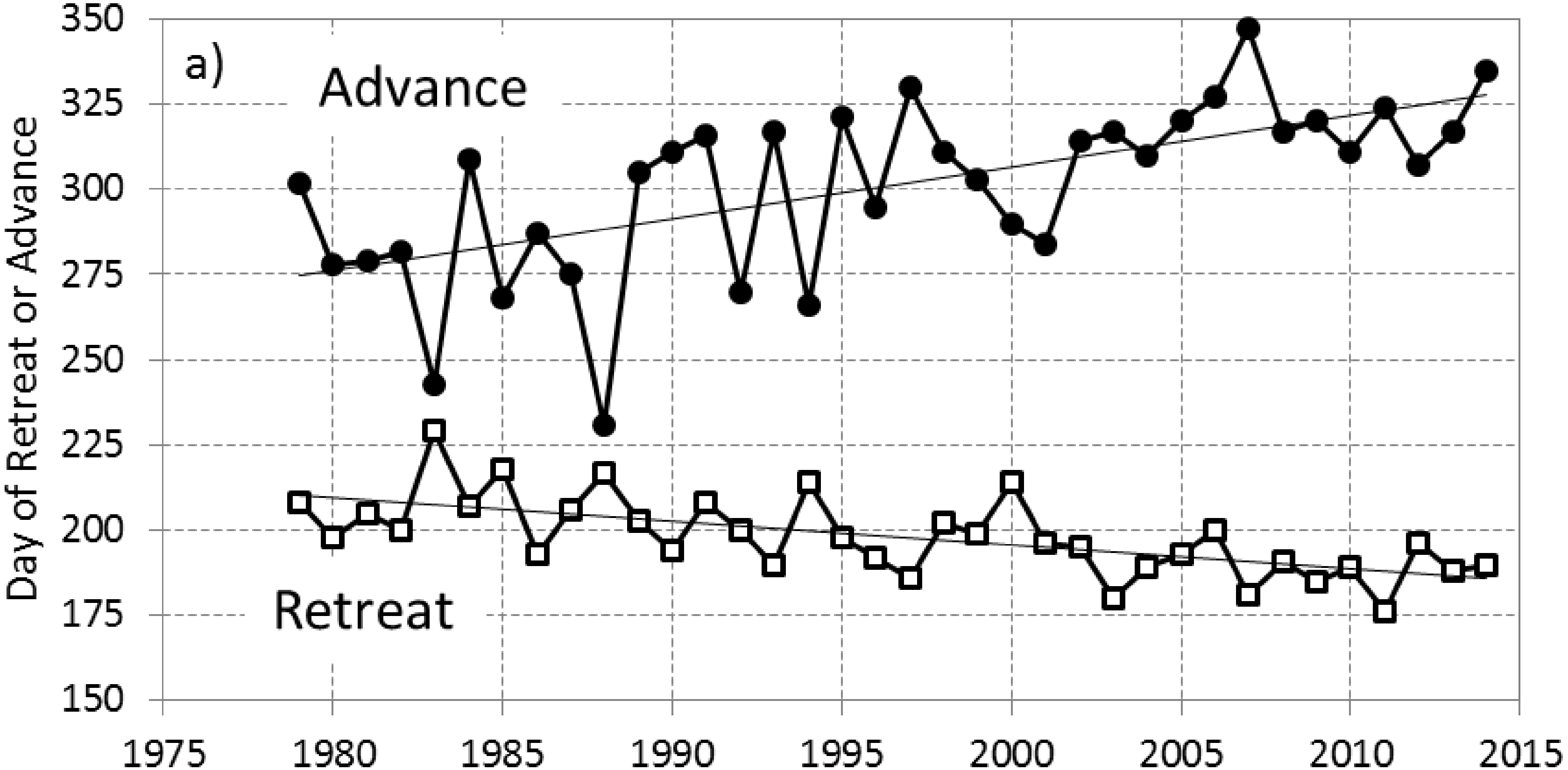


Retreat date: First day that average ice concentration in the study area drops below 30%

Advance date: First day (after minimum is reached) that average ice concentration in the study area exceeds 30%

Average retreat date: **July 17**
Average advance date: **October 28**

Pronounced linear trends



Retreat: -0.70 days/year (25 days over the period 1979-2014)
Advance: +1.52 days/year (55 days over the period 1979-2014)

