Indication of an unusual change in the Arctic's late-summer sea ice thickness-volume relationship

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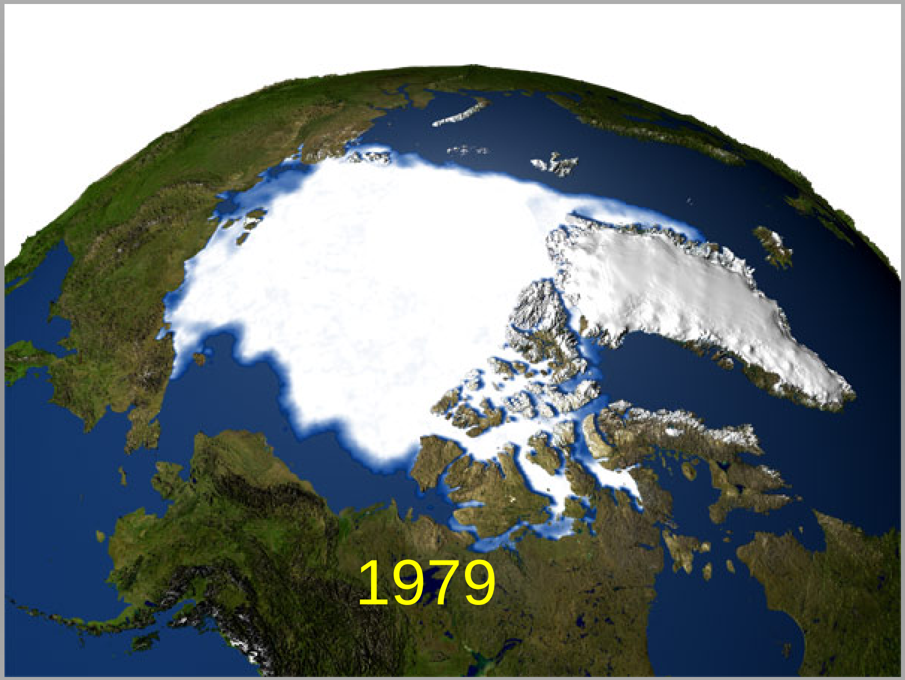
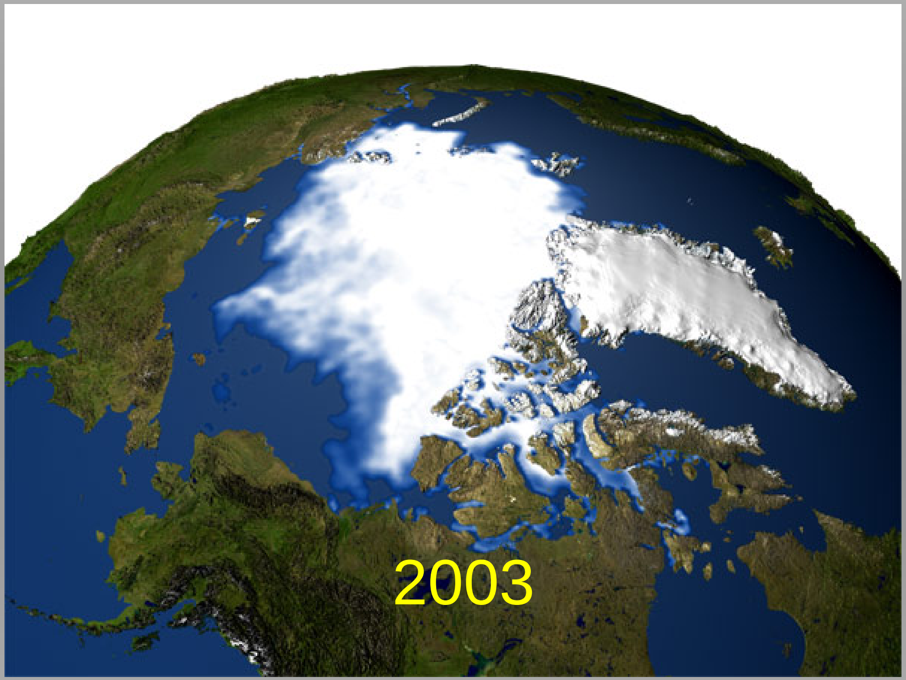
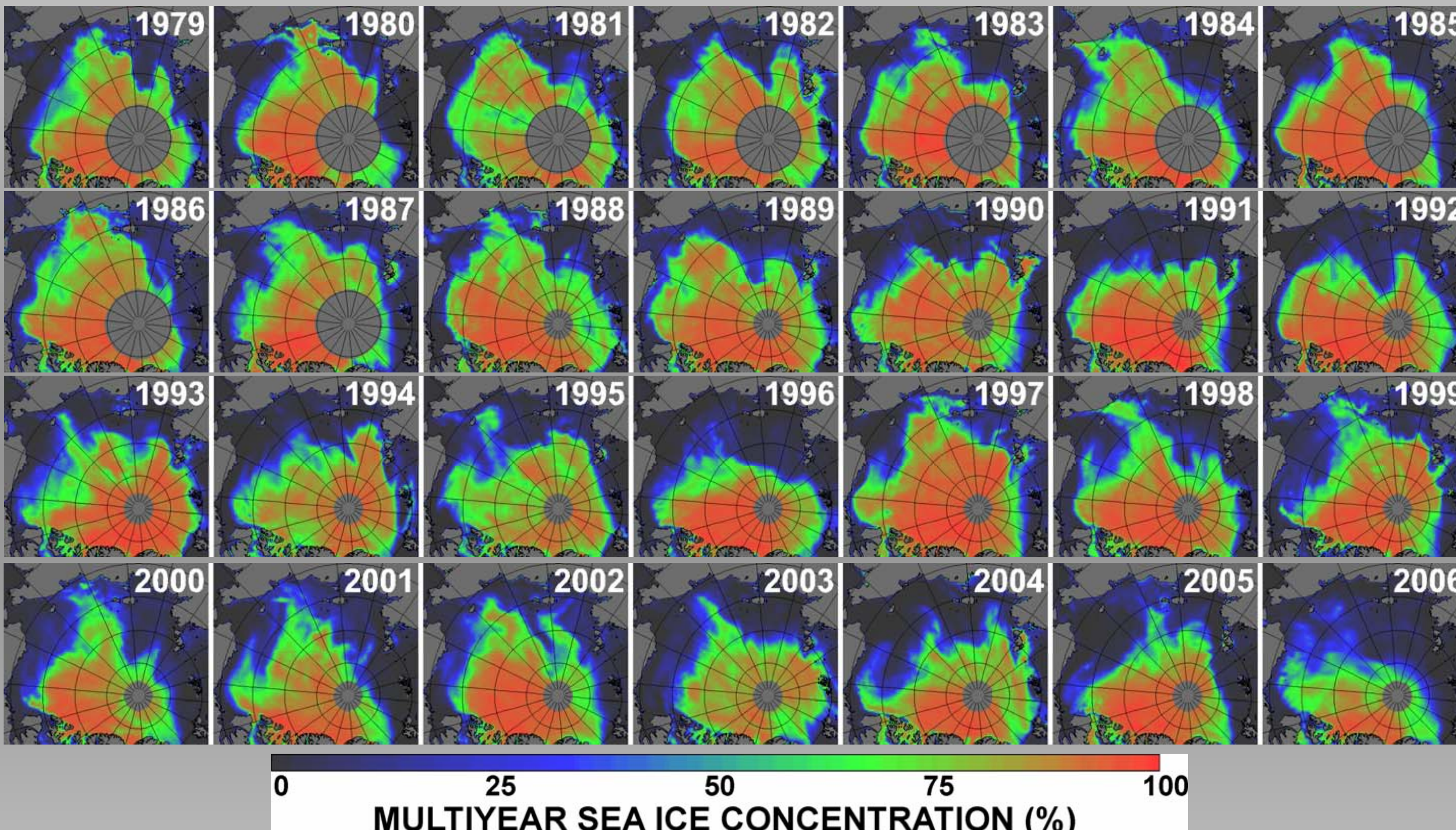
RECENT WARMING OF ARCTIC MAY AFFECT WORLDWIDE CLIMATE

