WCRP World Climate Research Programme

Arctic Ocean processes and their predictability

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Seasonal to Multi-decadal Predictability of Polar Climate
A pan-WCRP workshop initiated by SPARC and CliC
October 25-29, 2010

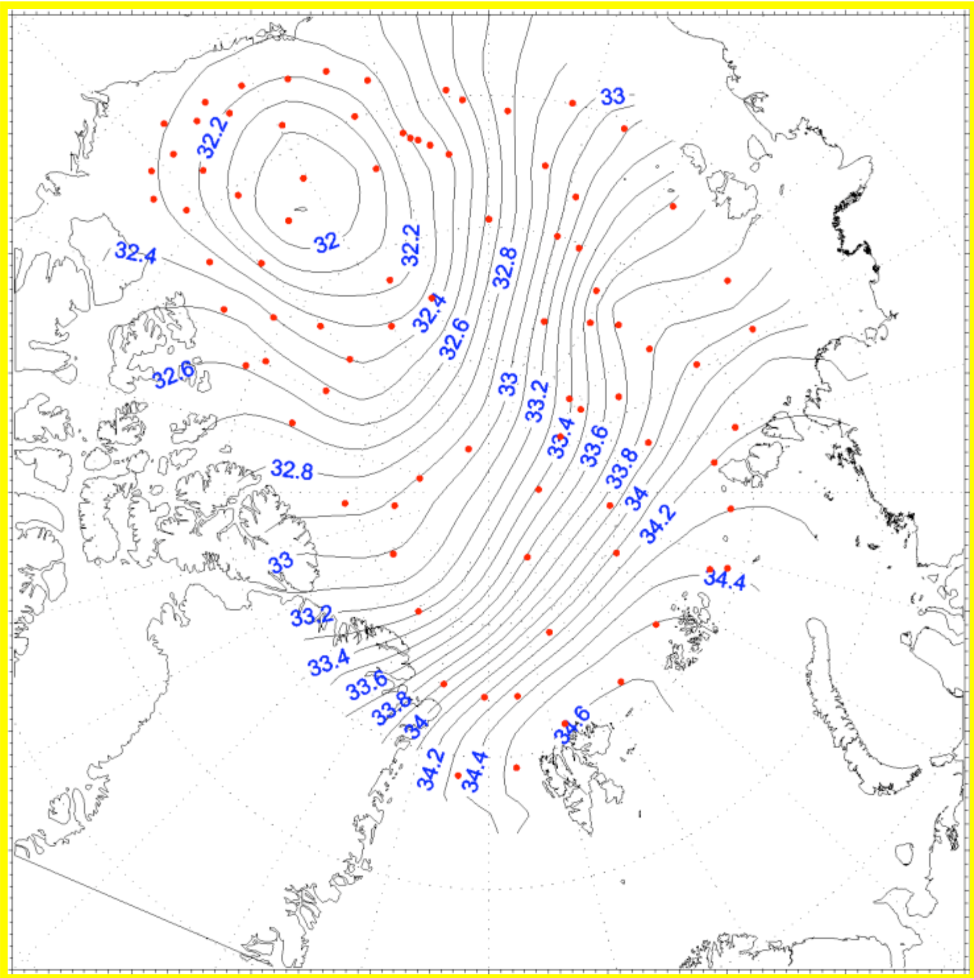
George Boer (from yesterday’s talk):

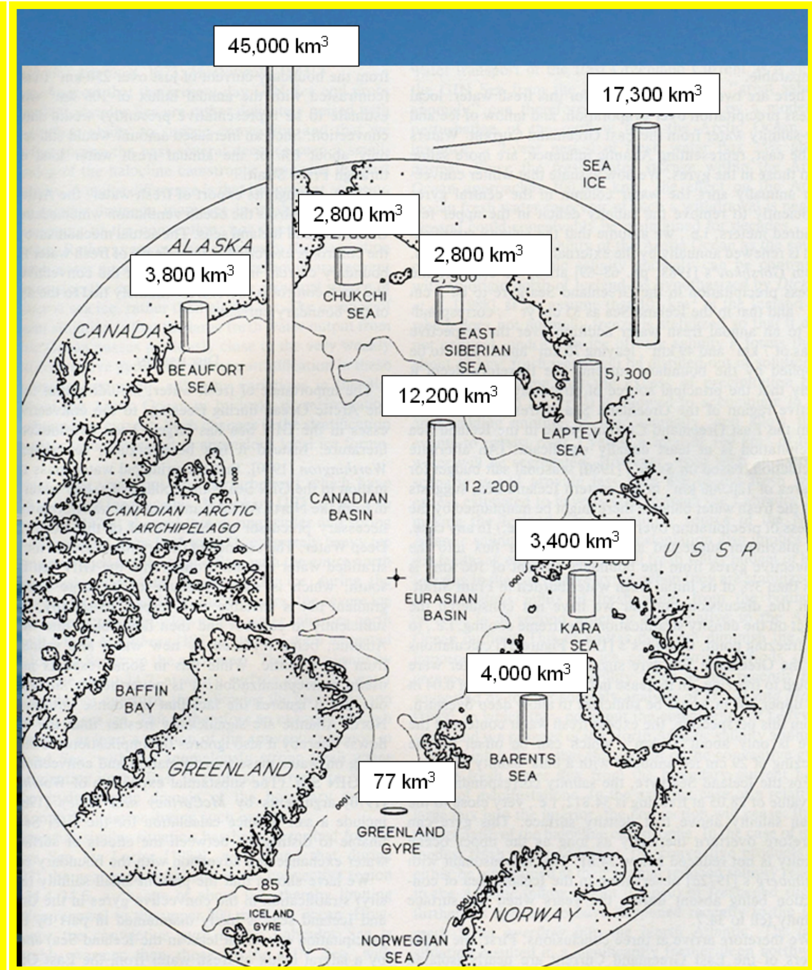
“Prospects are good for decadal predictions in polar regions:

Existence of long timescale processes

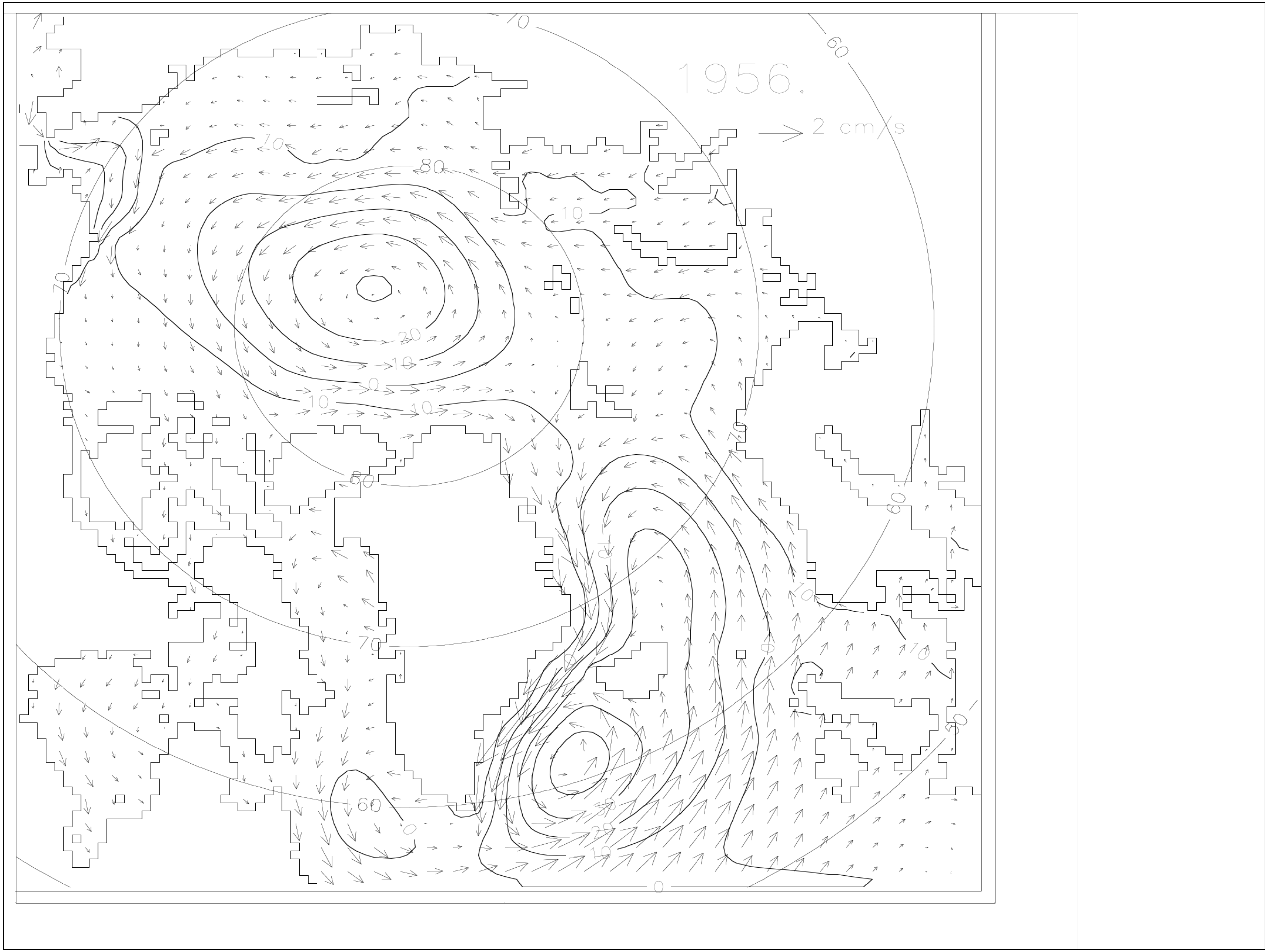
Results of predictability studies

Scientific interests”





The Beaufort Gyre (BG) is the largest freshwater reservoir in the Arctic Ocean. It contains ~ 45,000 km^3 of fresh water, calculated relative to salinity of 34.80 (Aagaard and Carmack, 1989). Its freshwater volume is 15 times larger than the annual river runoff to the Arctic Ocean and twice that stored in sea ice.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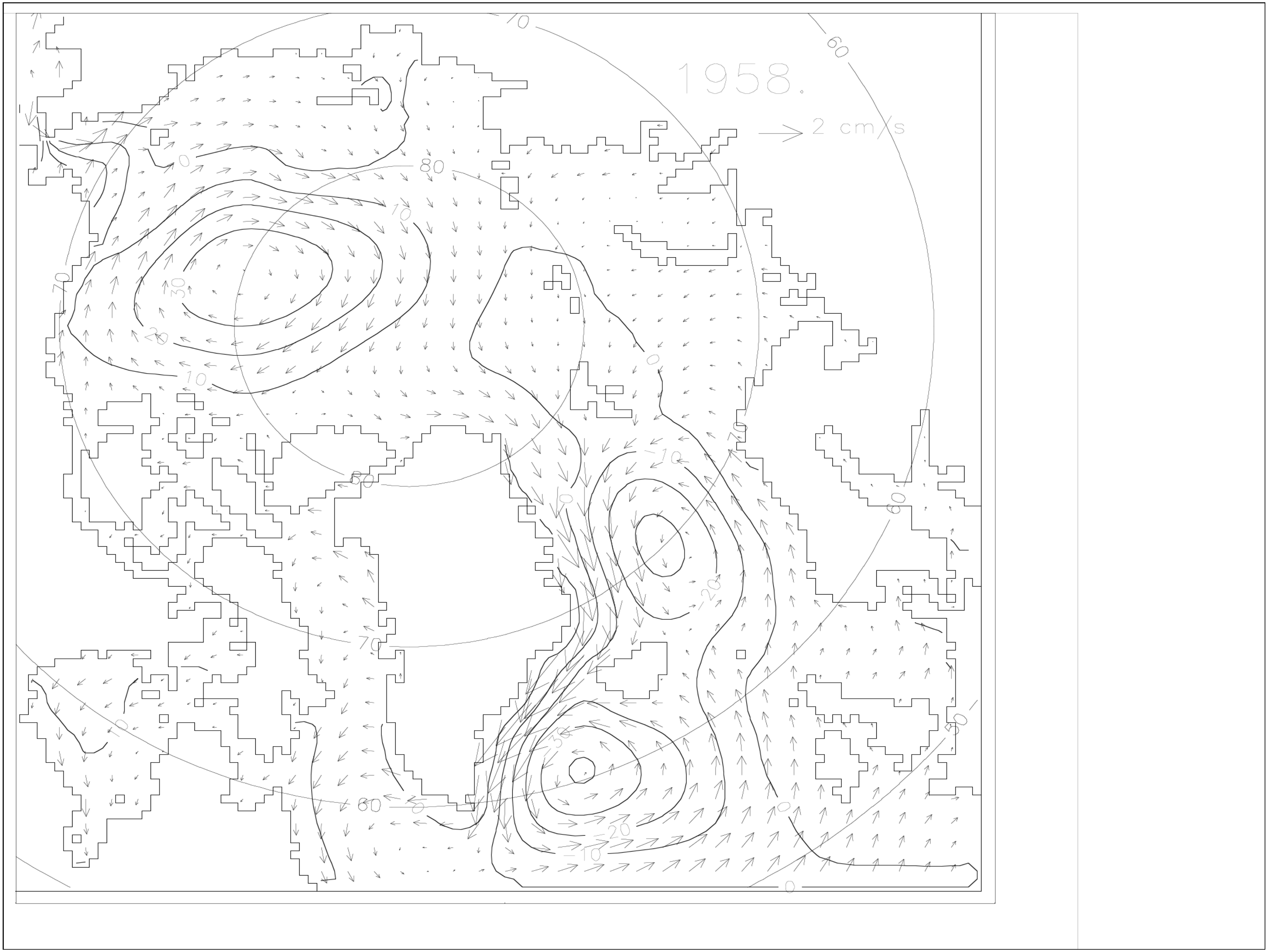