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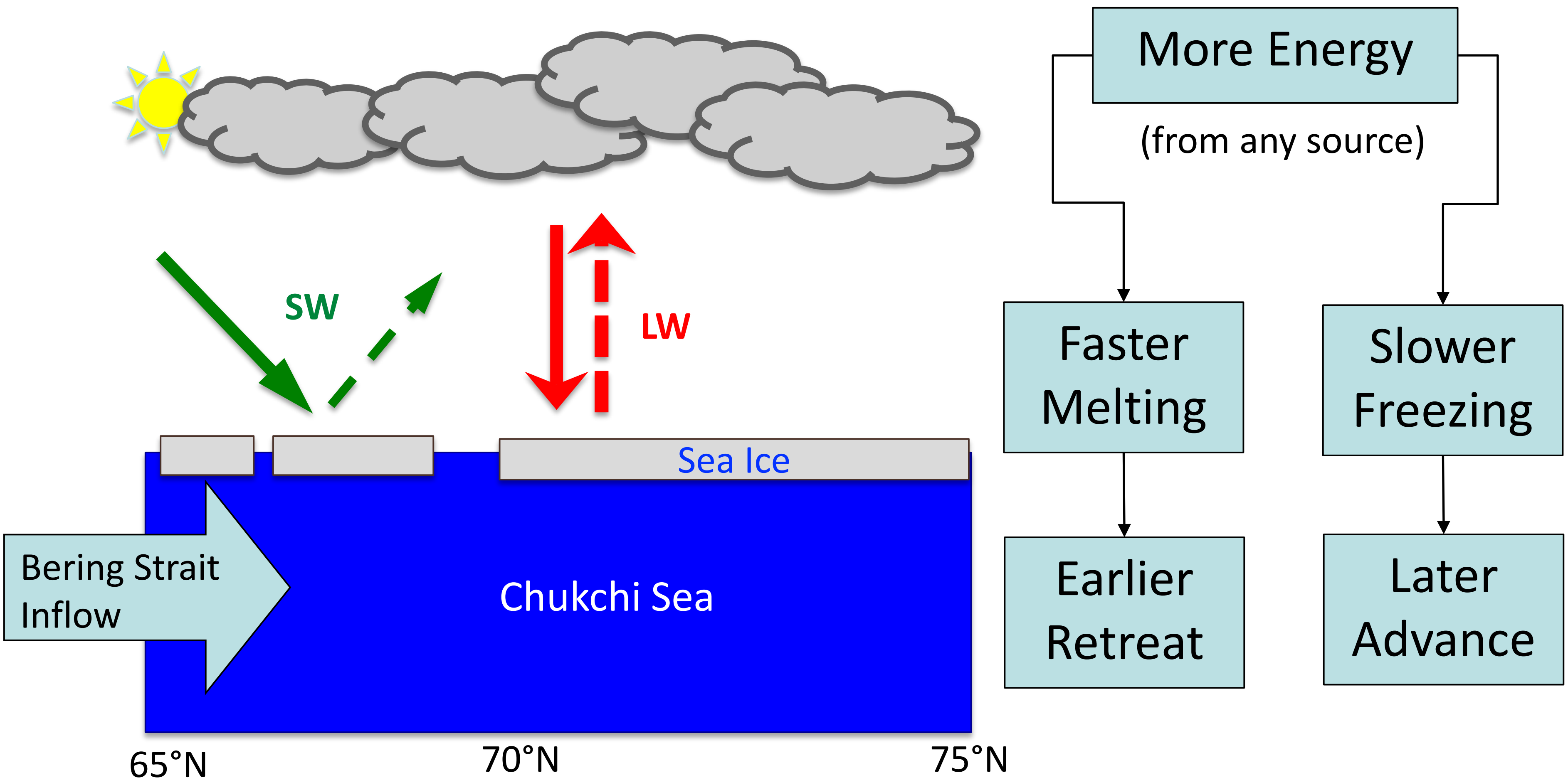
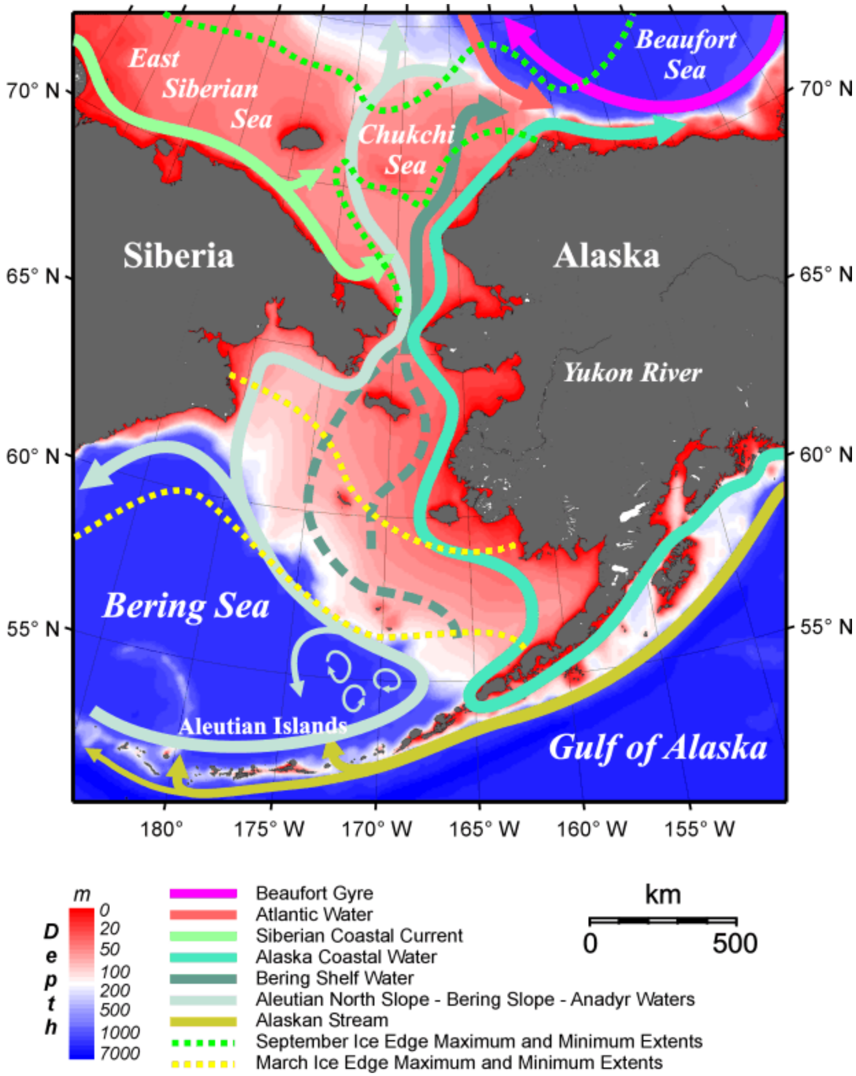
Goal: Predict the dates of sea ice retreat and advance in the Chukchi Sea