NASA - October 23, 2003, Press Release



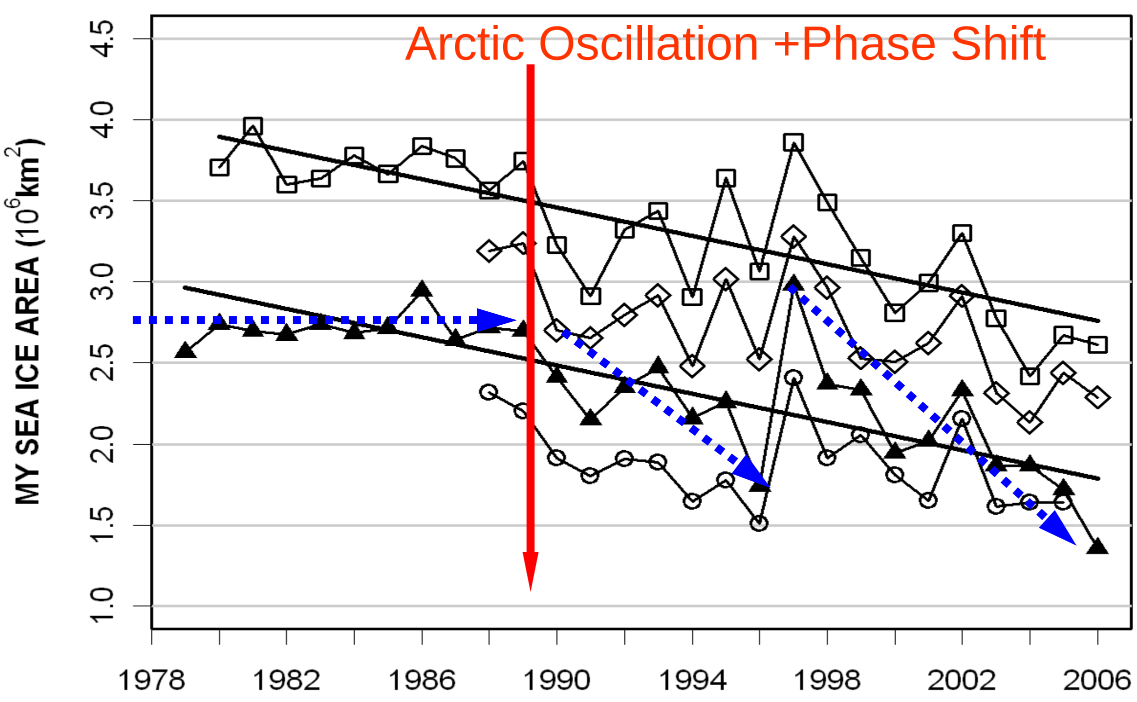


JANUARY PERENNIAL (Multiyear) SEA ICE DISTRIBUTIONS



Belchansky et. al (2005) Variations in the Arctic's multiyear sea ice cover: A neural network analysis of SMMR-SSM/I data, 1979–2004, Geophys. Res. Lett., Vol. 32.

MULTIYEAR SEA ICE AREA TRENDS



Method	January	Slope $10^3 km^2 year^{-1}$	Significance
	1979-2006		
Okean-ERS-RADARSAT NN		-38.5 (3.7%)	>0.99
	1980-2006		
Bootstrap minimum		-43.5 (4.2%)	>0.99
Okean-ERS-RADARSAT NN		-41.2 (4.0%)	>0.99
	1988-2005		
Bootstrap minimum		-43.8 (4.1%)	0.99
NASA Team minimum		-36.2 (3.4%)	0.99
Okean-ERS-RADARSAT NN		-40.0 (3.8%)	0.99
NASA Team MY ice		-20.3 (1.9%)	0.92

Sea Ice Thickness?

Published approaches:

1. Modeling (coupled ocean-ice-atmosphere)
2. Submarine sonar ice draft data (intermittent time-series)
3. Satellite altimetry (ice free-board)

This study:

Neural Network Model (empirical approach)

1. “Supervised”
2. Training (learning) data = *in situ* ice thickness measurements
3. Input data = influential geophysical parameters (time-integrated)
4. 25 km x 25 km pixel resolution
5. Monthly (1982-2003) temporal resolution

NEURAL NETWORK LEARNING DATA:

Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics

Aircraft Landing Observations from the Former Soviet Union, 1928-1989

25 km x 25 km

n = 2157

n = 907

National Snow and Ice Data Center. 1998, updated 2005. *Submarine upward looking sonar ice draft profile data and statistics*. Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.

National Snow and Ice Data Center. 2004. *Morphometric characteristics of ice and snow in the Arctic Basin: aircraft landing observations from the Former Soviet Union, 1928-1989*. Compiled by I.P. Romanov. Boulder, CO: National Snow and Ice Data Center. Digital media.