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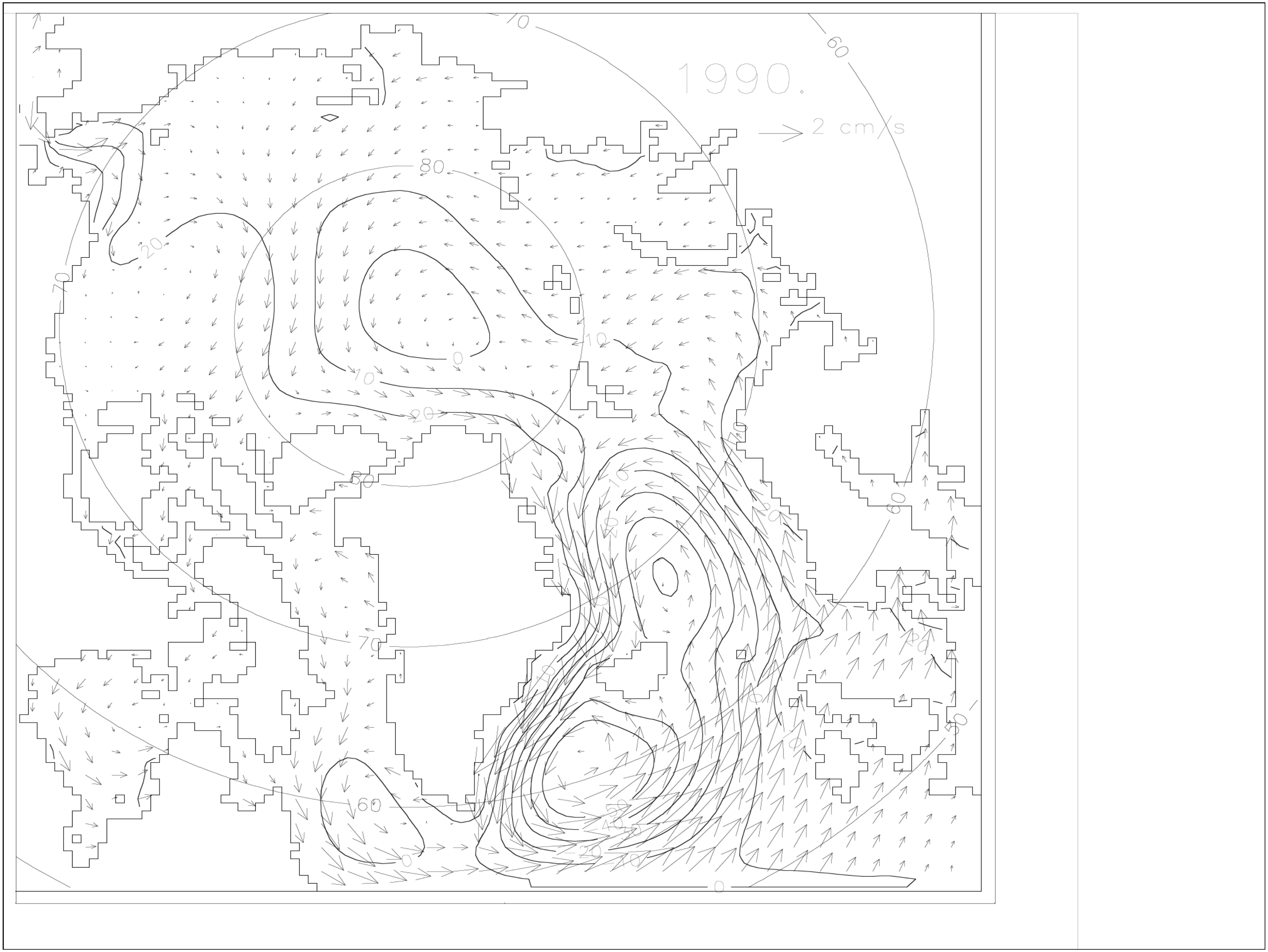
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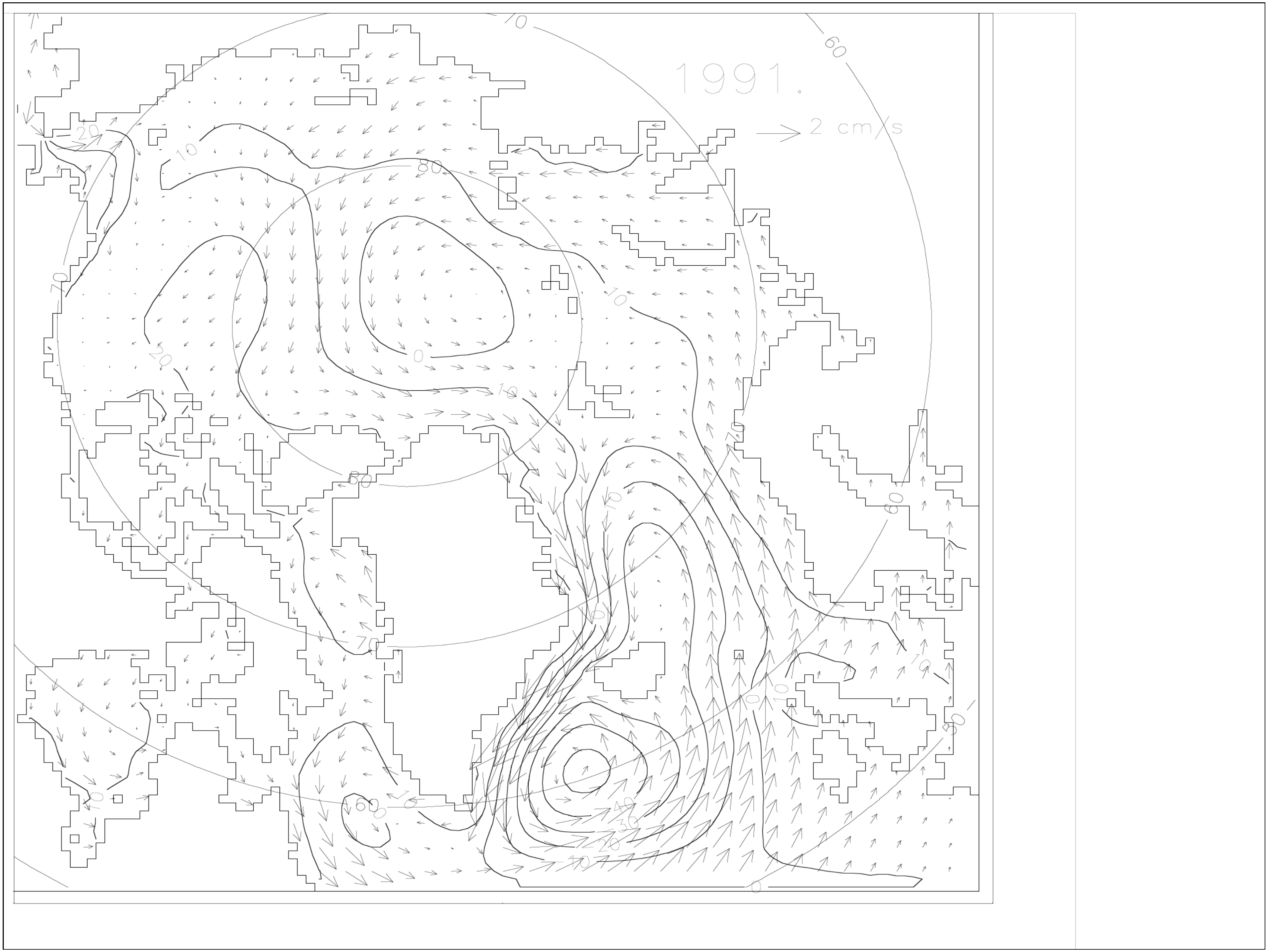
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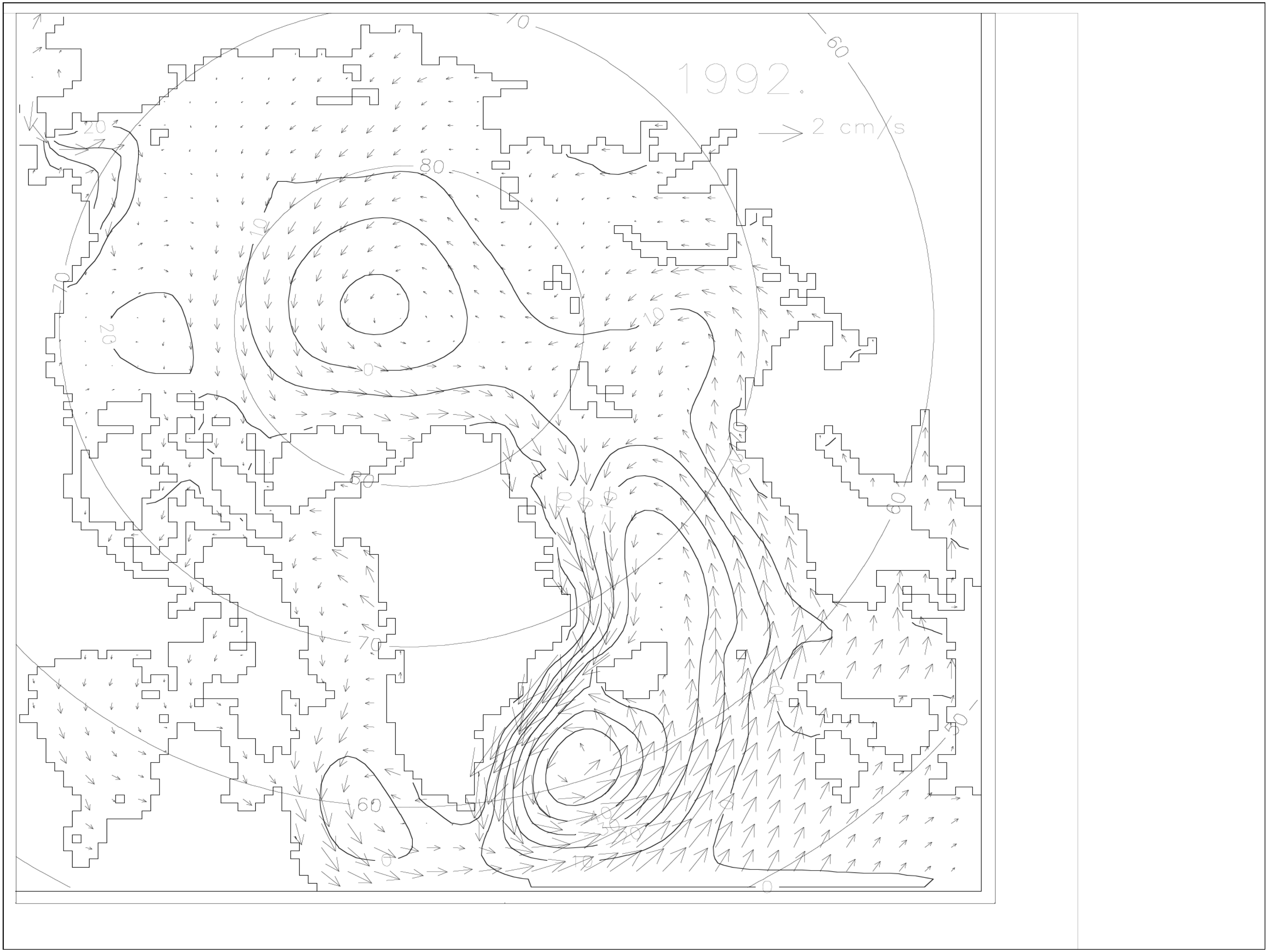
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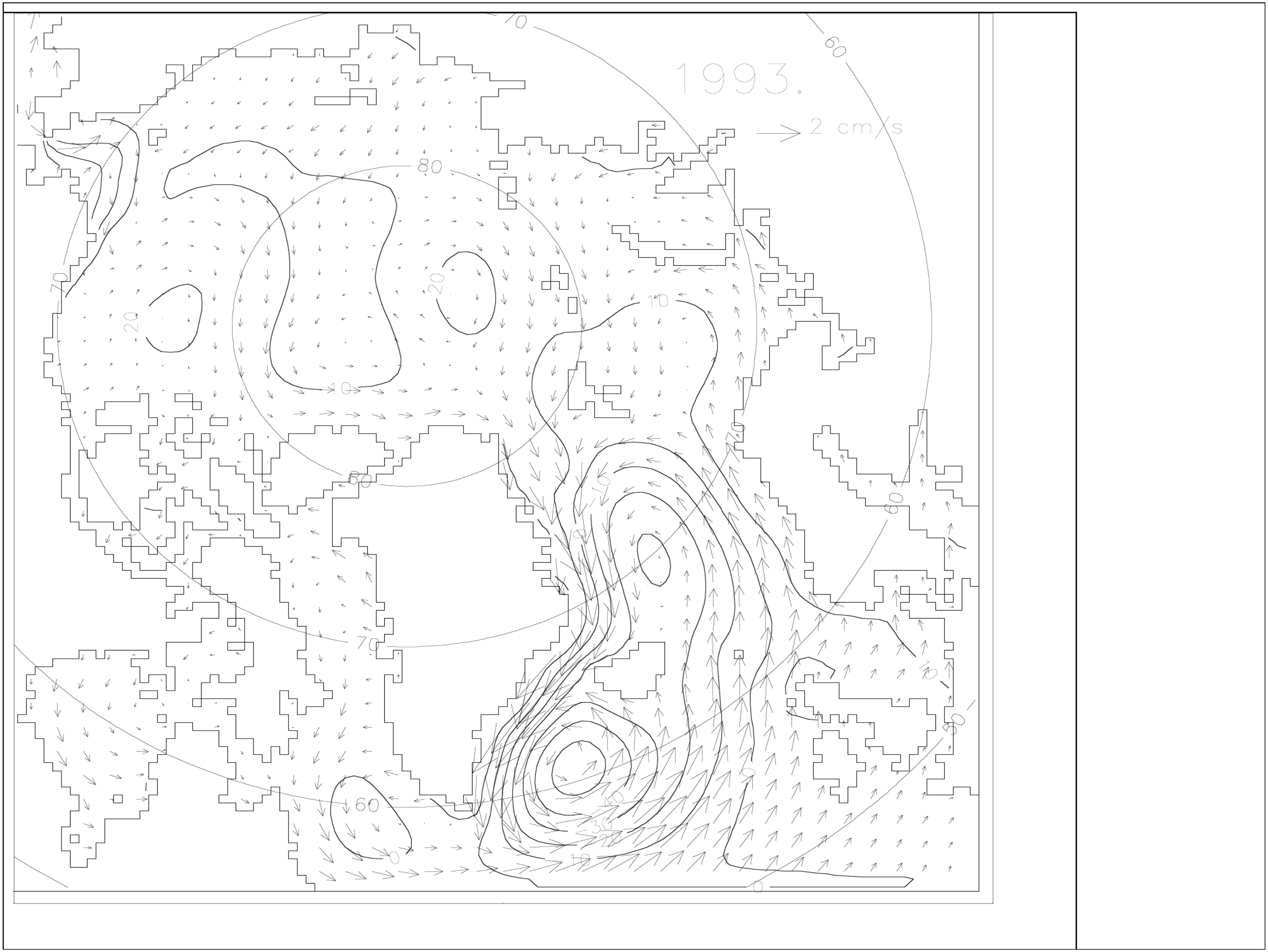
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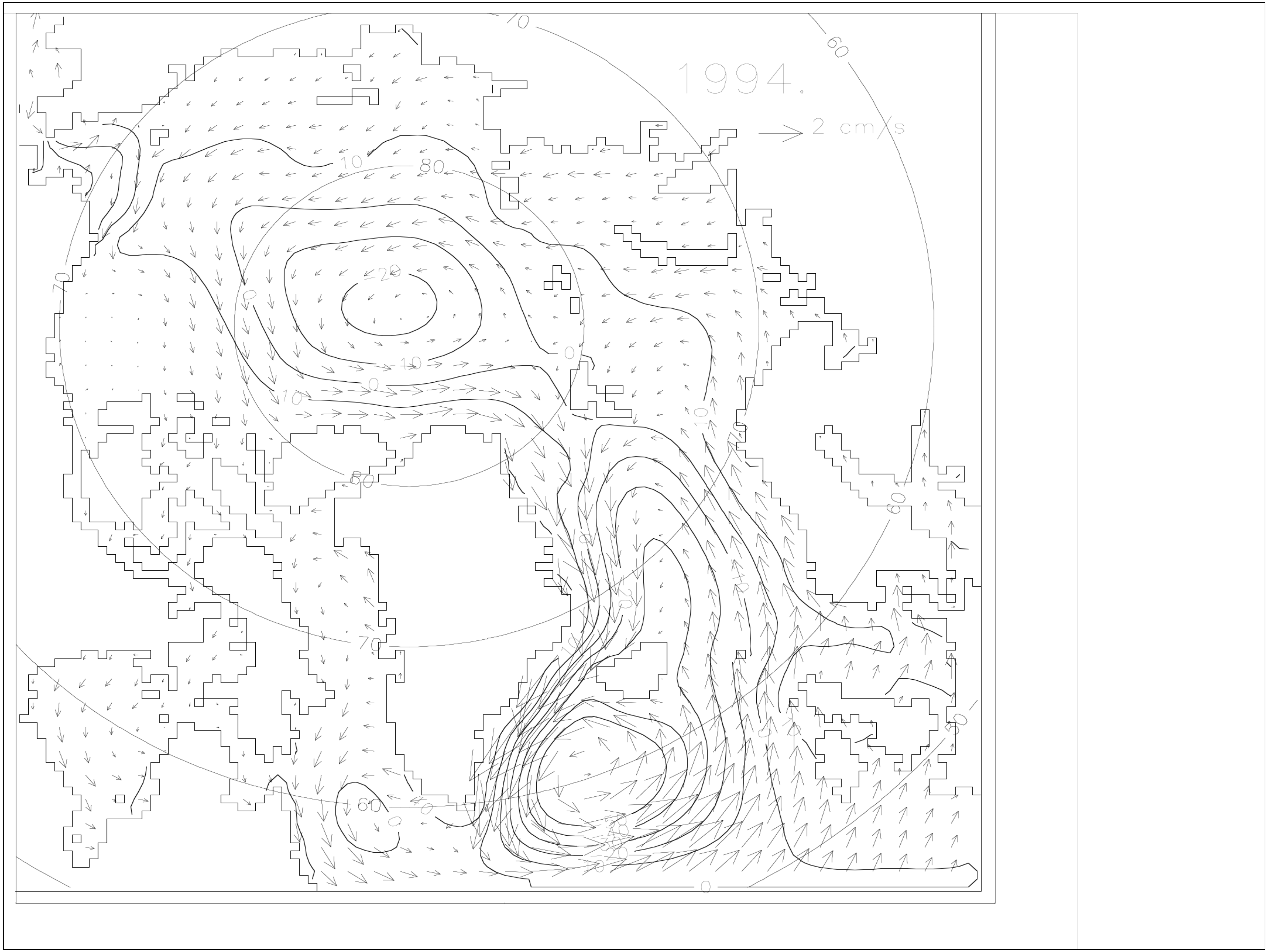