A thermodynamic point of view

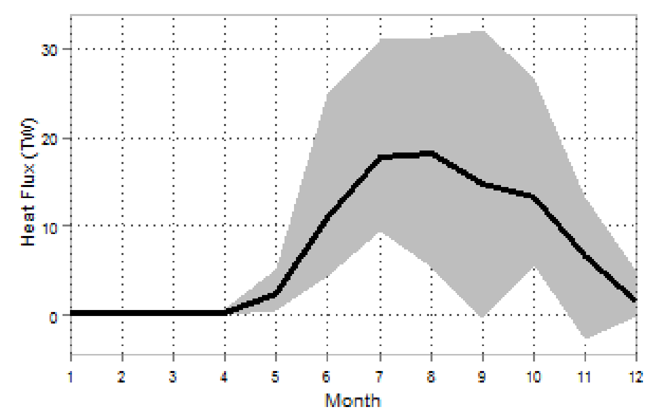


The Bering Strait inflow

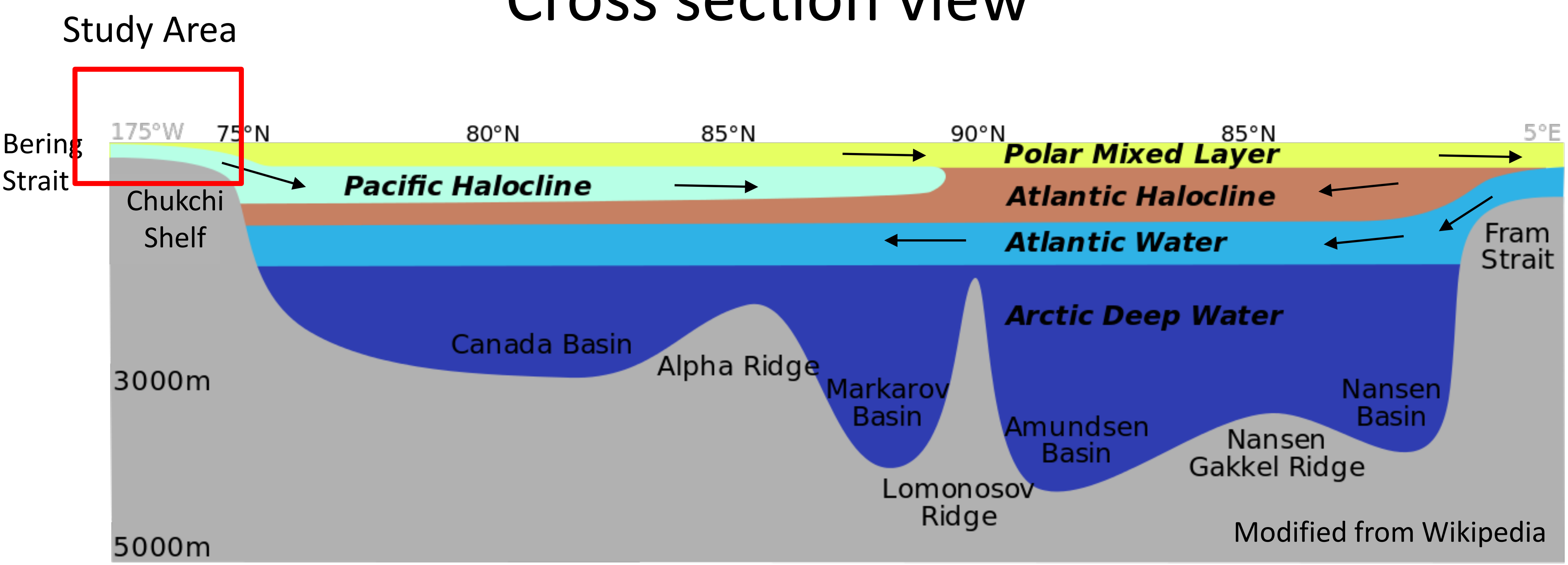


- Water flows from Pacific to Atlantic across Arctic Ocean [*Woodgate et al.*, 2005]
    - Driven by pressure differences
    - Local winds often blow against current
- Bering Strait inflow warmer than Arctic Ocean
- Heat inflow has a pronounced seasonal cycle, summer maximum (from Alaskan Coastal Current)