NEURAL NETWORK INPUT PARAMETERS (N=7):

NOAA-CIRES Climate Diagnostics Center

NCEP/NCAR Reanalysis Monthly Means

Clear sky downward longwave flux	W/m^2
Clear sky downward solar flux	W/m^2
Net longwave radiation	W/m^2
Net shortwave radiation	W/m^2

Polar Exchange at the Sea Surface POLES A NASA EOS Interdisciplinary Investigation

IABP/ POLES Surface Temperature Data Set

Freeze degree month	^{o}C

NSIDC

Polar Pathfinder Monthly 25 km EASE-Grid Sea Ice Motion Vectors

Ice velocity	cm/s
Ice divergence/convergence index	>0

Notably Not Represented:

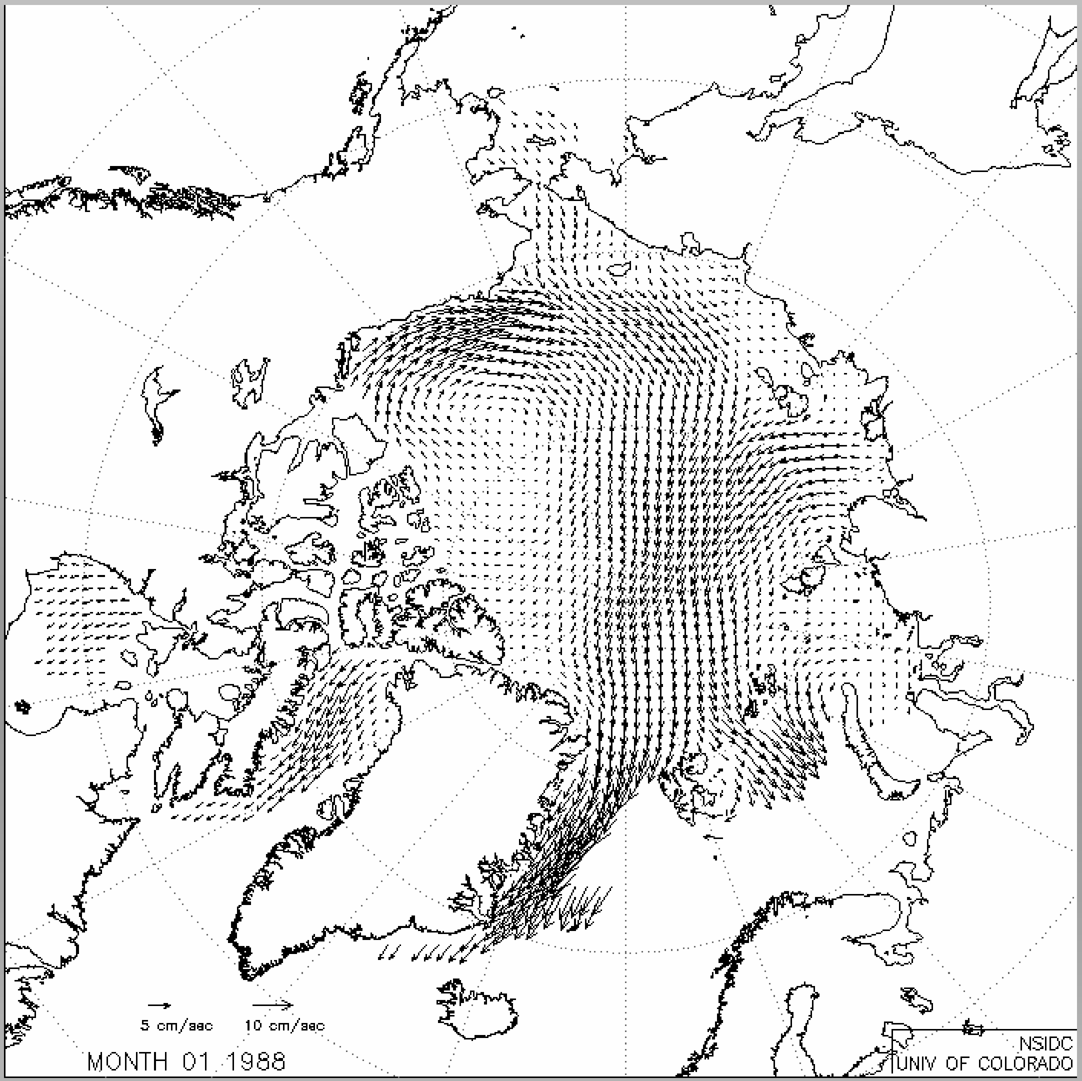
- Ocean temperature and circulation
- Snow cover on sea ice

Polar Pathfinder Monthly 25 km EASE-Grid Sea Ice Motion Vectors

- 1979-2003
- Sea Ice Buoys
- AVHRR
- SMMR-SMM/I

Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I

Comiso, J. 1999, updated 2005. *Bootstrap sea ice concentrations for NIMBUS-7 SMMR and DMSP SSM/I*, June to September 2001. Boulder, CO, USA: National Snow and Ice Data Center. Digital media.



Fowler, C. 2003. *Polar Pathfinder Daily 25 km EASE-Grid Sea Ice Motion Vectors*. Boulder, CO, USA: National Snow and Ice Data Center. Digital media.

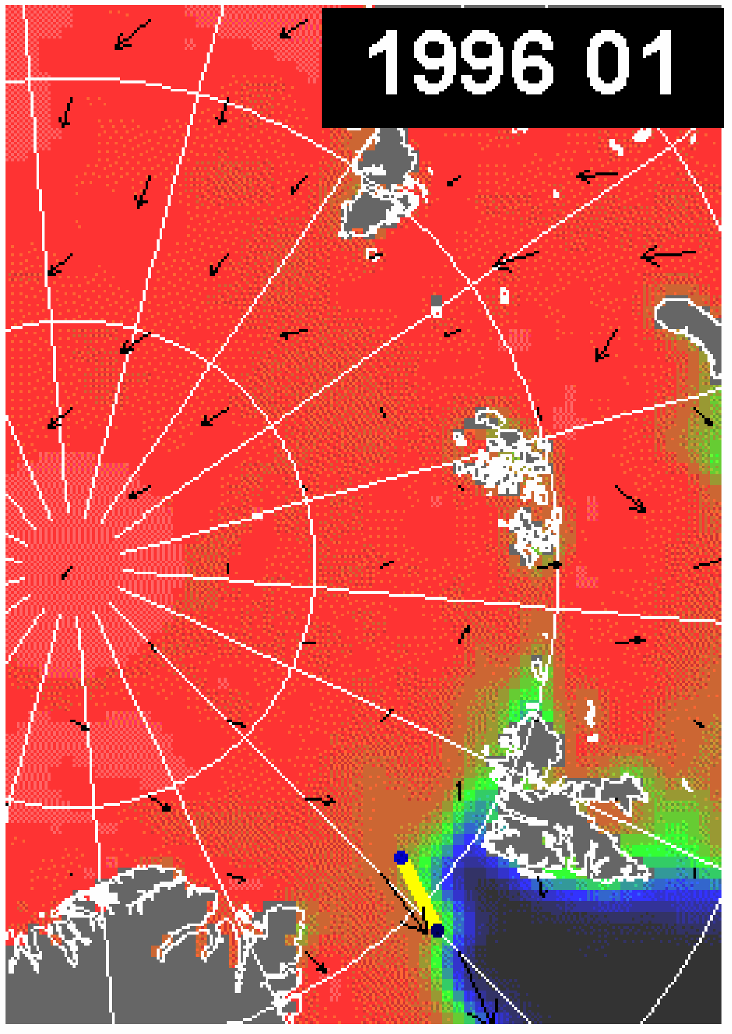
REVERSE-CHRONOLOGY ICE ADVECTION ALGORITHM