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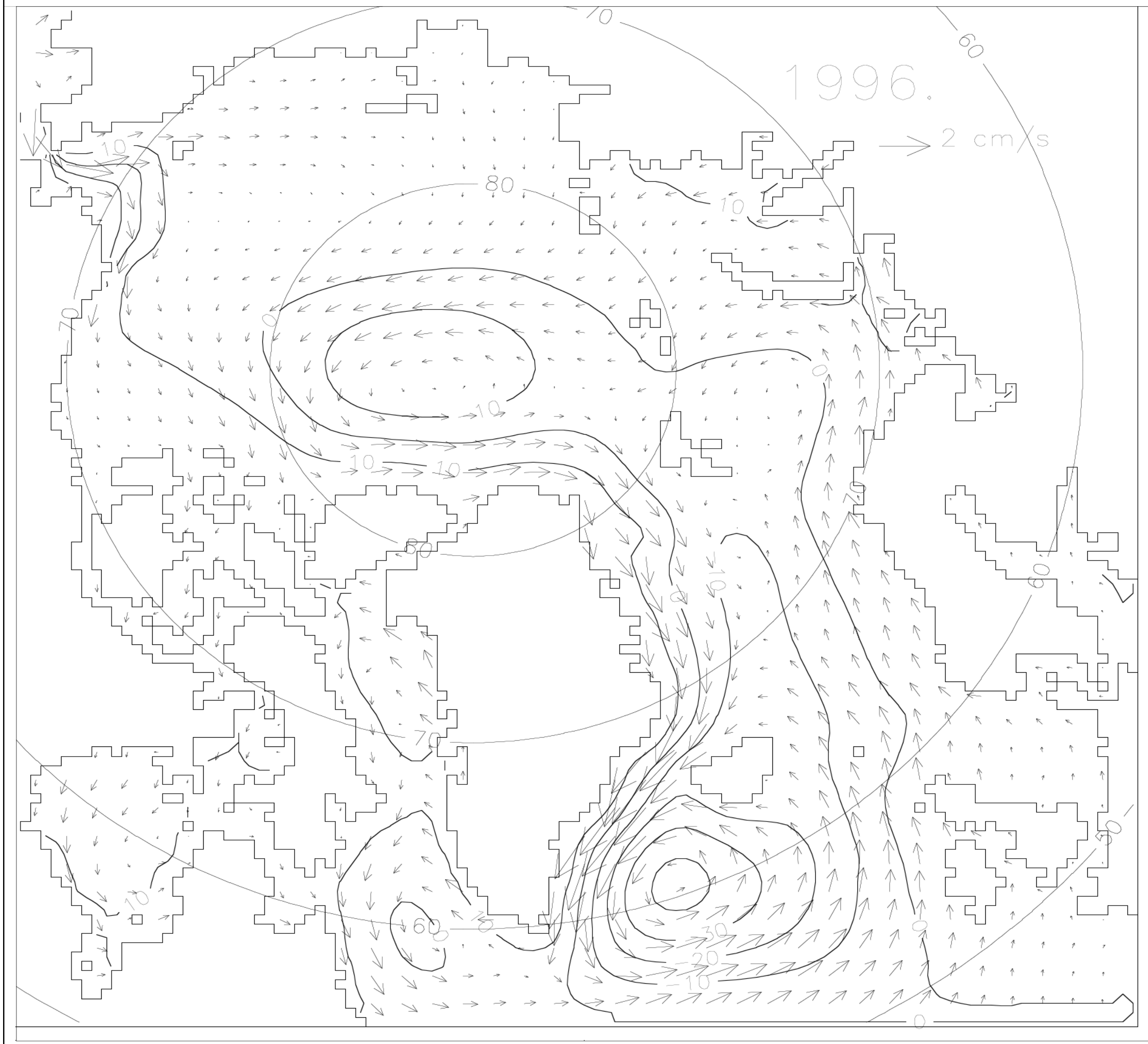
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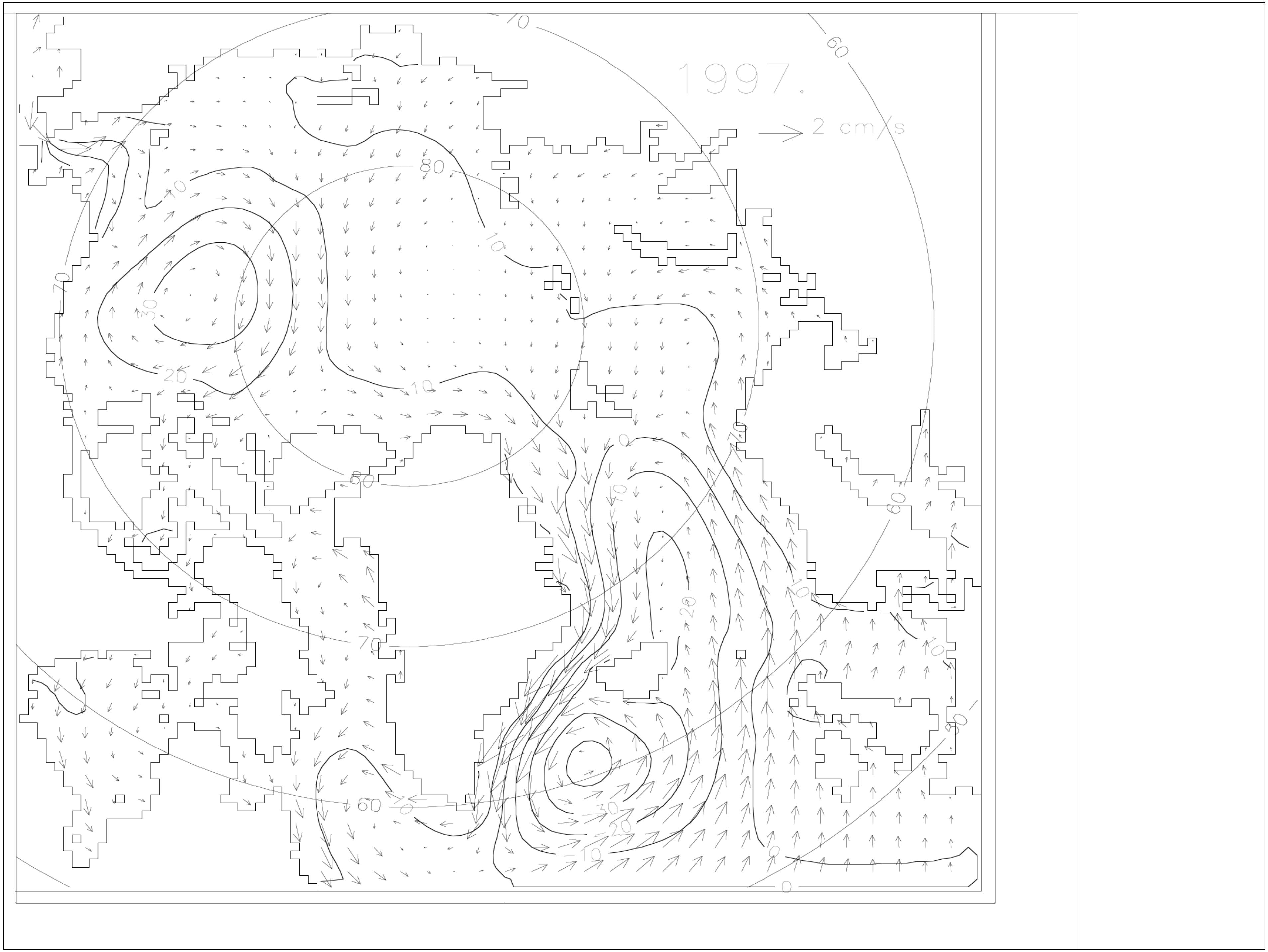
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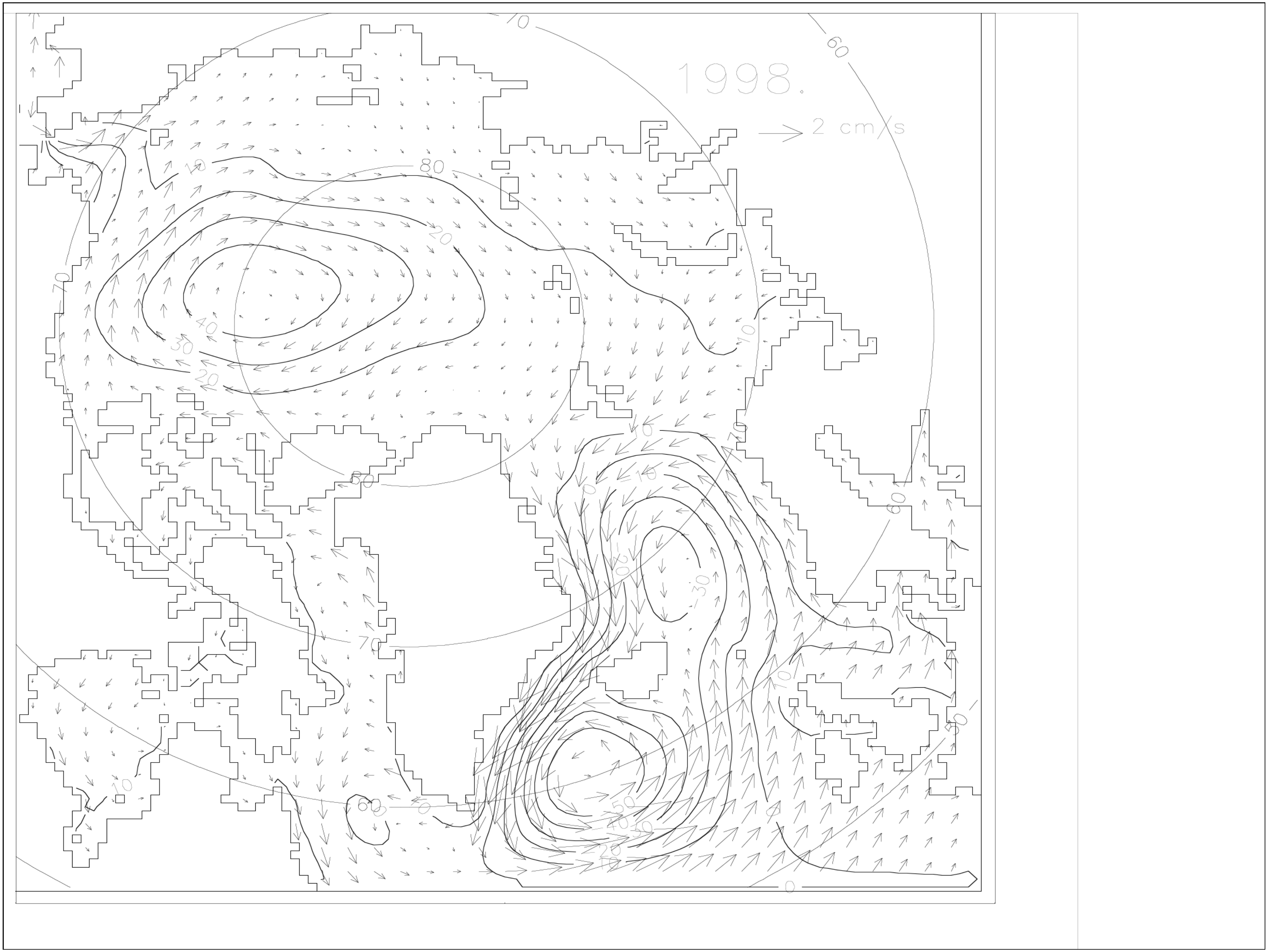
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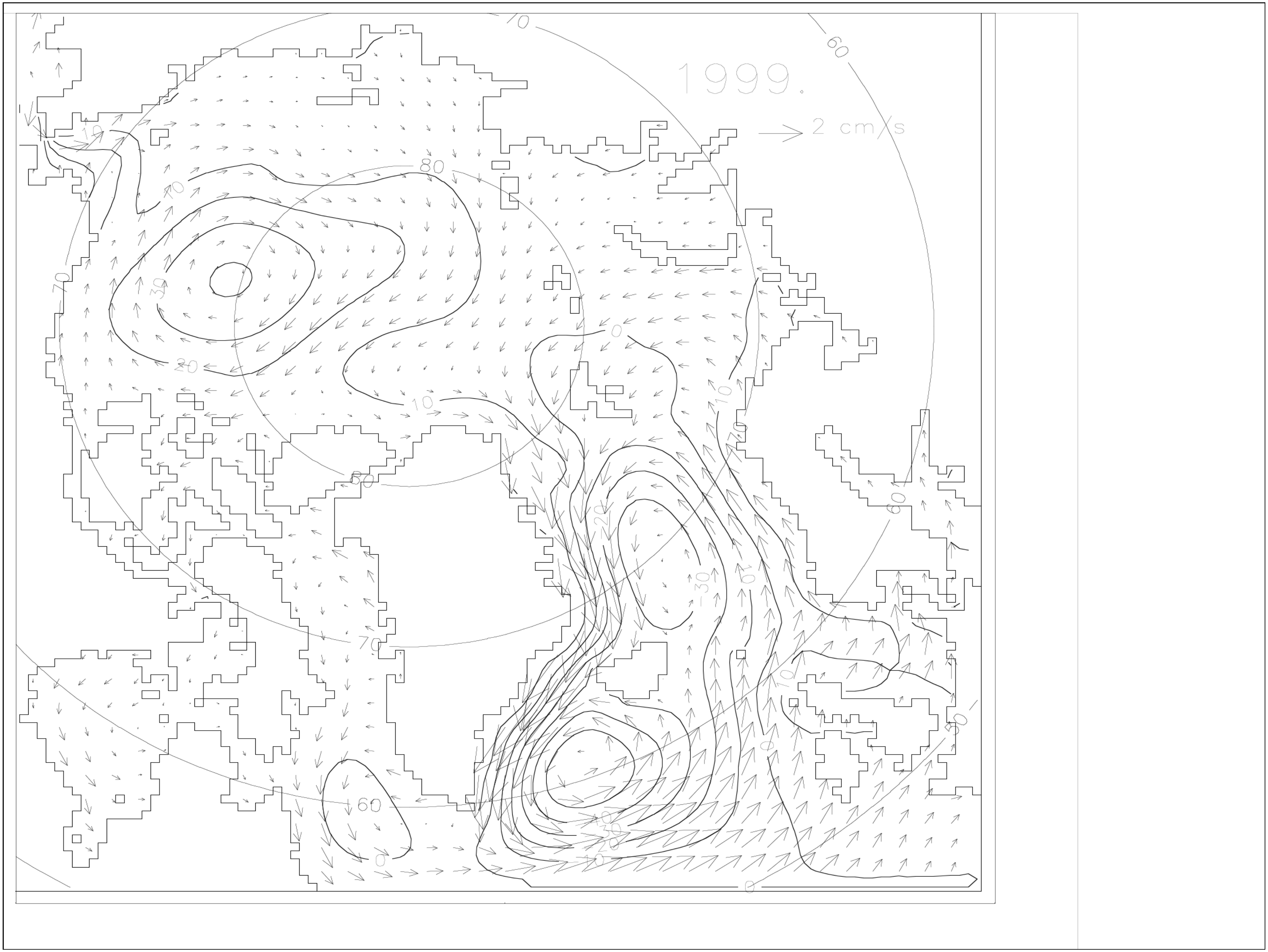
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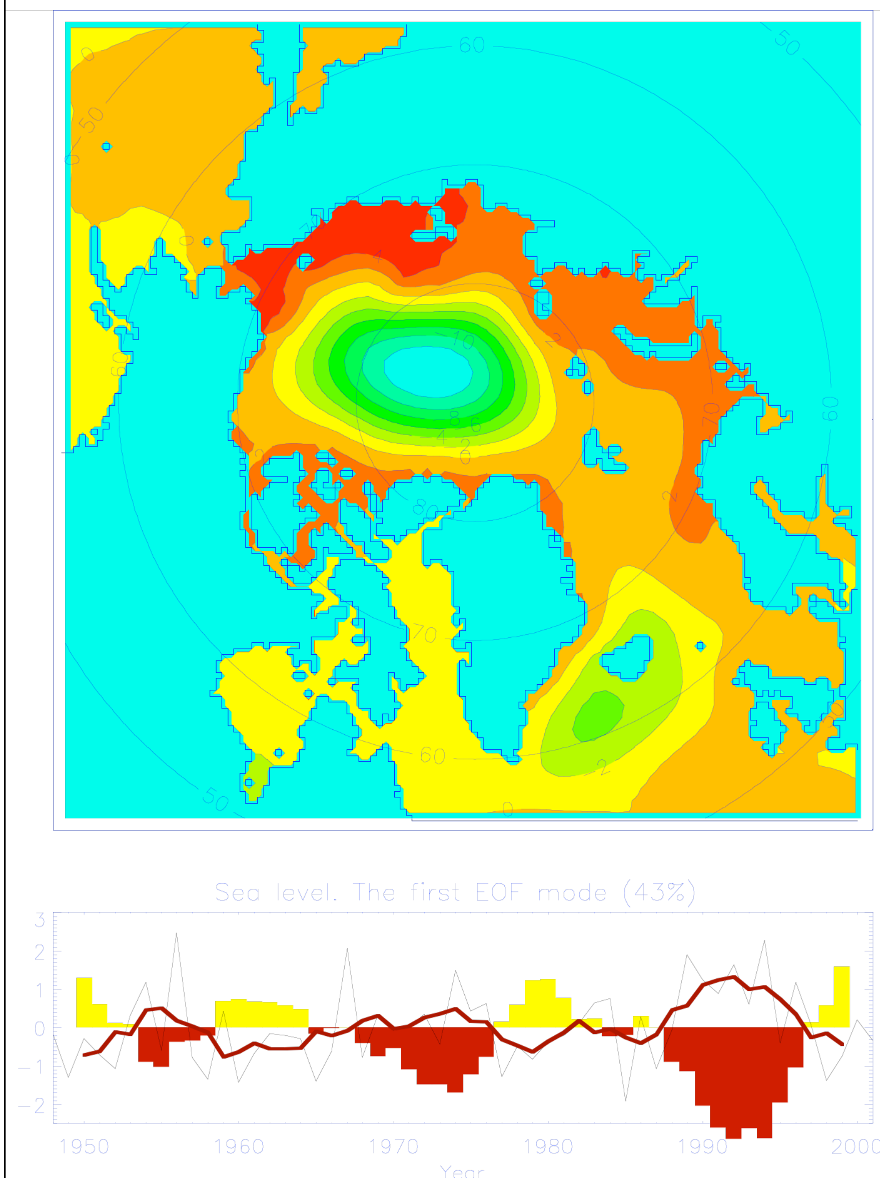
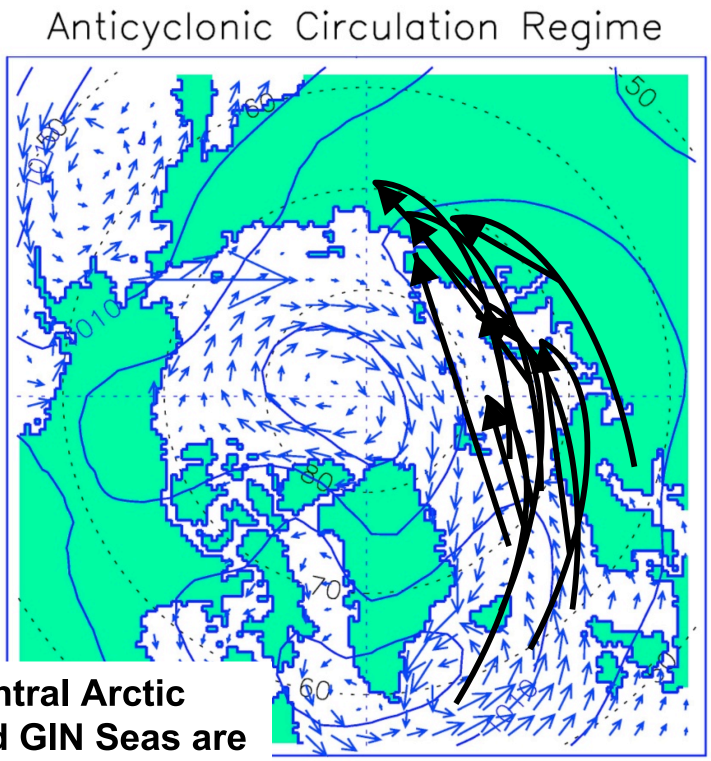