Seasonal cycle of Bering heat inflow



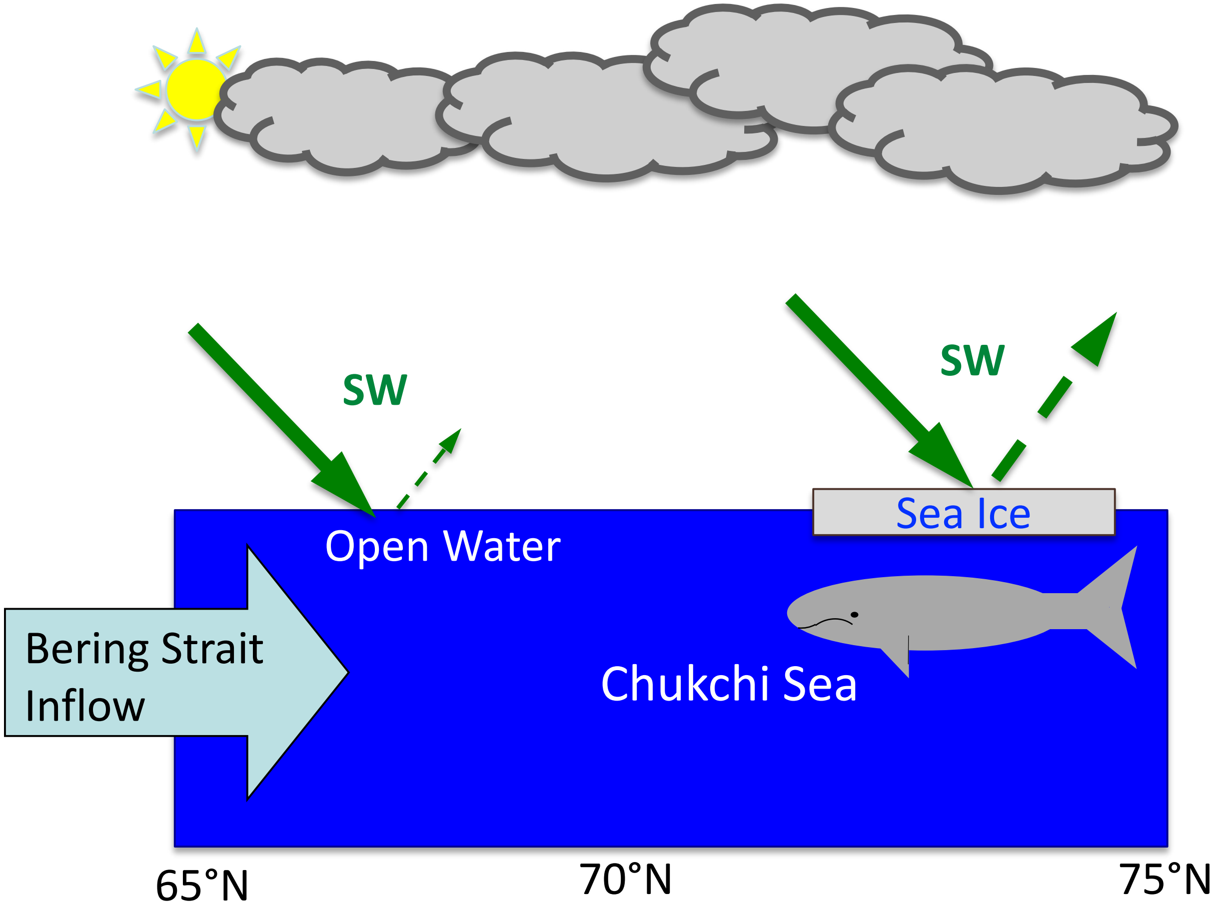
Cross section view



Bering Strait inflow forms Pacific Halocline

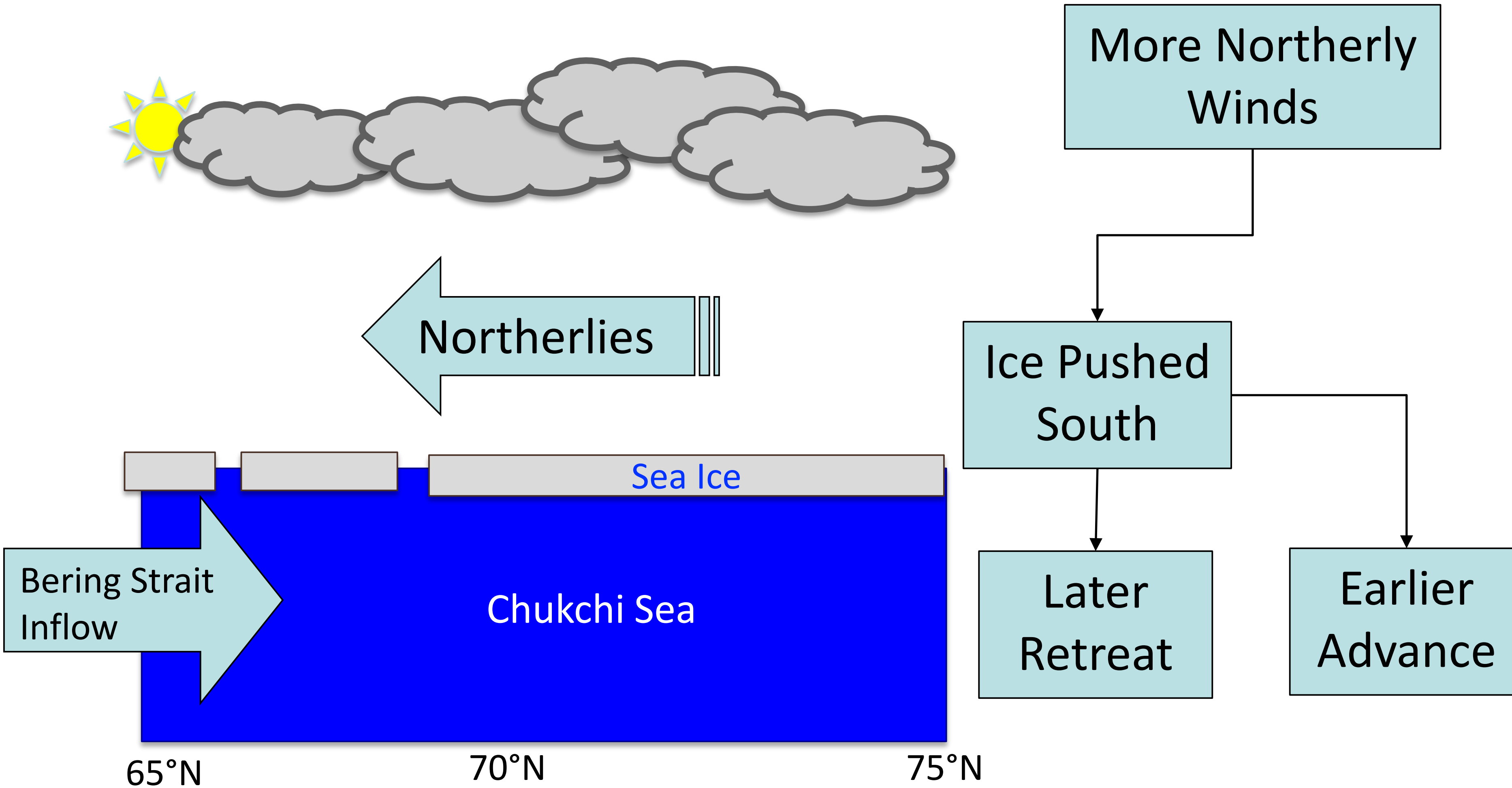
Key question: How much of the heat accompanying the volume and salinity transport can be brought to bear to melt ice or keep it from forming in the Chukchi Sea?