* Sea Ice Thickness *

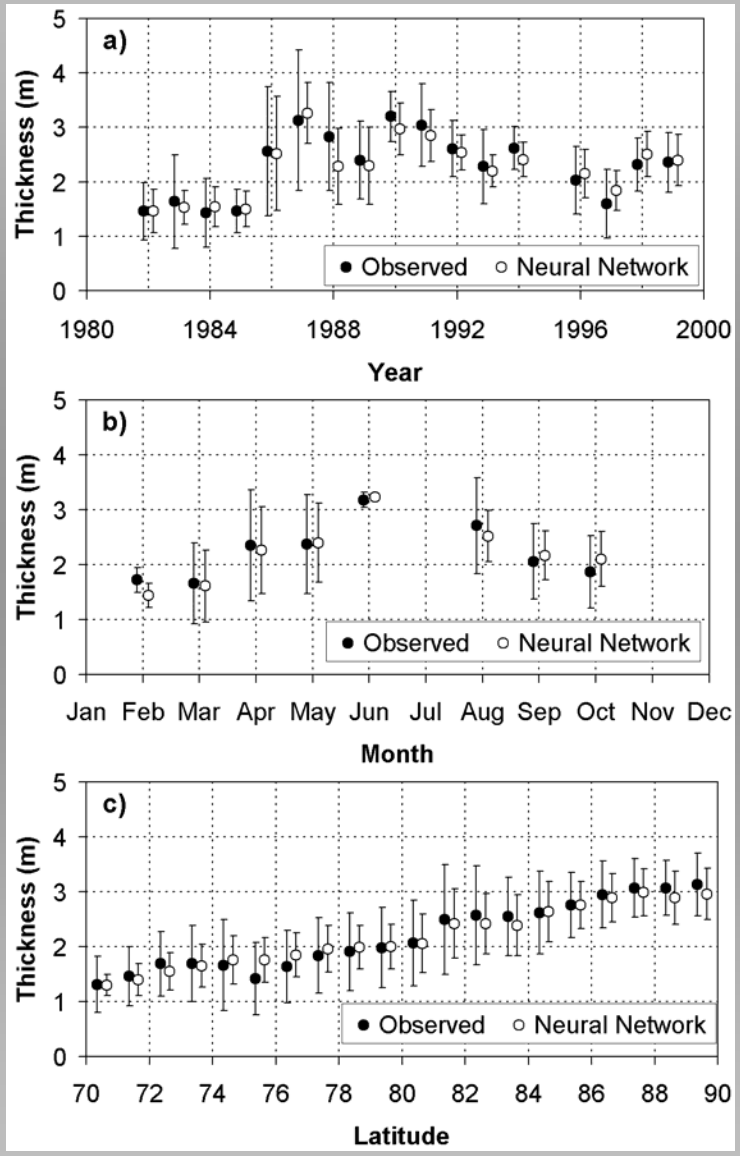
METHOD:

Track each ice-covered pixel iteratively backwards in time (based on the ice motion data) and accumulate each of the 7 environmental parameters over a 3-year period (or less if ice <3 years old, i.e. tracked to open water conditions).

Use the accumulated values for each of the 7 parameters as inputs to neural network.