1948-2001 EOF analysis of simulated SSH in the Arctic Ocean. This is the first EOF mode (43%).

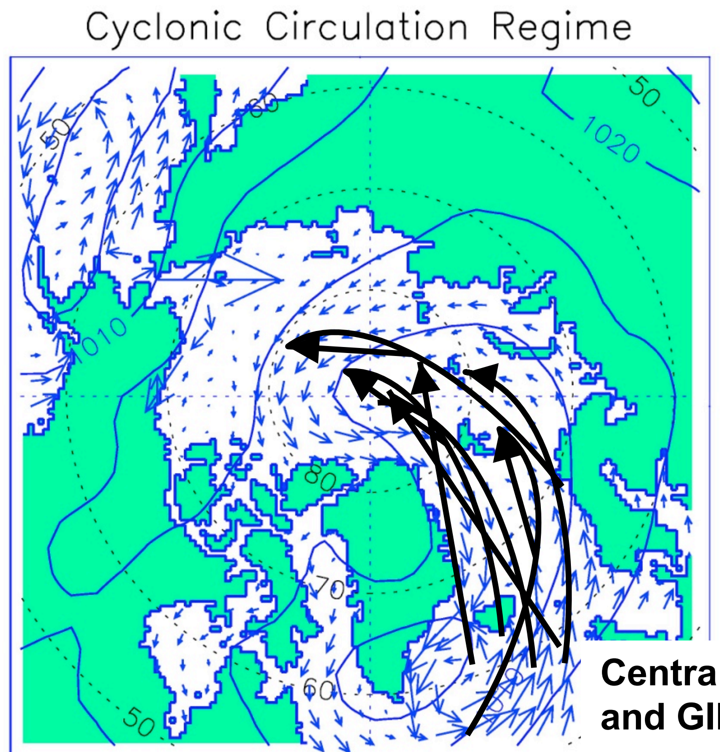
During ACCR (yellow bars and negative EOF coefficients) the sea level increases in the center of the ocean and decreases along coastline.

During CCR (red bars and positive EOFs) the sea level decreases in the center of the ocean and increases along coastlines.

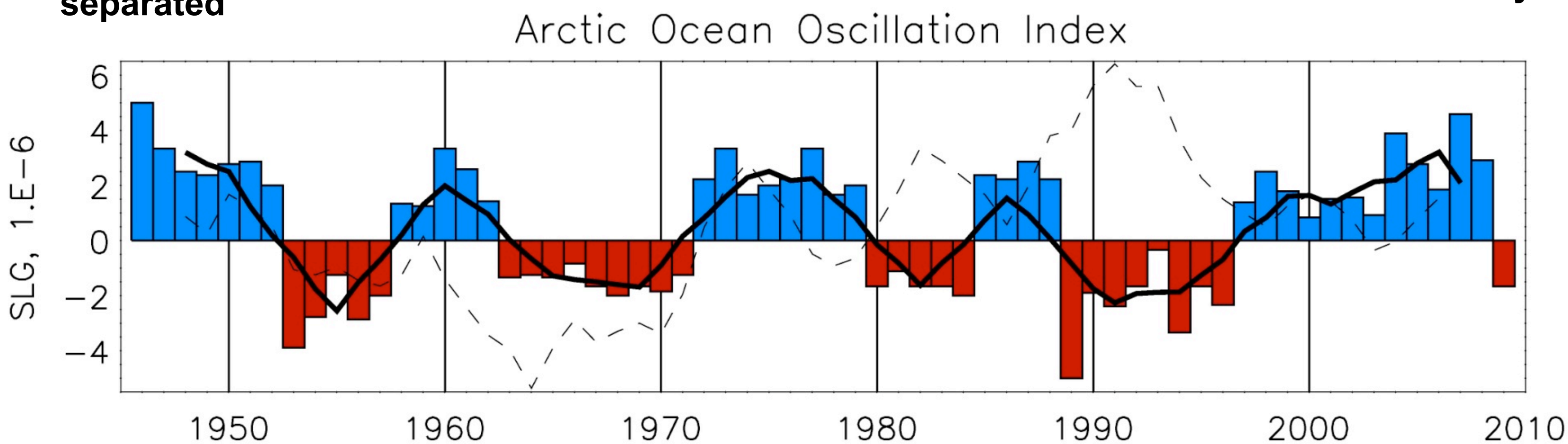
Circulation in the Beaufort Gyre is in phase with the circulation in the Greenland Sea Gyre



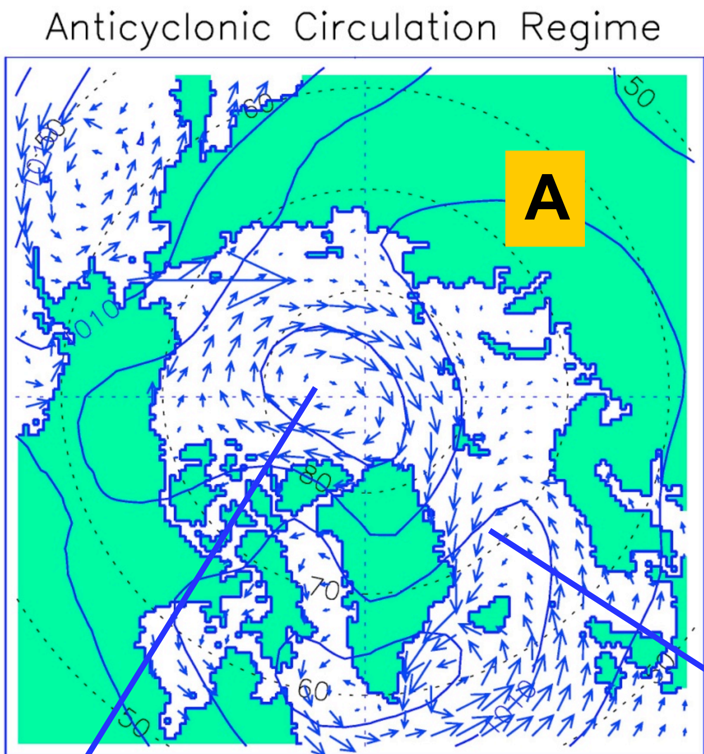
Central Arctic and GIN Seas are separated



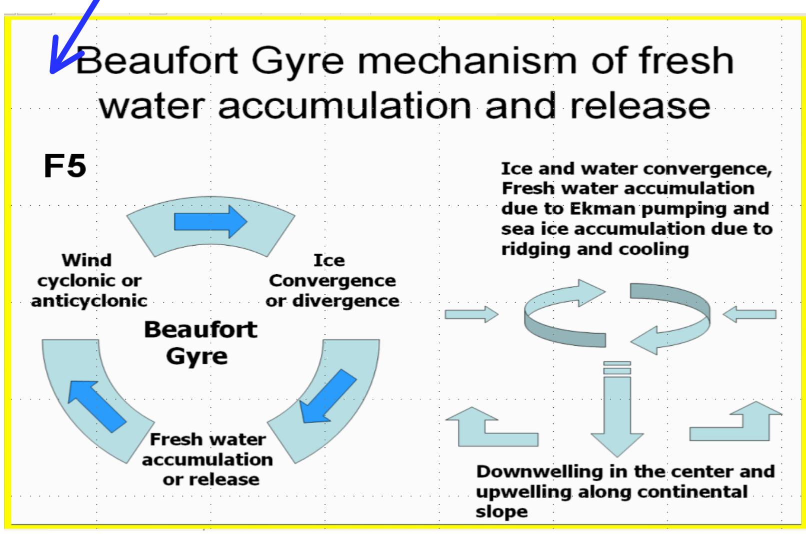
Central Arctic and GIN Seas are one system

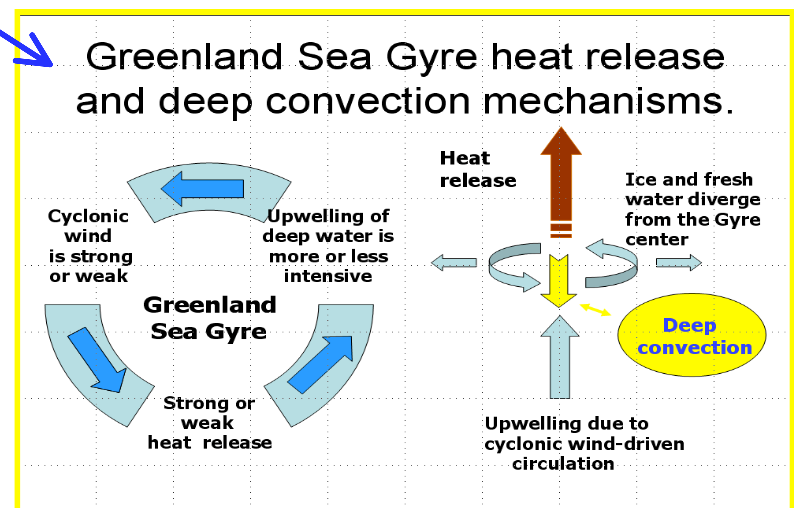


Bars and solid black line – AOO index; dashed – 5-year running mean AO index

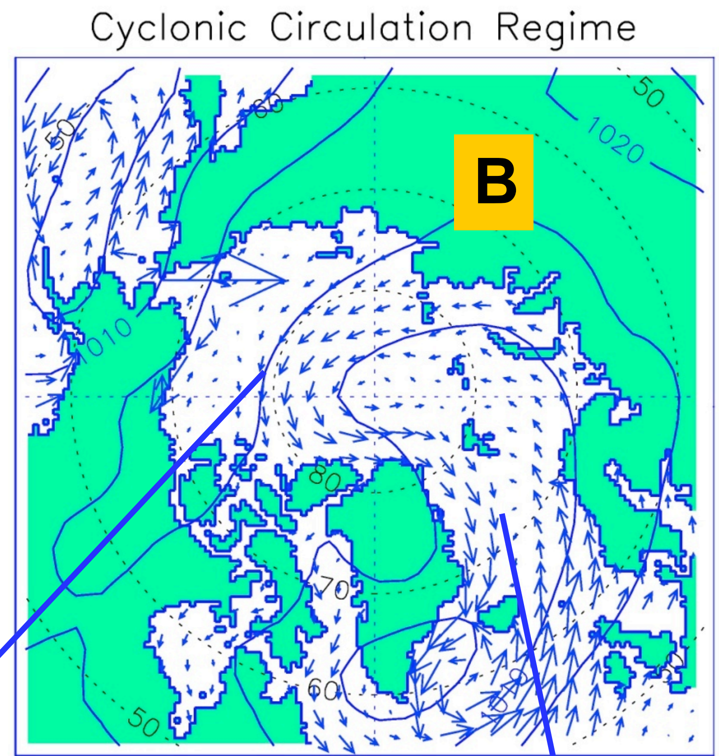


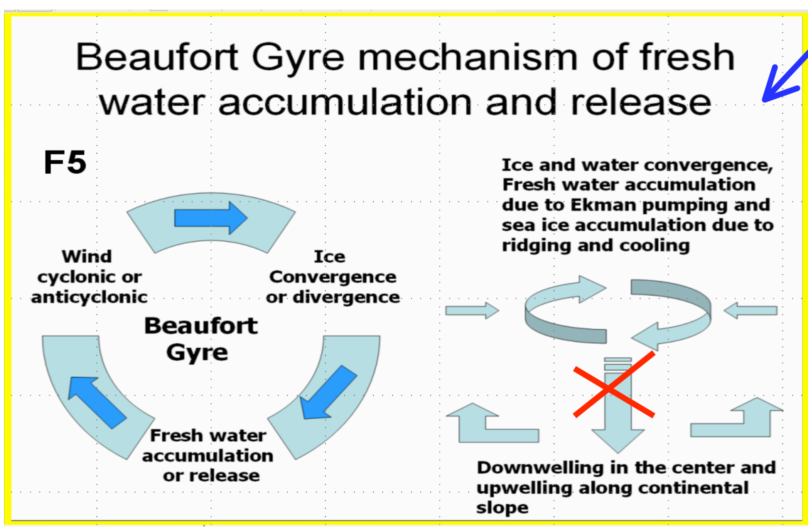
When the ACCR dominates the Arctic, the interaction between the two basins is damped, and strong convection in the central Greenland Sea favors intense heat flux to the atmosphere over the Greenland Sea region. These conditions increase the dynamic height gradient between the two regions that ultimately forces them to interact.