Albedo feedback and ocean heat uptake



Earlier Retreat (for any reason) → Lower Albedo → Longer Open Water Period → More Energy Absorbed → Warmer Water → Later Advance

Surface winds complicate the picture

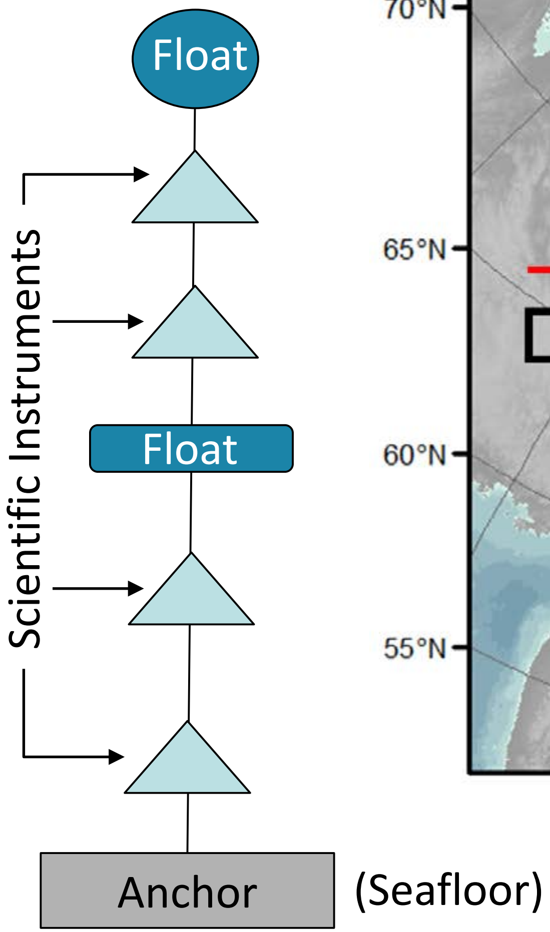


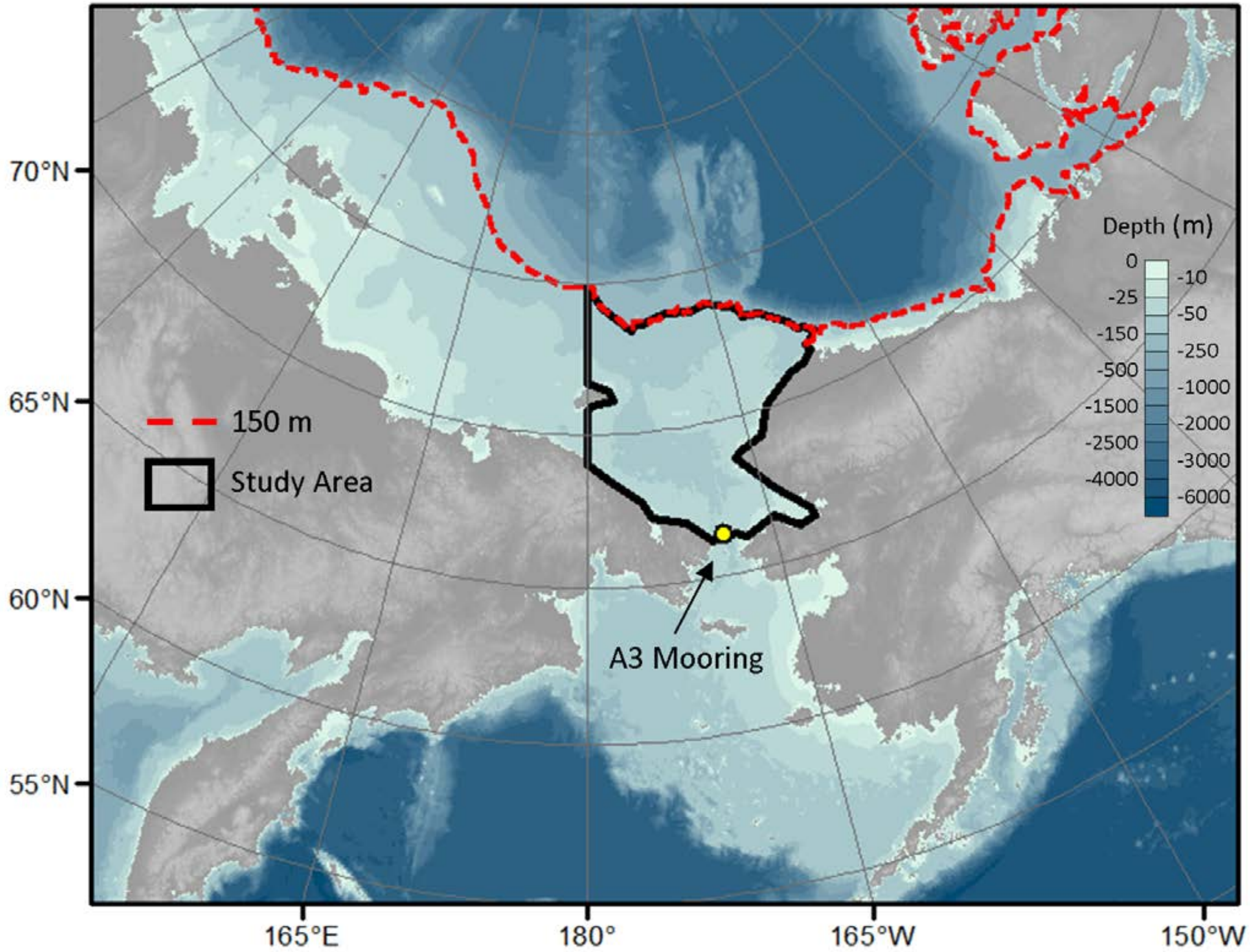
Data Sources

- **Passive microwave record** for sea ice concentration (1979-2014)
- **Atmospheric fields** (radiation, SLP, surface temperature, wind) from the MERRA and ERA-Interim reanalyses (1979-2014)
- **Ocean heat transport** (in TW) through the Bering Strait from the A3 mooring (September 1990 through September 1992, August 1997 through December 2013)