NEURAL NETWORK ICE THICKNESS VS. LEARNING DATA



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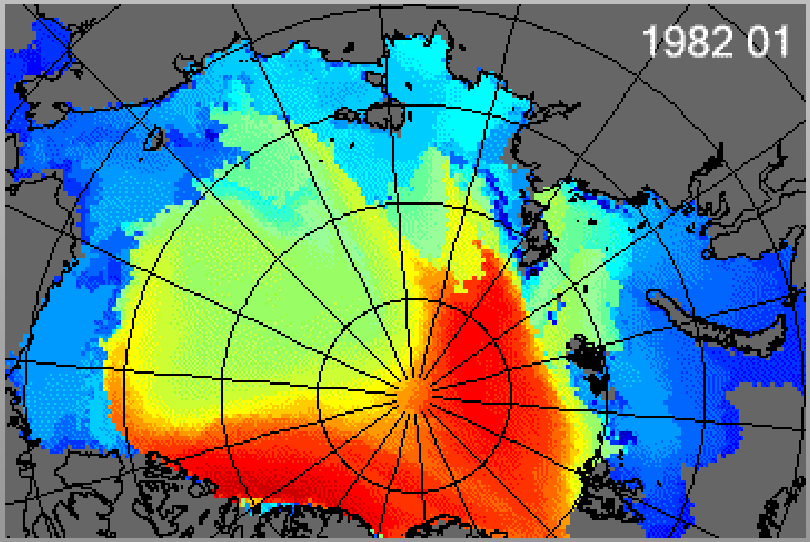
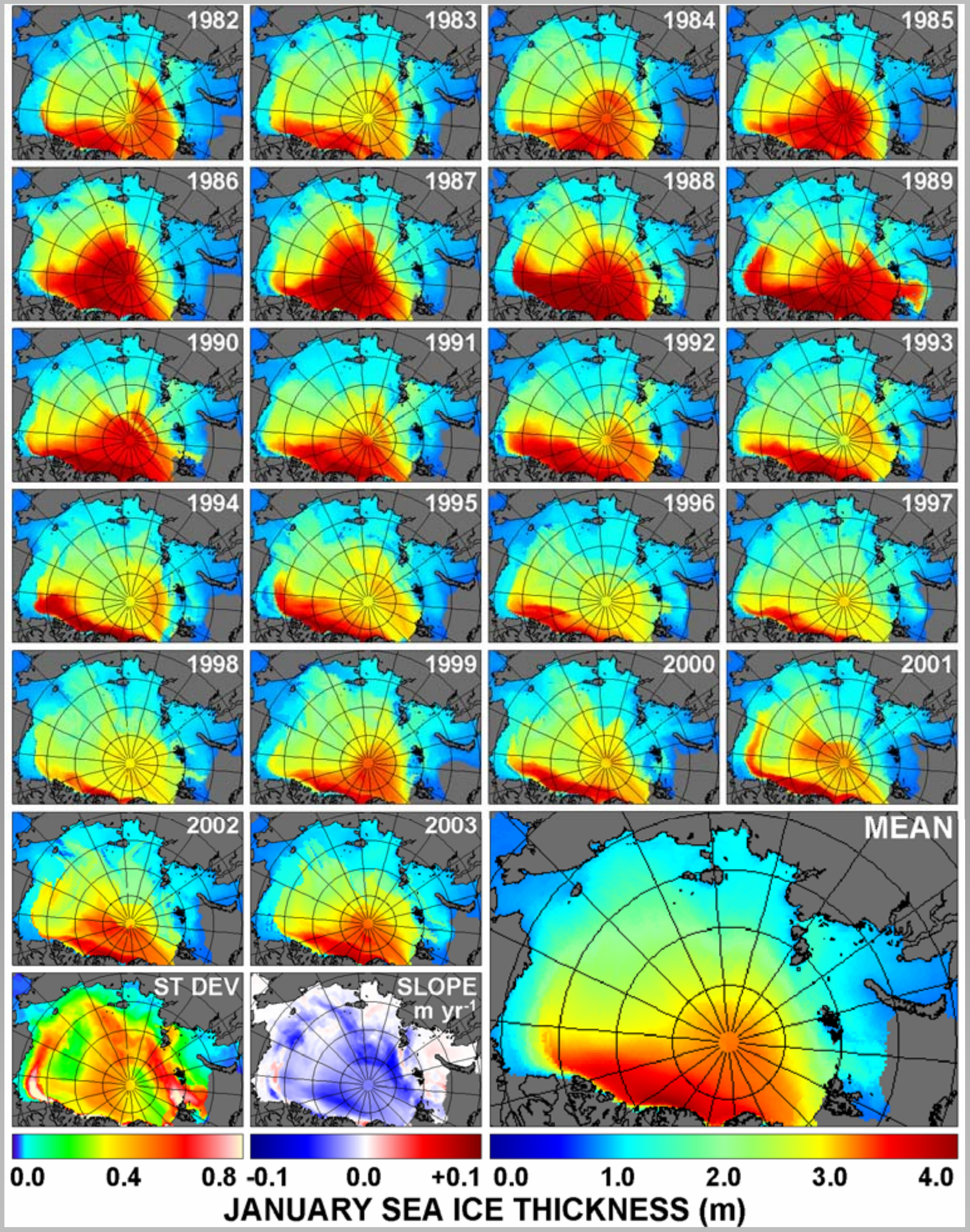
RESULTS - ARCTIC SEA ICE THICKNESS





Ice thickness was calculated with a neural network (NN) of 7-12-1 topology that was taught with thickness measurements from submarine sonar ice draft and surface drilling measurements. The NN inputs 7 parameters that describe each pixel's accumulated history during the previous 3 years (or less for ice <3 years in age).

Neural Network Input Parameters:

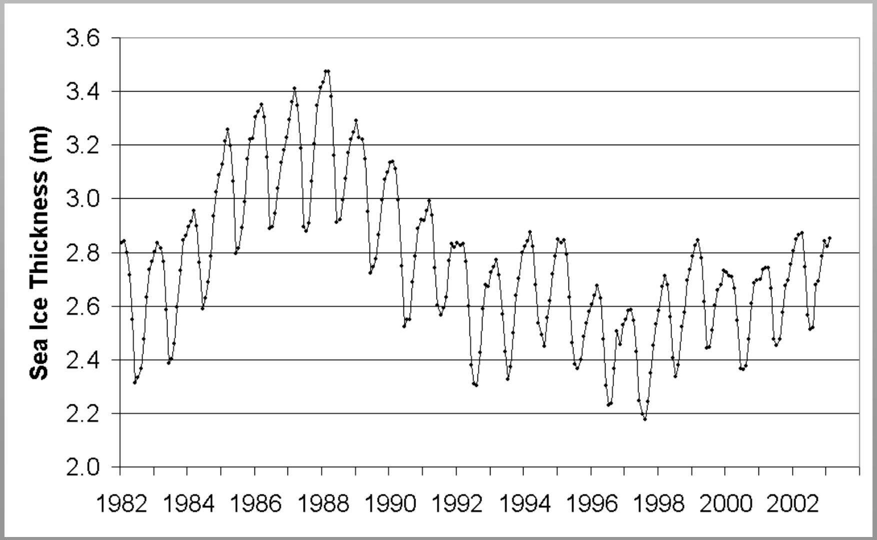
1) **Clear-sky shortwave irradiance**
2) **Clear-sky longwave irradiance**
3) **Net shortwave radiative flux**
4) **Net longwave radiative flux**
5) **Freeze-degree month (-2C threshold)**
6) **Ice drift velocity**
7) **Ice divergence/convergence index**

Table 1. Average discrepancies (m) between NN SIT estimates and several *in situ* measurements and summaries (observed minus NN). Independent samples were compared with NN SIT pixels; independent stations were compared within a 100-km radius. AO (Arctic Ocean); EA (East Arctic); BS (Beaufort Sea); NP (North Pole); SEB (Southeast Beaufort Sea); FS (Fram Strait).