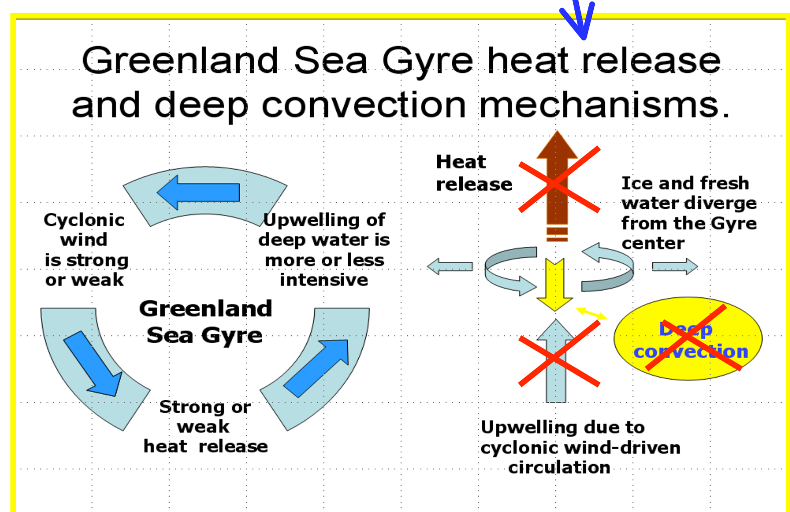


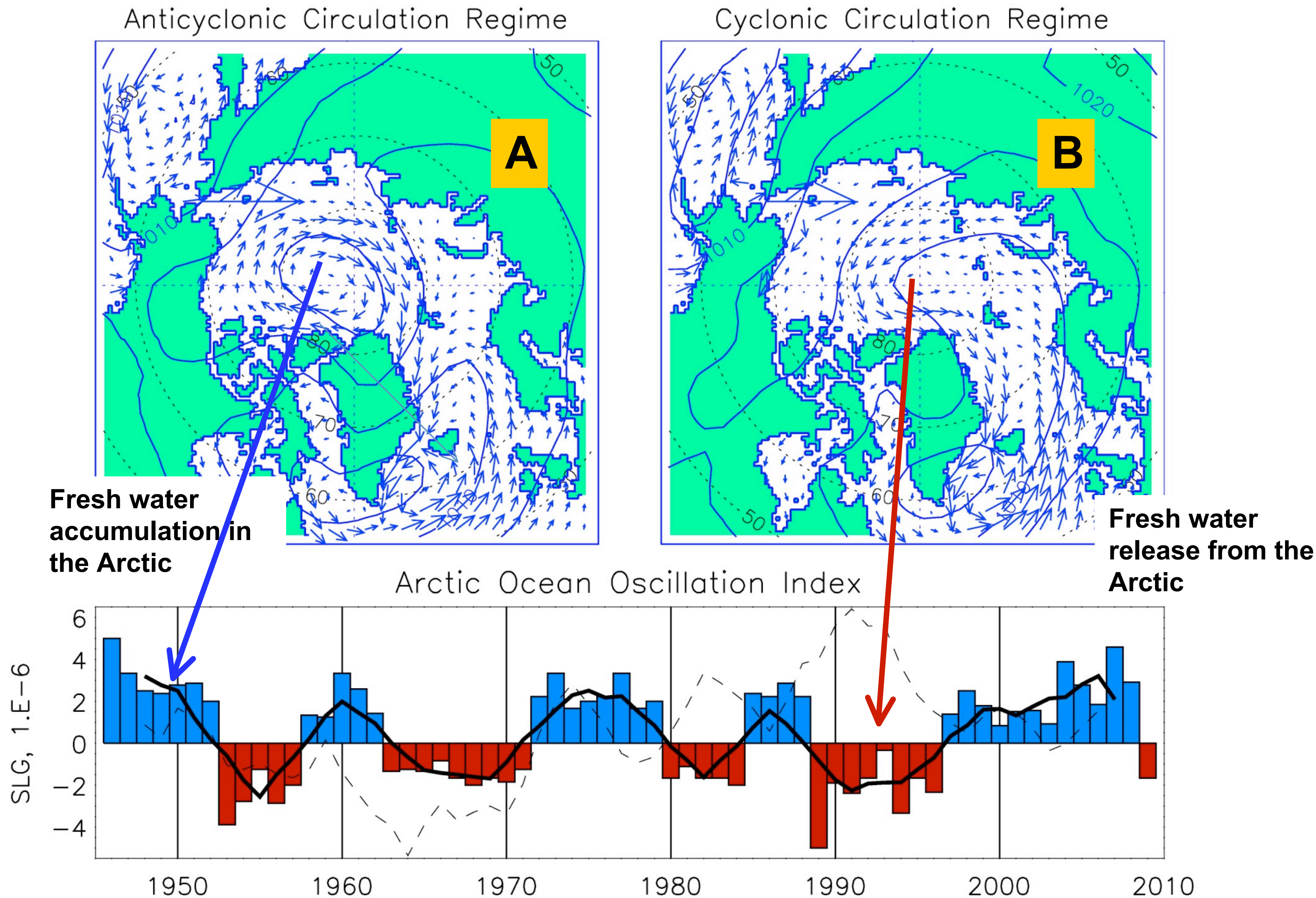


The second state (Cyclonic circulation regime, CCR) is characterized by intense interaction between the basins: the Arctic gains heat advected from the Greenland Sea region and the Greenland Sea receives freshwater released from the Arctic Ocean.



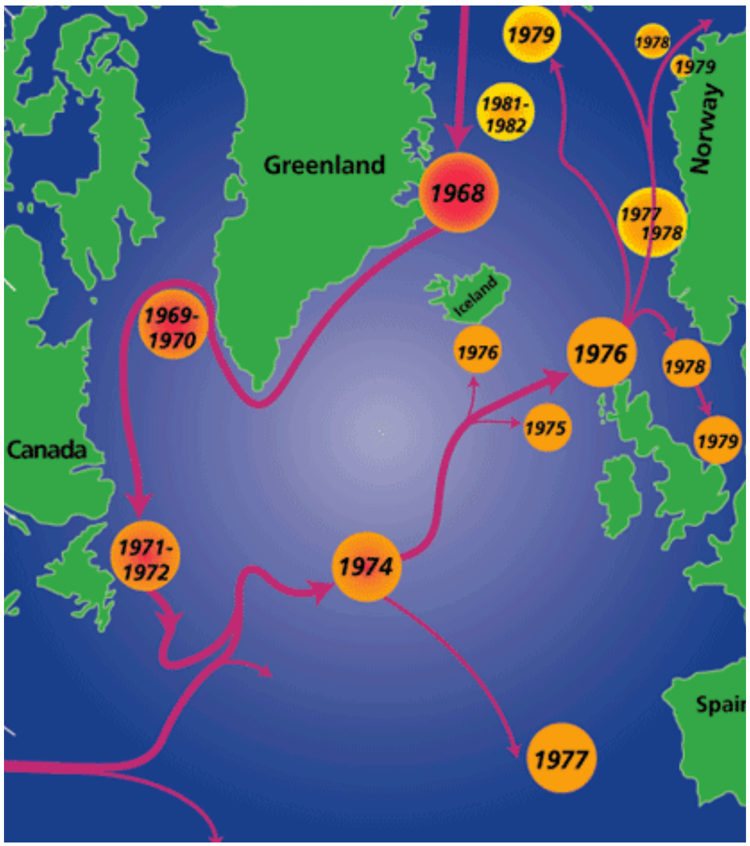






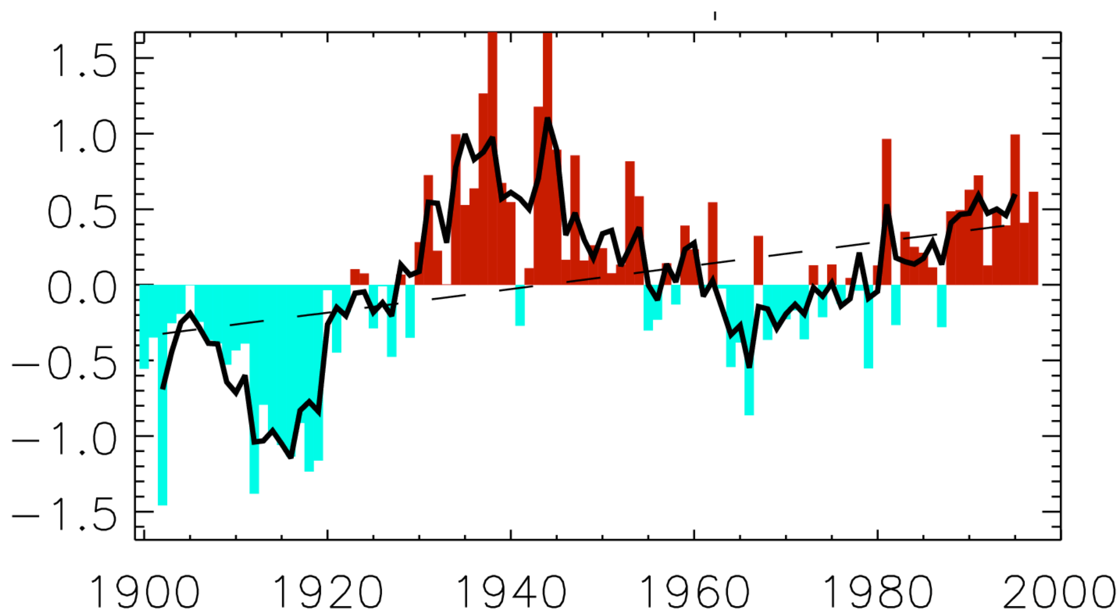
Proshutinsky and Johnson, 1997 (JGR) updated

The Great Salinity Anomaly, a large, near-surface pool of fresher-than-usual water, was tracked as it traveled in the sub-polar gyre currents from 1968 to 1982.

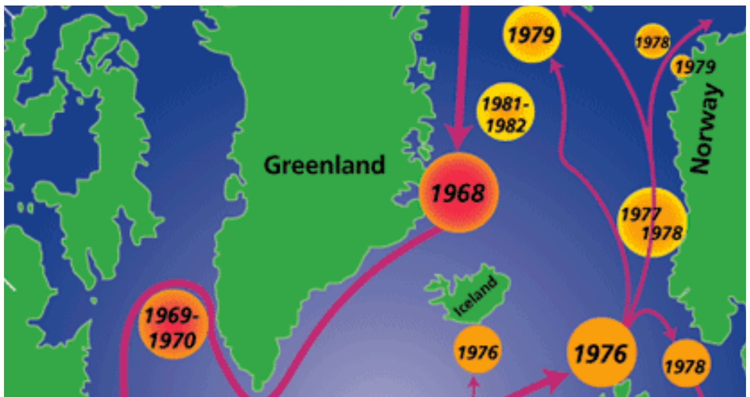


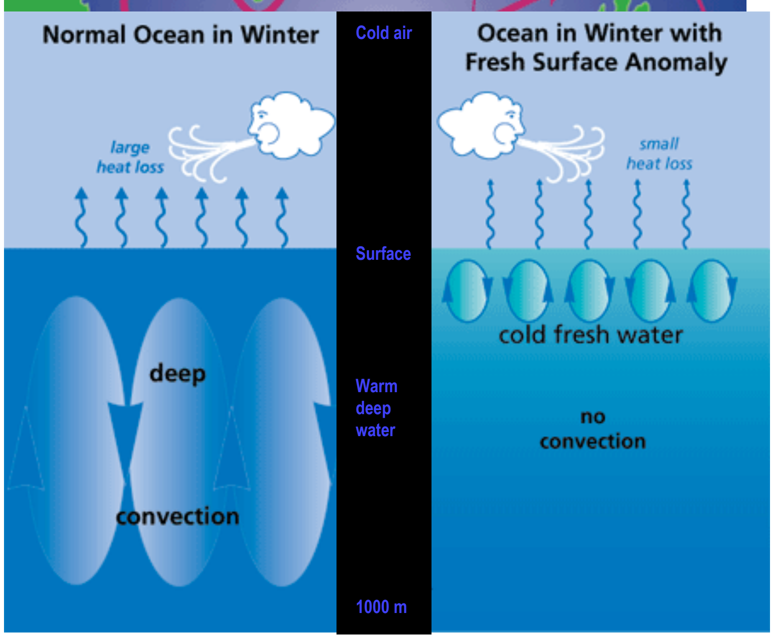
(GSA'70s; Dickson et al., 1988)

Arctic (north of 55N) air temperature anomalies relative to 1961-1990. University East Anglia data archive.

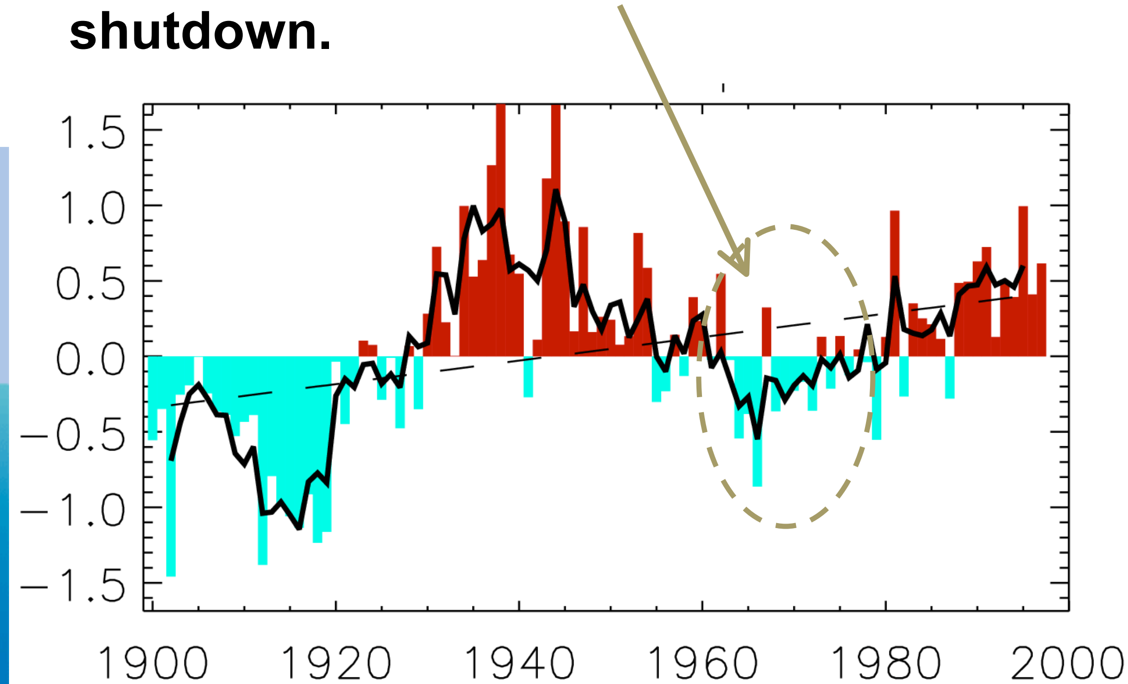


The Great Salinity Anomaly, a large, near-surface pool of fresher-than-usual water, was tracked as it traveled in the sub-polar gyre currents from 1968 to 1982.