Study area

A3 Mooring





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Methods

- Take seasonal (April-June and July-Sept) means
- De-trend everything
- Run simple correlations
- Find the best linear models for explaining*:
  - Variance in de-trended retreat day
  - Variance in de-trended advance day

* "Best" means the model with the highest explained variance that does not violate any of several statistical assumptions

Selected retreat day statistics

Variable	Correlations (p-values)		Record
Bering Strait Heat Inflow (BHI)		**-0.81** (0.000)	1990-91,1998, 2000-13
	MERRA	ERA-Interim	
10 m Meridional Wind	-0.29 (0.08)	-0.29 (0.09)	1979-2014
Downwelling Shortwave Radiation	**+0.39** (0.02)	+0.24 (0.16)	1979-2014
Downwelling Longwave Radiation	**-0.50** (0.00)	**-0.37** (0.02)	1979-2014

Pearson correlations between de-trended time series of retreat day (RD) and seasonal oceanic, surface radiation, and atmospheric variables averaged for April through June. Bold values are significant at $p < 0.05$ (p-values are in parentheses and assume independent observations). Radiation fluxes are defined as positive downwards.

Best Model:

$$\mathbf{RD = \alpha + \beta(BHI)} \quad \mathbf{R^2 = 0.68}, \text{ 15 degrees of freedom}$$

$\beta = -3.42 \pm 1.17$ days/TW (95% confidence interval; $p < 0.01$)

Role of the Bering Strait heat inflow

- Best model has Bering Strait heat inflow as **only** retreat day predictor
- Average annual heat inflow from the A3 mooring of 4.1×10^{20} J could melt 2.6 m of ice averaged over the Chukchi Sea domain
  - Excursions of 1×10^{20} J corresponding to 0.6 m of ice are common in the record – enough variability in heat to impact retreat/advance day variability
- By the time Pacific waters exit the Arctic ocean they are at freezing point [*Steele et al.*, 2004] – heat must go somewhere
- Rough estimates indicate that only about ¼ of the annual heat inflow is sequestered in the Pacific Summer Water layer in the western Arctic [*Woodgate et al.*, 2012].

Advance day (AD) statistics

Variable	Correlations (p-values)		
Retreat Day (RD)	**-0.58** (0.000)		1979-2014
Bering Strait Heat Inflow (BHI)	**+0.67** (0.002)		1991-1992, 1998-2013
	MERRA	ERA-Interim	
10 m Meridional Wind	+0.15 (0.37)	+0.15 (0.37)	1979-2014
Downwelling Shortwave Radiation	-0.10 (0.55)	+0.04 (0.82)	1979-2014
Downwelling Longwave Radiation	**+0.37** (0.02)	**+0.50** (0.00)	1979-2014

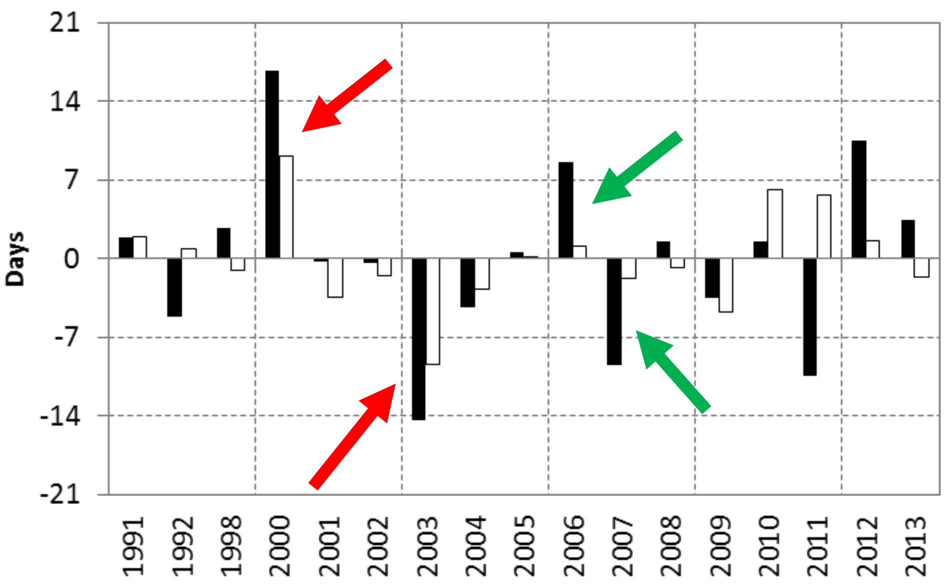
Pearson correlations between de-trended time series of advance day and retreat day (RD), as well seasonal oceanic, surface radiation, and atmospheric variables averaged for July through September. Bold values are significant at $p < 0.05$ (p-values are in parentheses and assume independent observations). Radiation fluxes are defined as positive downwards.