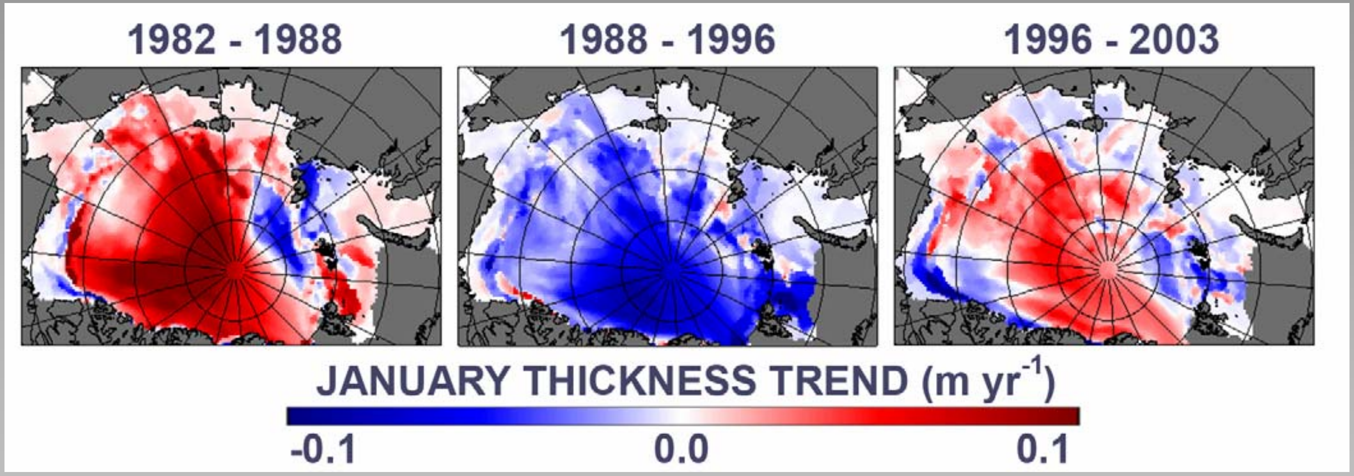
	Region	Mean	RMS	N
Dependent learning data				
SULS	AO	-0.01	0.53	2157
ALO	EA	0.03	0.51	907
SULS + ALO	AO	0.00	0.52	3064
Dependent regions				
Rothrock et al. [1999]	AO	0.11	0.42	15
Yu et al. [2004]	AO	-0.10	0.42	14
Independent samples				
Haas and Eicken [2001][1]				
Drill-hole	EA	0.18	0.90	147
Electromagnetic	EA	-0.10	0.54	67
CRREL[2]	BS	0.10	0.60	95
Independent stations				
Moritz [submitted][3]	NP	-0.24	0.43	13
Melling [2001]	SEB	0.37	1.07	72
Melling et al. [2005]	SEB	0.71	0.90	12
Vinje et al. [1998]	FS	0.41	0.72	49
Witte and Fahrbach [2005]	FS	-0.51	0.92	117
Independent map pixels				
Løvås and Brude [1999]	AO	0.16	0.62	104878

Data source:
[1]http://www.pangaea.de/
[2]http://www.crrel.usace.army.mil/sid/IMB/
[3]http://psc.apl.washington.edu/northpole/

ALTERNATING ICE THICKNESS TRENDS



+7.6 cm/yr **-6.1 cm/yr** **+2.1 cm/yr**



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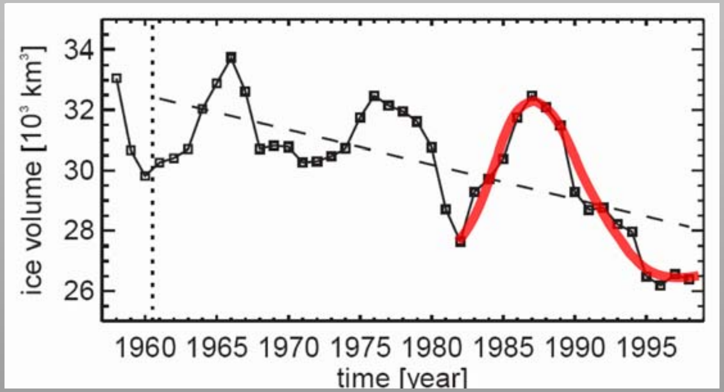
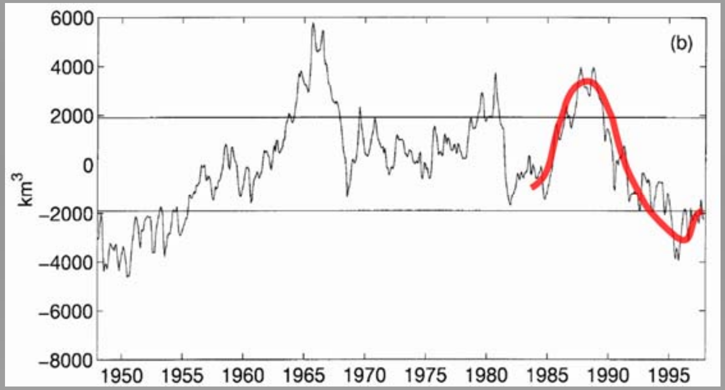
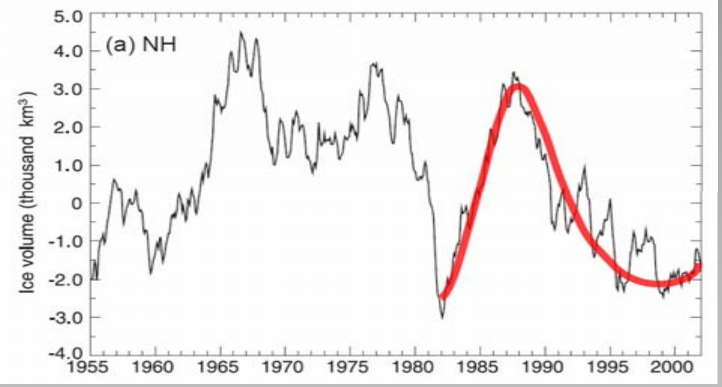
CORROBORATING PUBLISHED MODEL RESULTS (Ice Volume)



Hilmer, M., and P. Lemke (2000), On the decrease of arctic sea ice volume, *Geophys. Res. Lett. 27*, 3751–3754.

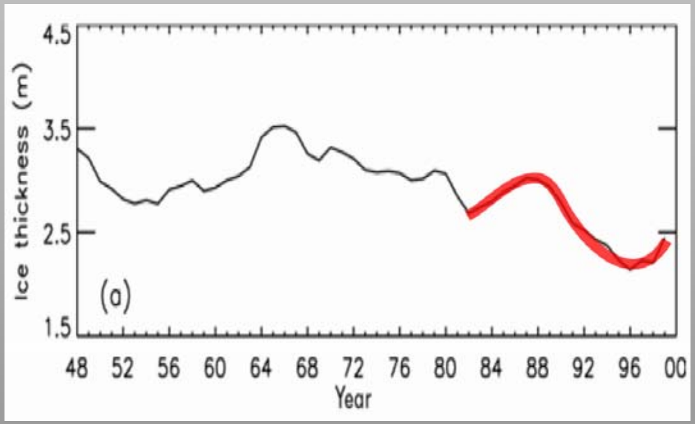


Köberle, C., and R. Gerdes, (2003), Mechanisms determining the variability of arctic sea ice conditions and export, *J. Clim., 16*, 2843–2858.