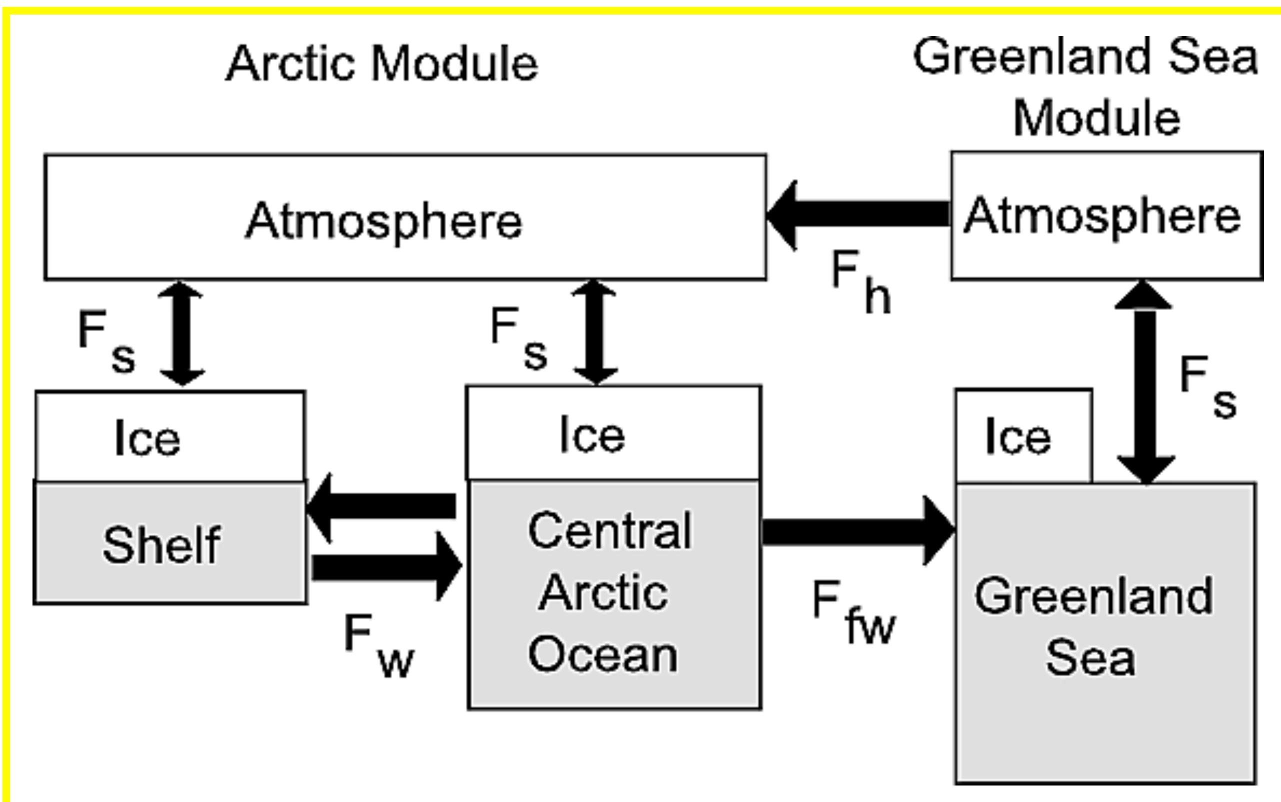




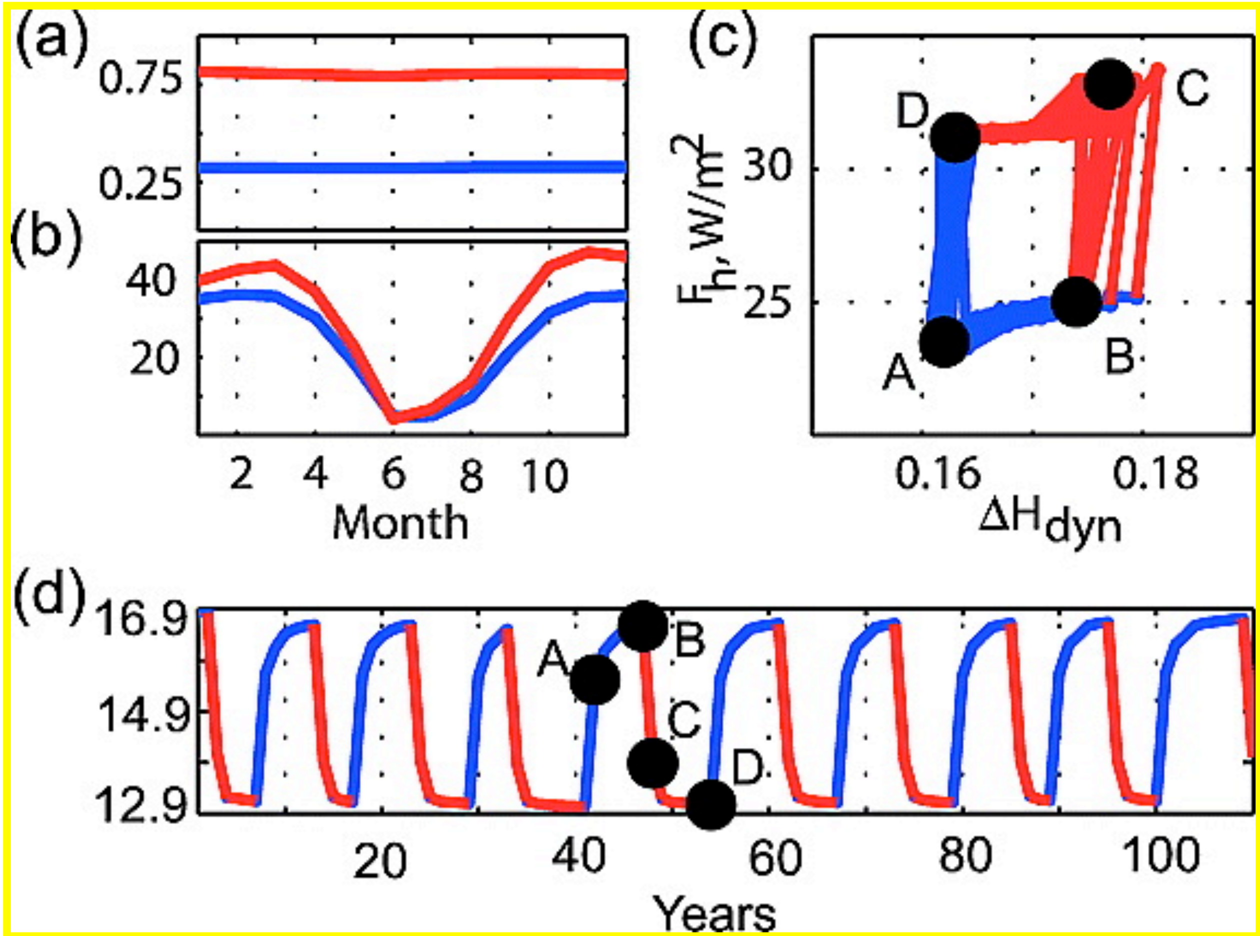
This surface freshening of the North Atlantic coincided very well with Arctic cooling of the 1970s. At this time warm cyclone trajectories were shifted south and heat advection to the Arctic by atmosphere was shutdown.



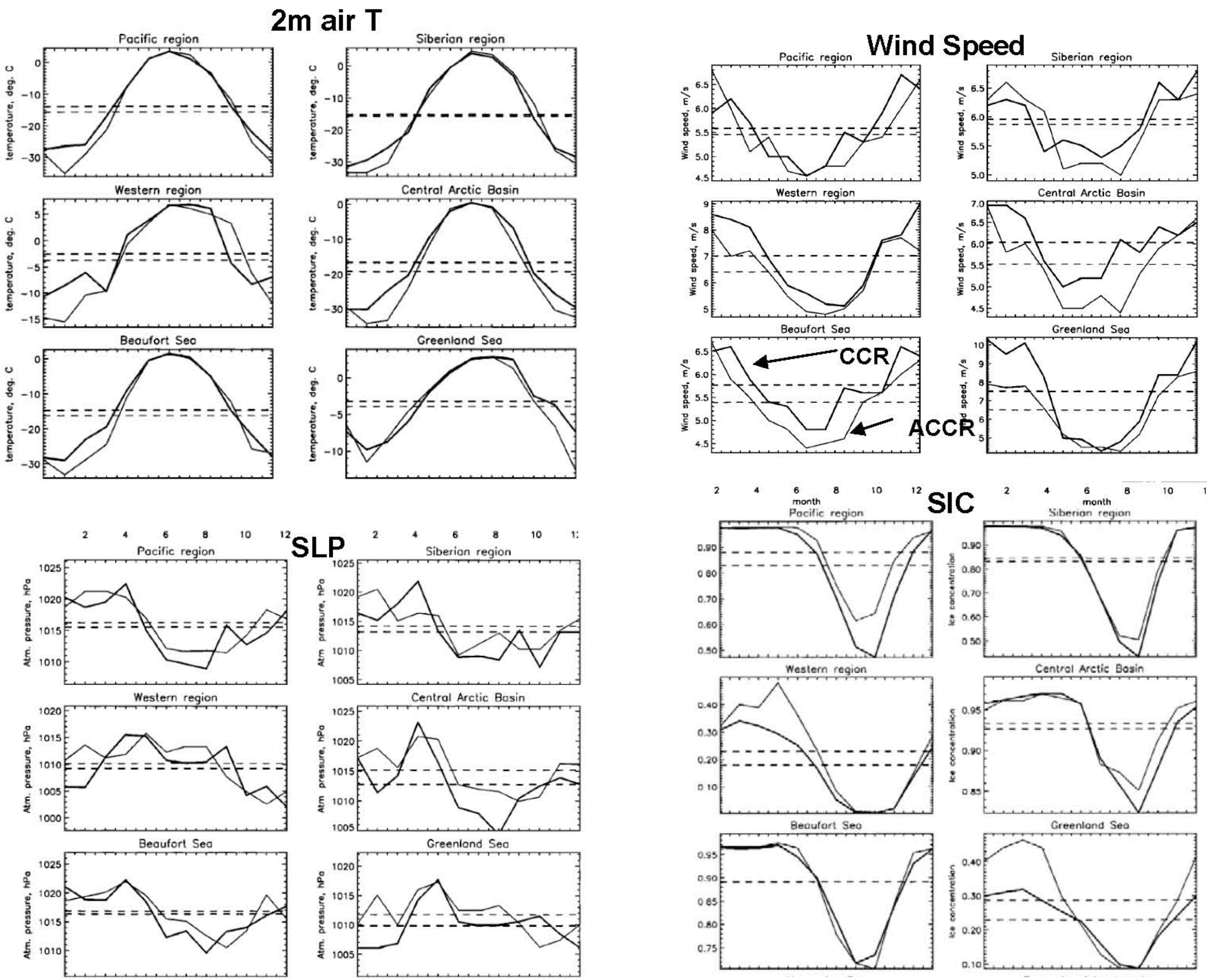
We hypothesize that Arctic climate variability is regulated by heat and freshwater exchange between the Arctic Ocean and the Greenland, Norwegian and Irminger Seas (GIN seas). The interaction between basins is weak during anticyclonic and strong during cyclonic circulation regimes. Regime shifts are controlled by the system itself through oceanic and atmospheric gradients that increase during the anticyclonic regime and decrease during the cyclonic regime. This conceptual mechanism for Arctic decadal variability has been reproduced in a simple box model experiment.



Schematic of the Arctic Ocean–Greenland Sea model system. Fs is surface heat flux, Fw is water exchange between the Arctic Ocean model and Arctic shelf box model, Ffw is the freshwater flux to the Greenland Sea model, Fh is heat flux to the Arctic



F14: (a) Monthly outflow (Sv) from the upper 100 m of the Arctic Ocean during the weak interaction phase (blue) and strong interaction phase (red). (b) Similar to (a) but for the heat flux (W/m2). (c) Heat flux vs. gradient of dynamic height (ΔHdyn) for 110 years of simulated behavior. (d) Annually averaged surface air temperature difference (ΔT) between the Arctic and GIN Sea for 110 years. Bullets denote system states shown on (c). On (c) and (d), red segments denote cyclonic years, blue anticyclonic years. Different climate states are reproduced in the model by different rates of Ffw and Fh (F14a and F14b).


2m air T
Pacific region
Siberian region
Western region
Central Arctic Basin
Beaufort Sea
Greenland Sea
temperature, deg. C
Wind Speed
Pacific region
Siberian region
Western region
Central Arctic Basin
Beaufort Sea
Greenland Sea
Wind speed, m/s
CCR
ACCR
month
SLP
Pacific region
Siberian region
Western region
Central Arctic Basin
Beaufort Sea
Greenland Sea
Atm. pressure, hPa
SIC
Pacific region
Siberian region
Western region
Central Arctic Basin
Beaufort Sea
Greenland Sea
Ice concentration

Motivation for coordinated idealized FW and circulation experiments

- Theory, observations and model results allow us to conclude that both thermohaline and wind-driven forcing are important to the Arctic Ocean's dynamics and thermodynamics (hydrography and circulation).

- But unfortunately, the role of individual factors in the circulation and hydrographic fields cannot be easily evaluated because observed temperature and salinity distributions reflect the combined effects of wind, baroclinicity, and topographic interaction. We also know that there is insufficient observational information for clearly separating the roles of atmospheric and thermohaline forcing in the Arctic Ocean.

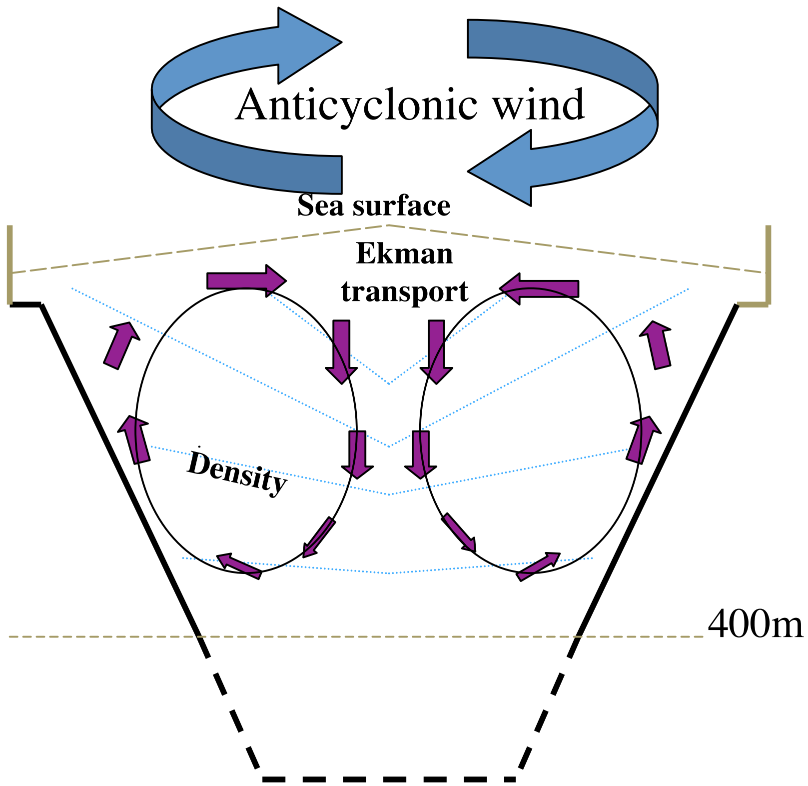
- Through numerical modeling, however, the relative strengths of the circulations and major features of hydrographic fields arising from atmospheric driving and thermohaline driving can be assessed and compared

Goals for idealized experiments

- Separate different factors to understand their roles in the Arctic Ocean and sea ice dynamics and thermodynamics

- Understand model's work better and improve models: *Compare model results and understand sources of differences*

Mechanical: Ekman pumping



Fresh water PUMP-I

Major idea is to investigate the role of wind forcing in the processes of freshwater, circulation and hydrography

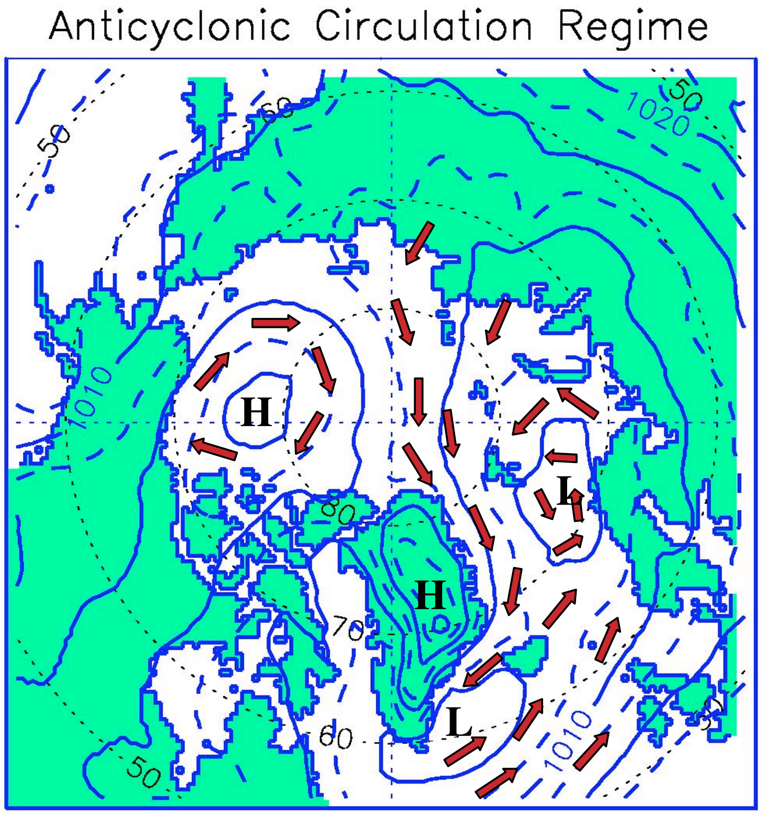
Conditions: ocean is a closed domain without fluxes via ocean boundaries, no river runoff, precipitation and evaporation. There is no sea ice and only wind is a driving force

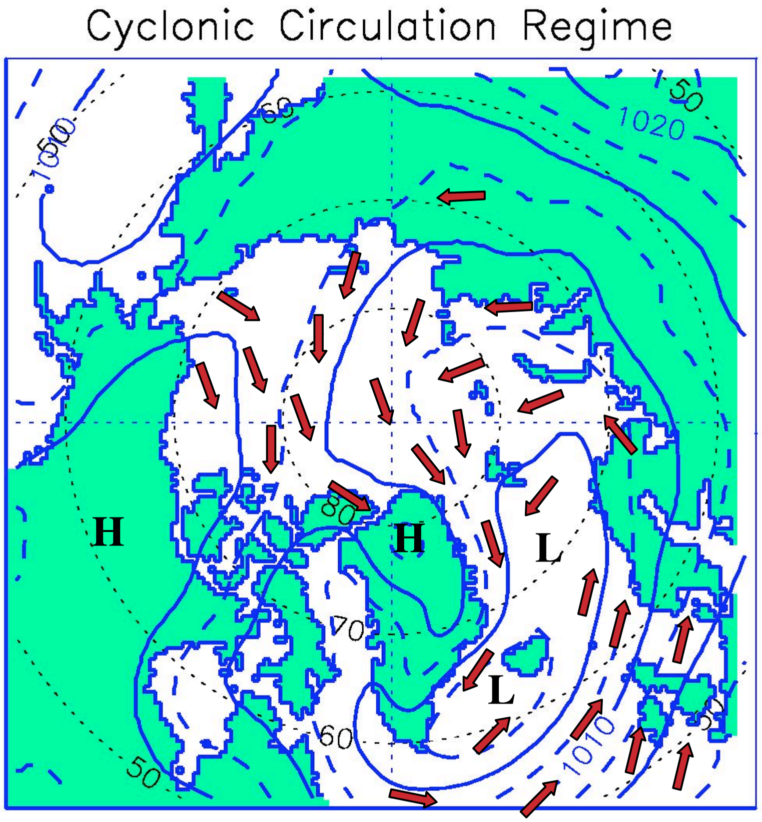
Initial conditions: horizontally uniform water temperature and salinity fields with a vertical stratification corresponding to mean parameters corresponding to a) upper mixed layer, b) Pacific water layer, c) Atlantic water layer and d) deep waters.