Best Model:

$$\mathbf{AD = \alpha + \beta_1(BHIa) + \beta_2(RD)} \quad \mathbf{R^2 = 0.67}\text{, 14 degrees of freedom}$$

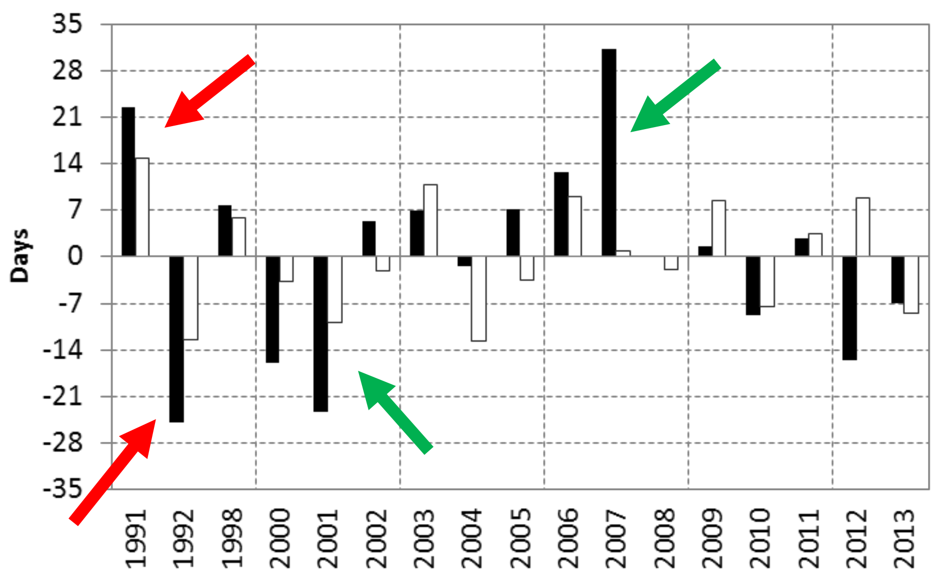
$\beta_1 = +3.79 \pm 1.49$ TW/day (95% confidence interval, $p < 0.01$)

$\beta_2 = -0.67 \pm 0.59$ days/day (95% confidence interval, $p = 0.04$)



Results from linear models

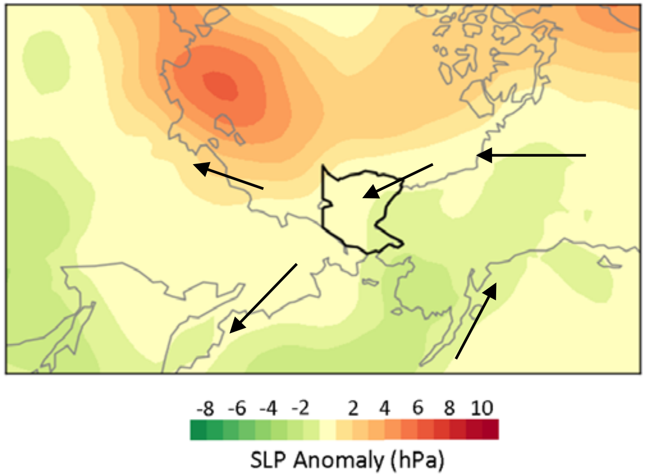
De-trended anomalies of retreat day (black, positive values mean a late retreat relative to the trend line) and model residuals (white)



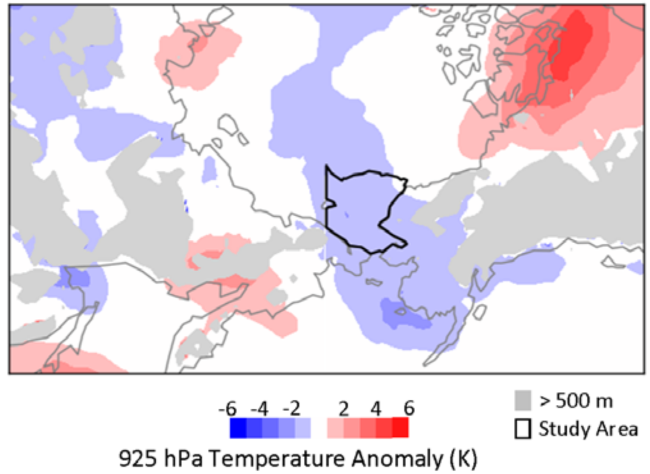
De-trended anomalies of advance day (black, positive values mean a late advance relative to the trend line) and model residuals (white)

Case studies for retreat

2000, Retreat Day = 215, August 2
Spring BHI = -0.91 TW

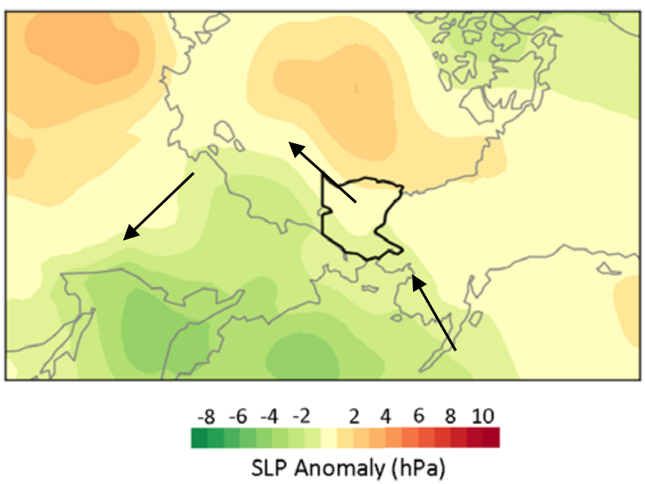


Trend: Pred. Retreat: 198, Residual: +17 days
Model: Pred. Retreat: 206, Residual: +9 days

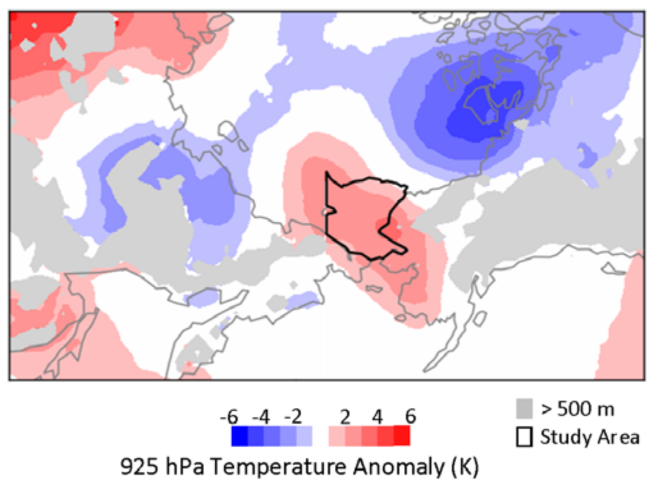


More easterly winds
Cooler temperatures
Later than predicted

2003, Retreat Day = 180, June 29
Spring BHI = +1.45 TW



Trend: Pred. Retreat: 194, Residual: -14 days
Model: Pred. Retreat: 189, Residual: -9 days