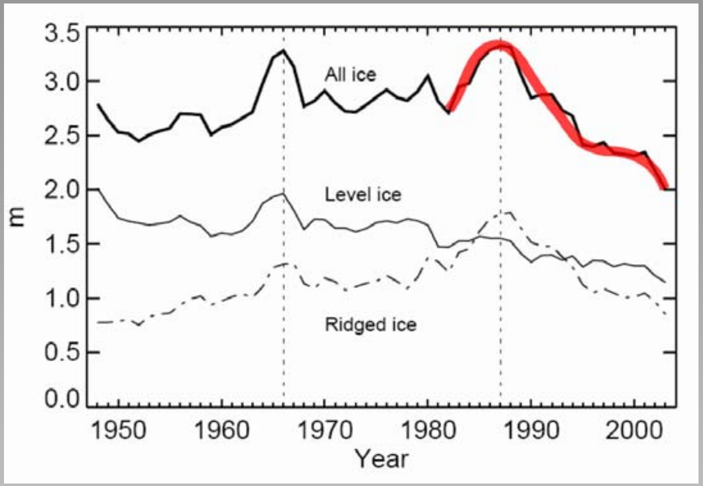
Fichefet, T., H. Goosse, and M. A. M. Magueda (2003), A hindcast simulation of Arctic and Antarctic sea ice variability, 1955–2001, *Polar Res., 22*, 91–98.

CORROBORATING PUBLISHED MODEL RESULTS (Ice Thickness)



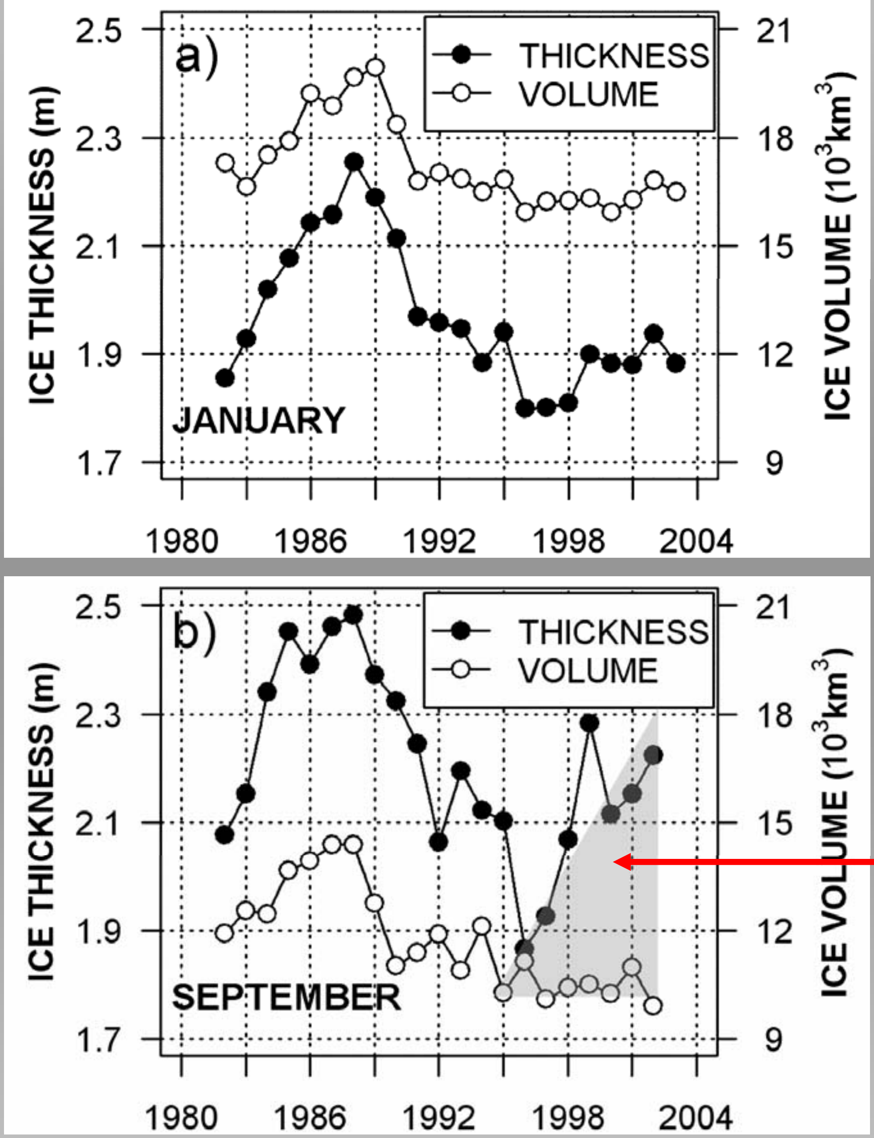
Rothrock, D. A., J. Zhang, and Y. Yu (2003), The Arctic ice thickness anomaly of the 1990s: a consistent view from observations and models, *J. Geophys. Res.*, *108*, 3083, doi:10,1029/2001JC001208.

CONTRADICTING PUBLISHED MODEL RESULTS (Ice Thickness)



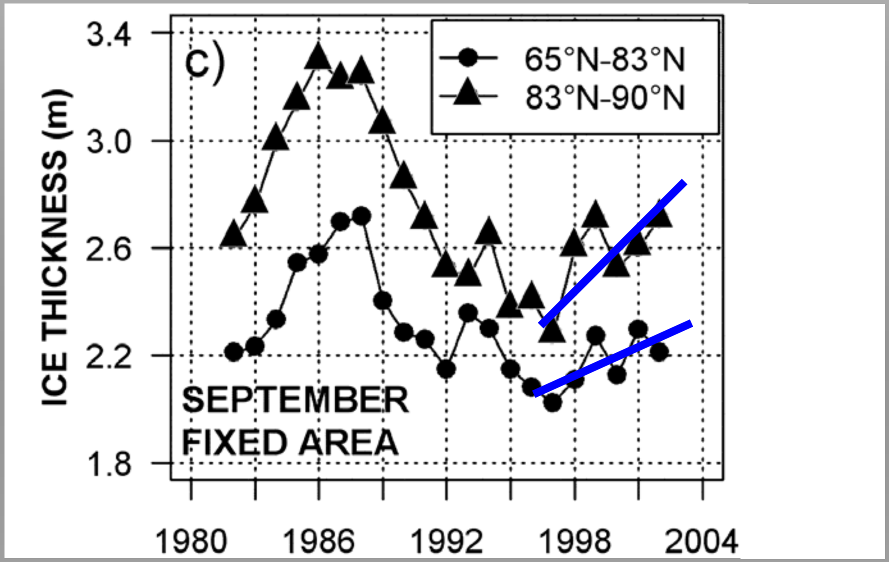
Lindsay R. W., and J. Zhang (2005), The thinning of arctic sea ice, 1988–2003: Have we passed a tipping point?, *J. Clim.*, *18*, 4879–4894.

ICE THICKNESS-VOLUME RELATIONSHIPS (this study)



Recent Disequilibrium….
Increasing ice thickness cannot indefinitely offset volume loss under conditions of diminishing ice extent.