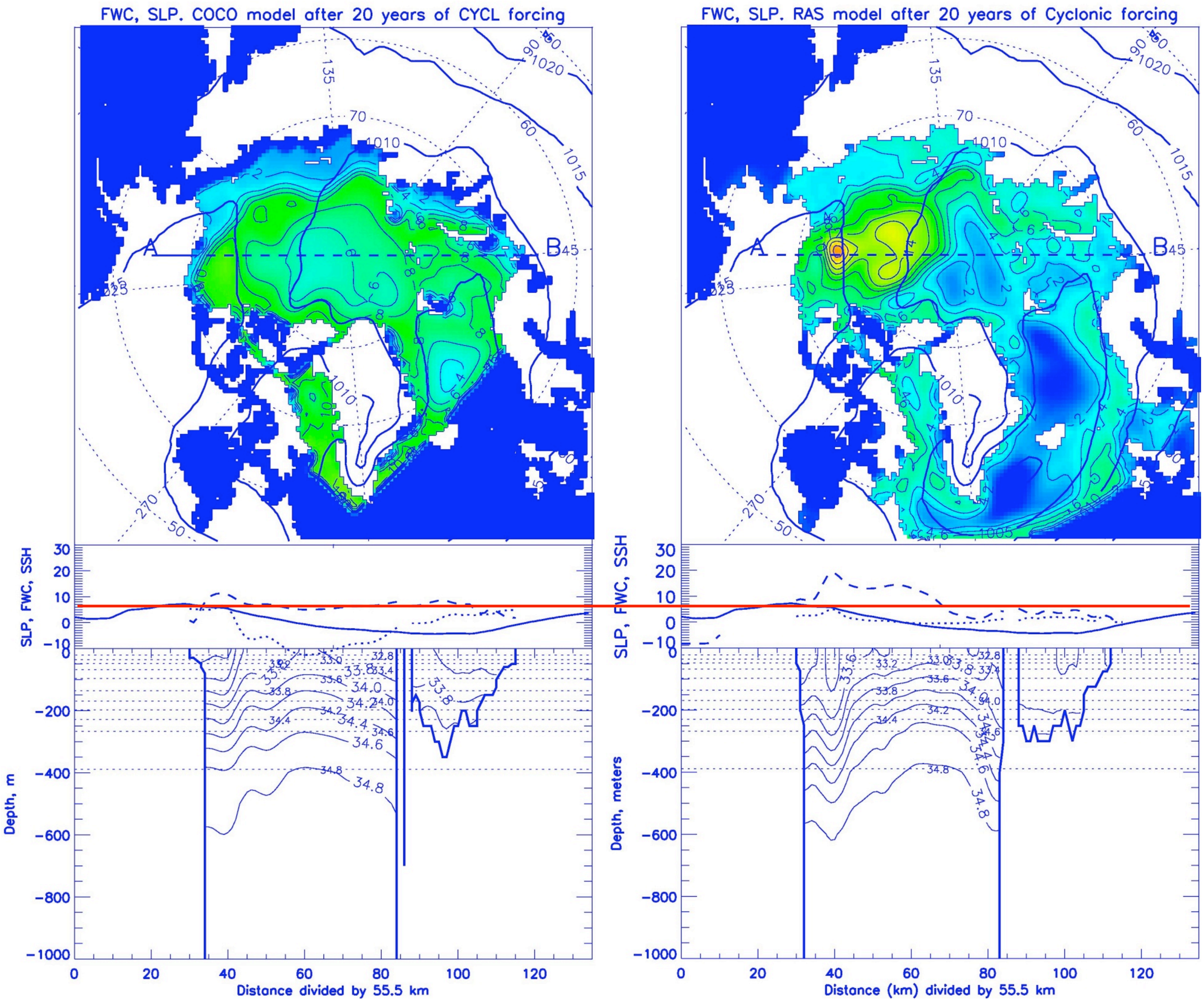
Forcing: Annual wind stresses calculated based on annual SLPs for a) 1989 and b) 2007 (AOMIP recommended algorithm)

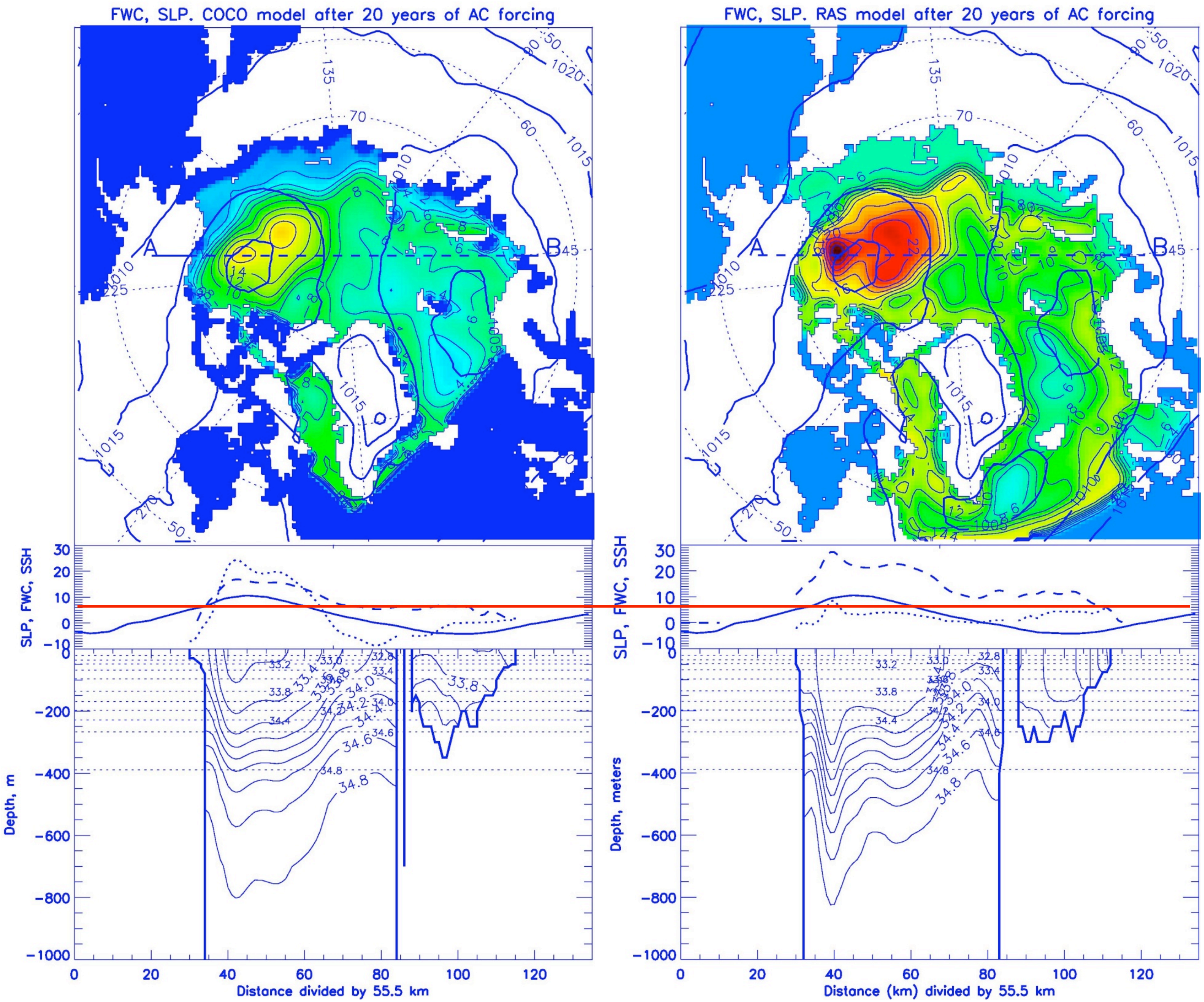
Forcing Regimes

Left – Anti-cyclonic; Right - Cyclonic






FWC, SLP. COCO model after 20 years of CYCL forcing
FWC, SLP. RAS model after 20 years of Cyclonic forcing
A
B
SLP, FWC, SSH
Depth, m
Depth, meters
Distance divided by 55.5 km
Distance (km) divided by 55.5 km

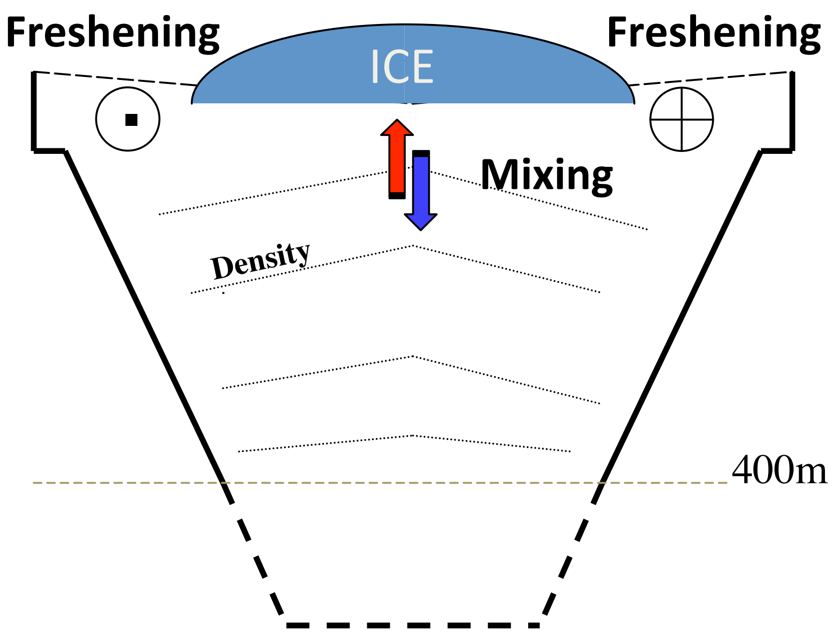


FWC, SLP. COCO model after 20 years of AC forcing
FWC, SLP. RAS model after 20 years of AC forcing
A
B
SLP, FWC, SSH
Depth, m
Depth, meters
Distance divided by 55.5 km
Distance (km) divided by 55.5 km

Thermodynamic: Cooling/warming

Cooling, ice formation

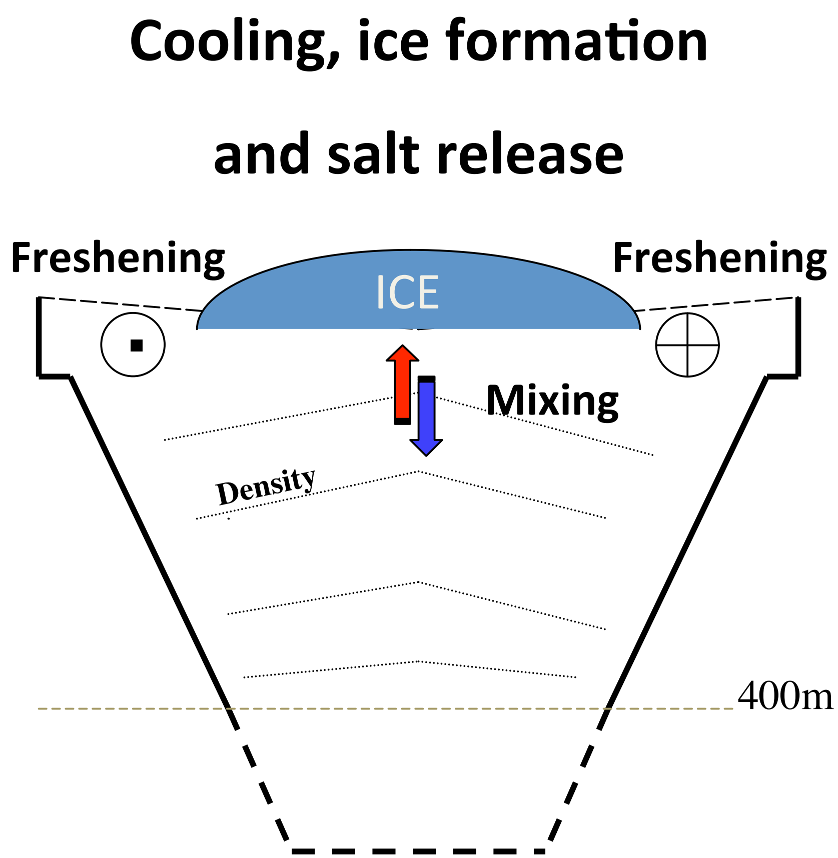
and salt release



Thermo-FW pump

Non-uniform seasonally and interannually changing Arctic cooling and warming accompanied by ice formation and melting results in the formation of horizontal water density and sea surface gradients and system of currents. Fresh water transformations due to this processes can be named “thermo-FW-pump”

Thermodynamic: Cooling/warming



Thermo-FW pump

Conditions: ocean is a closed domain without fluxes via ocean boundaries, no river runoff, precipitation and evaporation. There is no wind. Clouds are annual mean, and wind speed for calculation of heat fluxes is 5 m/s. Humidity is annual mean.

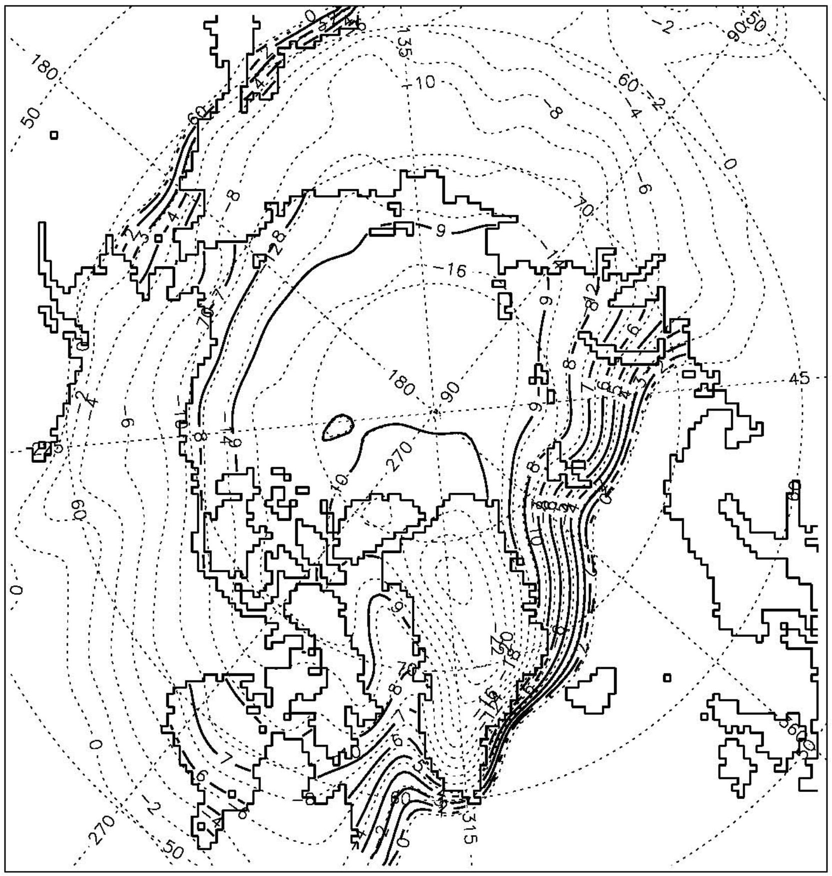
Initial conditions: horizontally uniform water temperature and salinity fields with a vertical stratification corresponding to mean: a) upper mixed layer, Pacific waters, Atlantic water layer and deep waters.