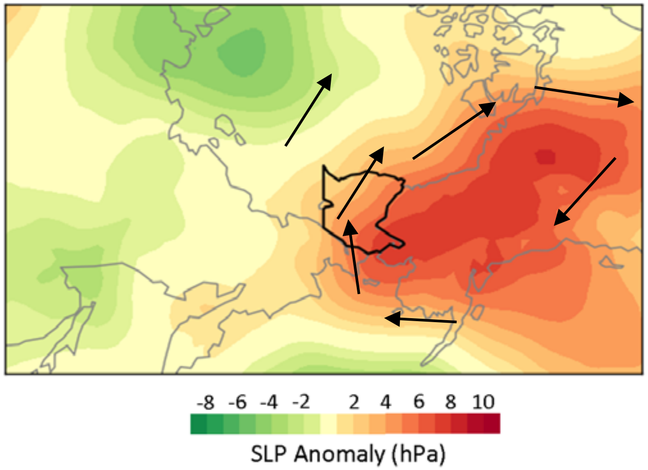


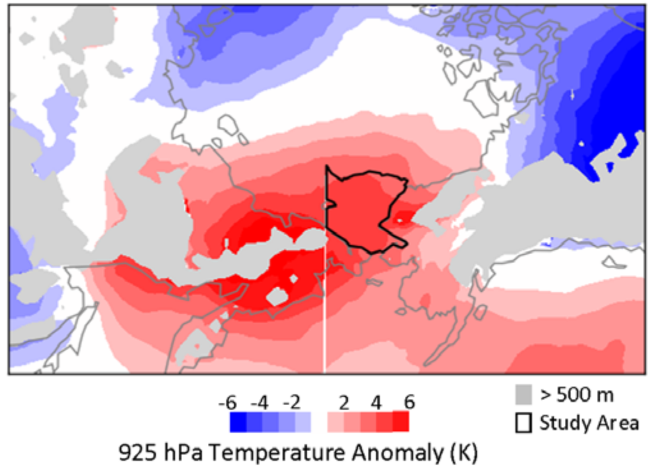
More southerly winds
Warmer temperatures
Earlier than predicted

Case studies for advance

1991, Advance Day = 316, November 12
Summer BHIa = +2.33 TW, Retreat = +2 days

Trend: Pred. Advance = 294, Residual = +22 days
Model: Pred. Advance = 301, Residual = +15 days

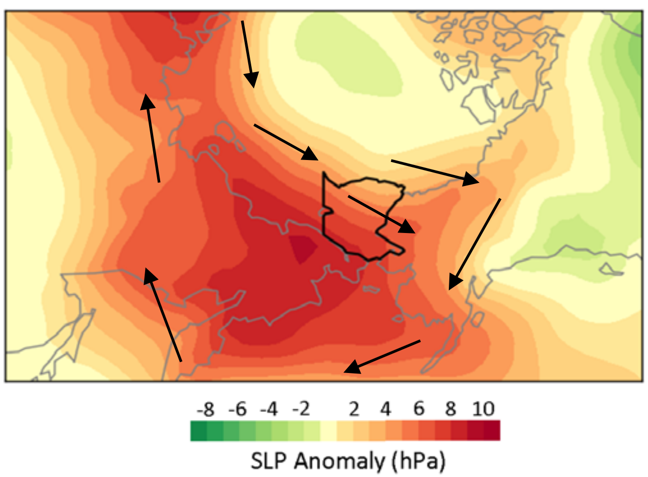


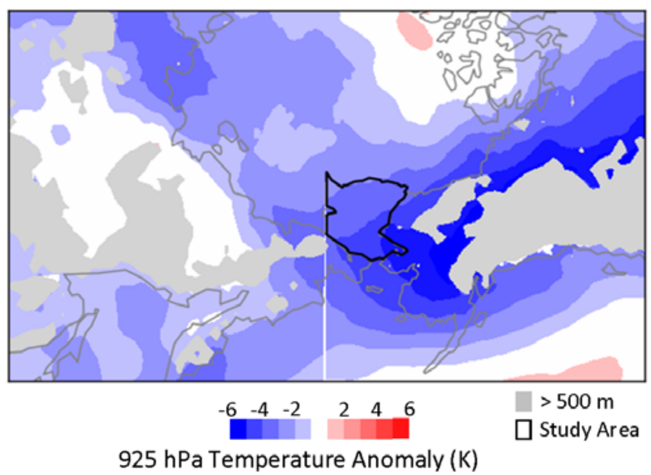


More southerly winds
Warmer temperatures
Later than predicted

1992, Advance Day = 270, September 27
Summer BHIa = -4.21 TW, Retreat = -5 days

Trend: Pred. Advance = 294, Residual = -24 days
Model: Pred. Advance = 283, Residual = -13 days





More north/westerly winds
Cooler temperatures
Earlier than predicted

Conclusions

- Chukchi Sea is opening earlier and closing later
- Bering Strait heat inflow is key to predicting the timing of sea ice retreat and advance
- Ice-albedo feedback also useful to predicting advance
- Practical problem: Bering Strait heat inflow only available from moorings – need to physically visit them!
- Major hurdle is that summer weather patterns are not predictable beyond the 7-10 day timescale.


Thank You!