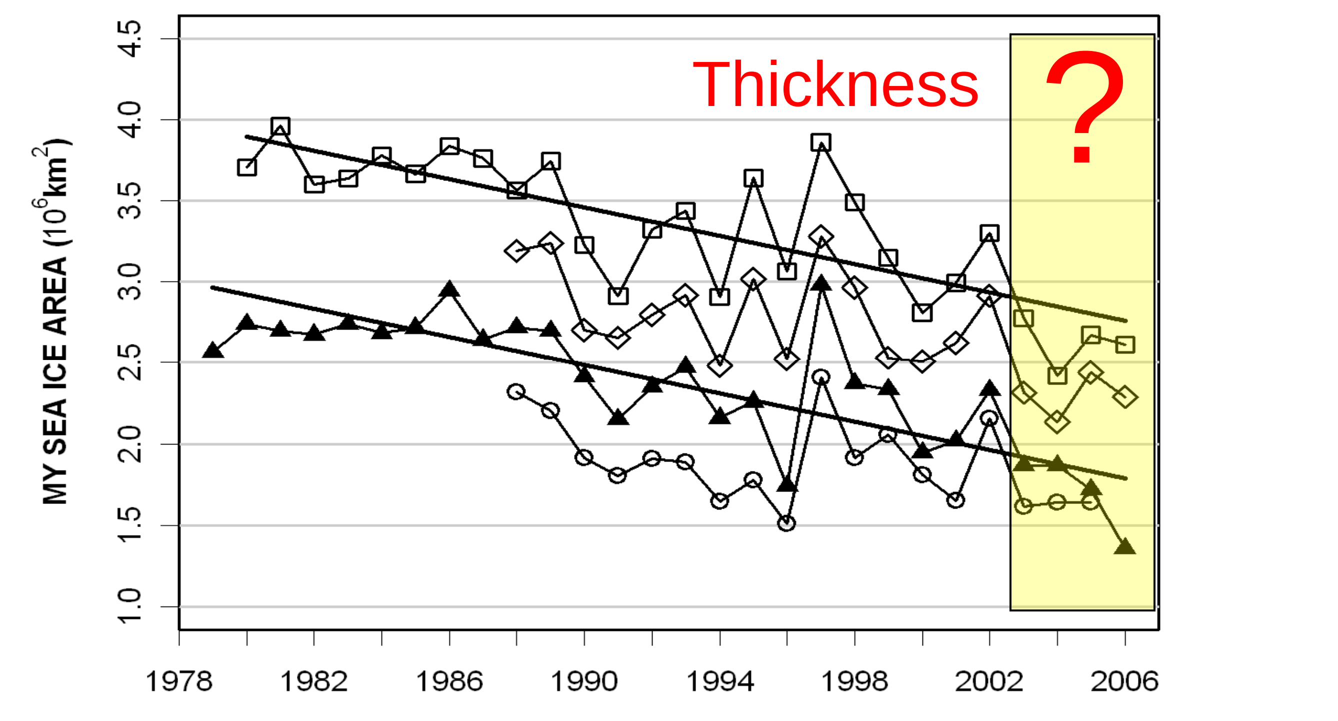
RECENT ICE THICKNESS CHANGE VS LATITUDE

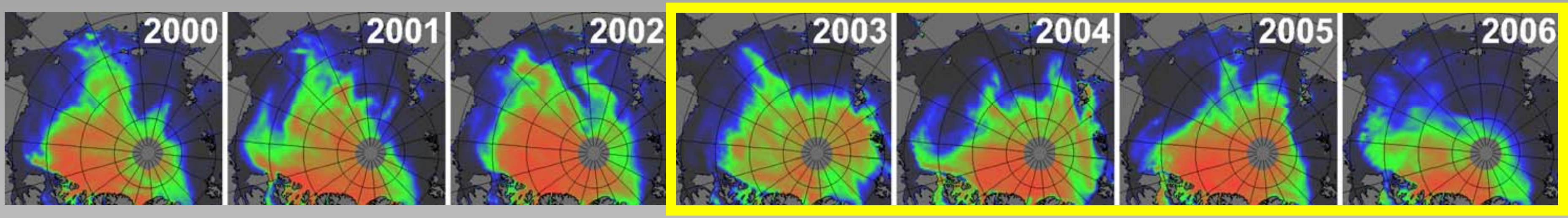


➢ The recent thickening trend appears more pronounced at higher latitudes.

THIS STUDY DOES NOT INCLUDE 2003 to PRESENT

(ice motion data not available)





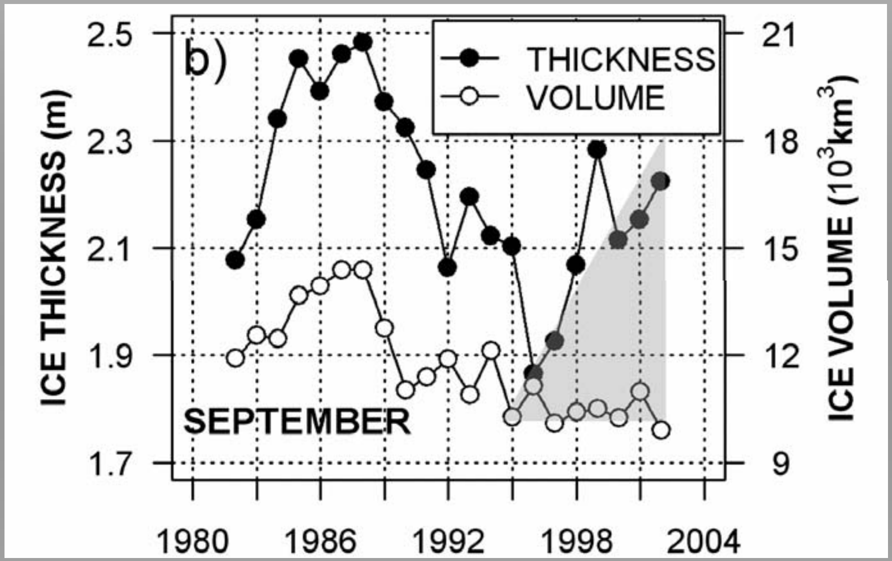
January MY ice concentrations

*new record minimum

*new record minimum

*new record minimum

CONCLUSIONS:



- The recent thickening trend (albeit modest) in perennial ice is more pronounced at very high latitudes.
- The trend is consistent with an anticipated decadal scale climate oscillation.
- But, resilience for returning ice conditions to a prior regime is challenged by the recent, persistent warming at the Arctic's periphery.
- Late summer ice thickness-volume relationships during 2003-present are not addressed by this study, and may be quite different now given the prior disequilibrium conditions and the continued loss of MY ice.

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Thank you....

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