Forcing: Monthly air temperatures for a) 1989 and b) 2007 conditions

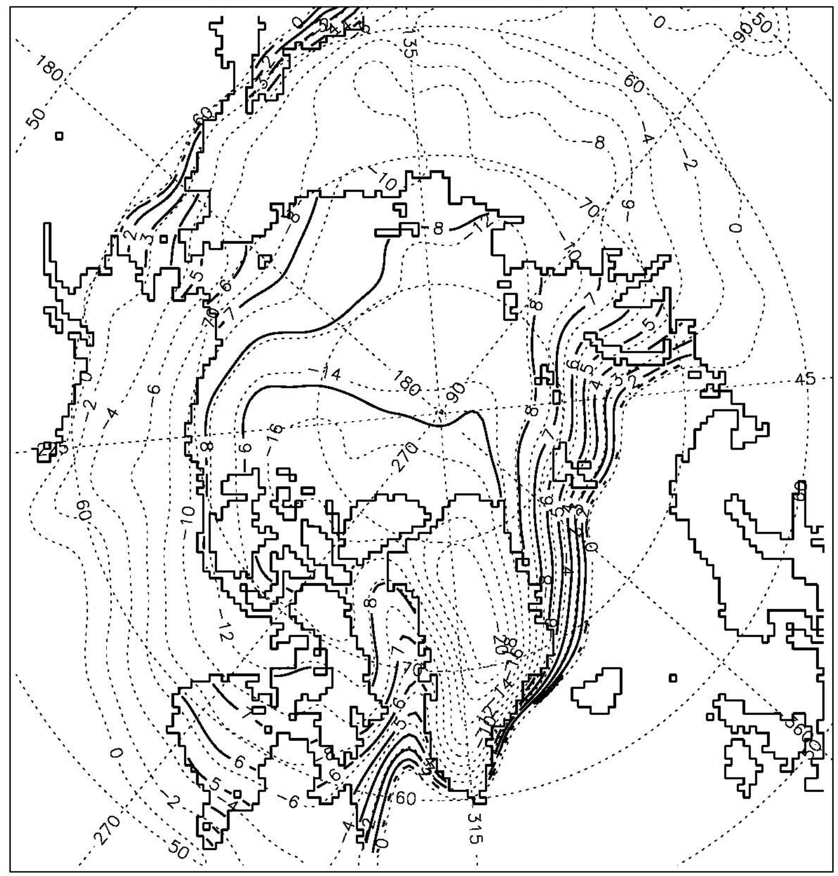
Expected ice thickness after 20 years

Zubov's model for calculation of ice thickness based on sum of freezing degree days: $I*I+50*I=8R$ where I is the ice thickness (cm) and R is the number of freezing degree-days. Solid lines – ice thickness (meters) and dotted lines – annual mean air temperature

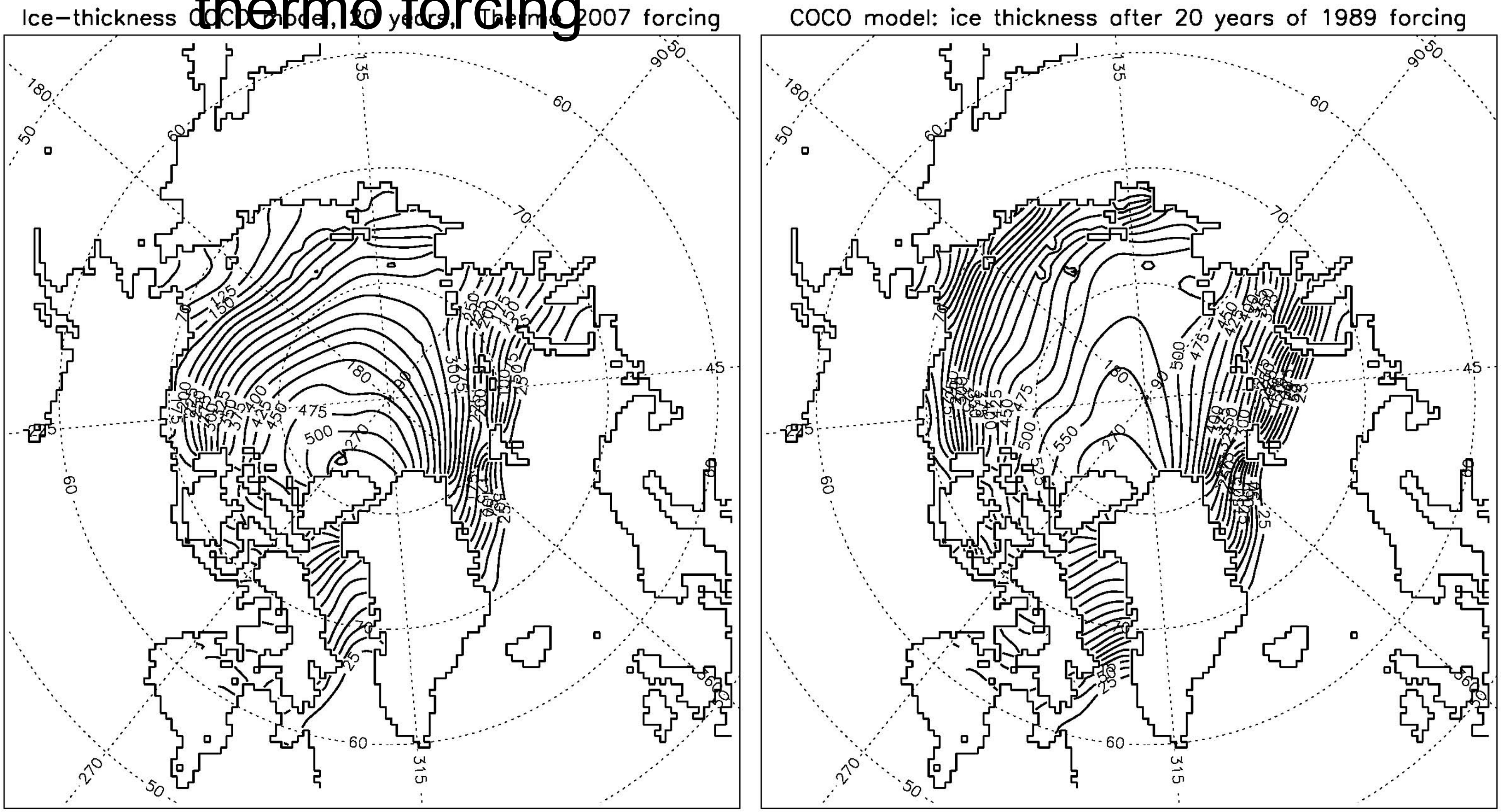
Zubov model results for 1989. Max = 10.70 m



Zubov model results for 2007. Max = 9.97 m



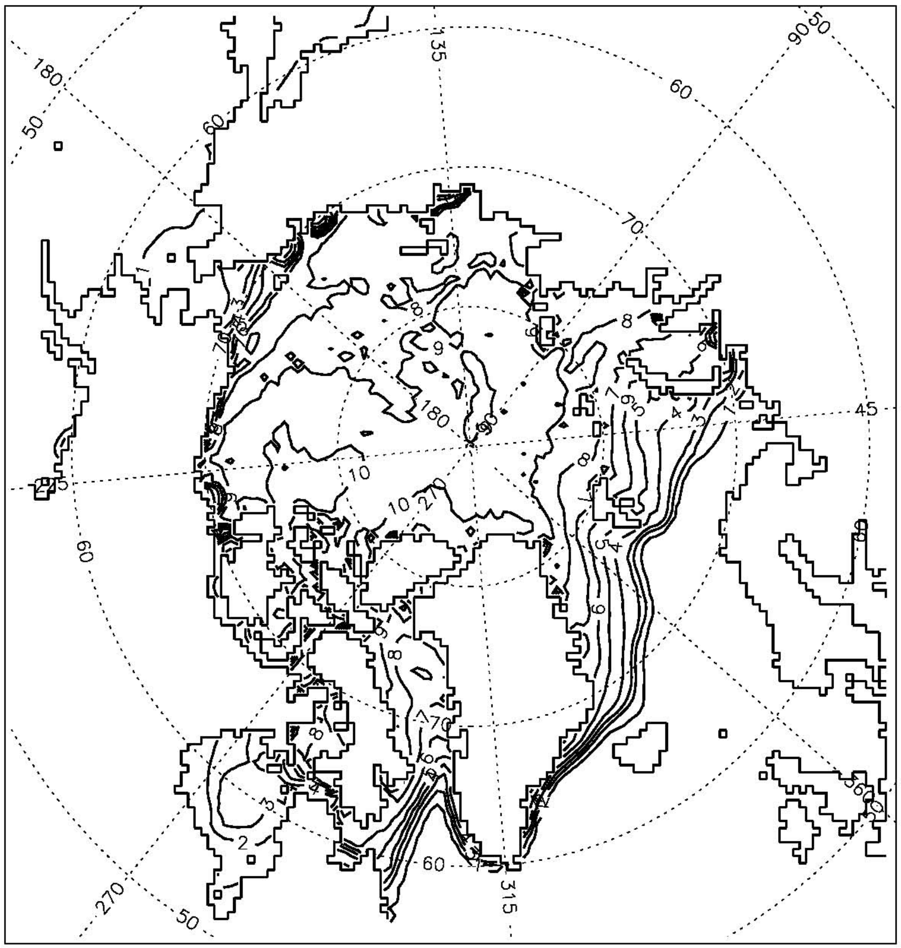
Sea ice thickness (meters) in the COCO model after 20 years of thermo forcing



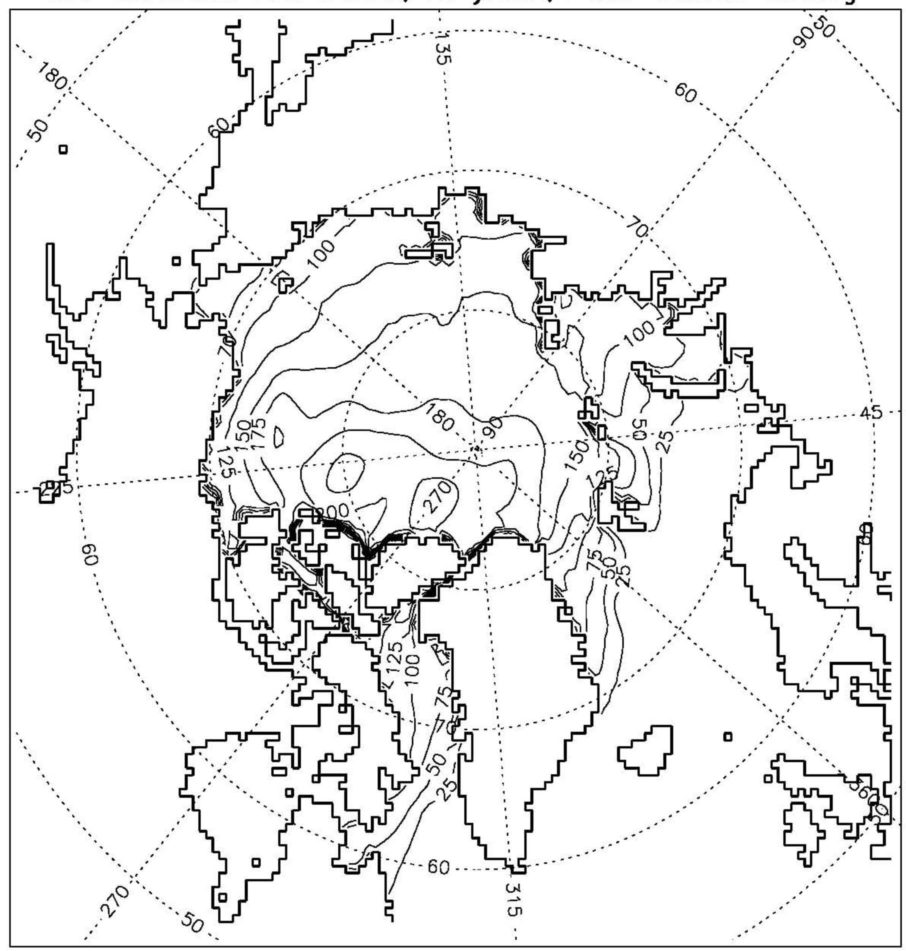
It is warmer in 2007 then in 1989 and more Atlantic water goes into the Arctic in 1989 than in 2007

Sea ice thickness (meters) in the UW (left) and RAS model (right) after 20 years of 2007 thermo forcing

UW model results. Max=12.2 m



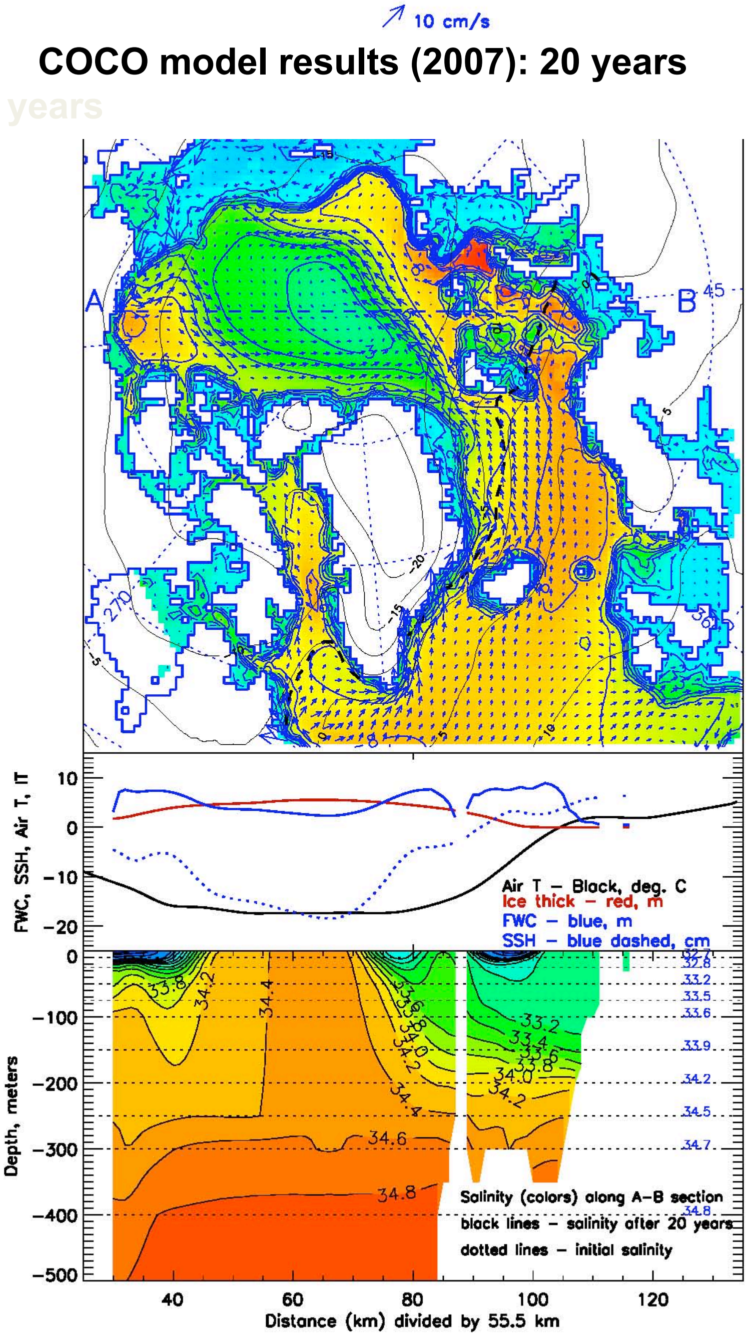
Ice−thickness RAS model, 20 years, 2007 thermo forcing

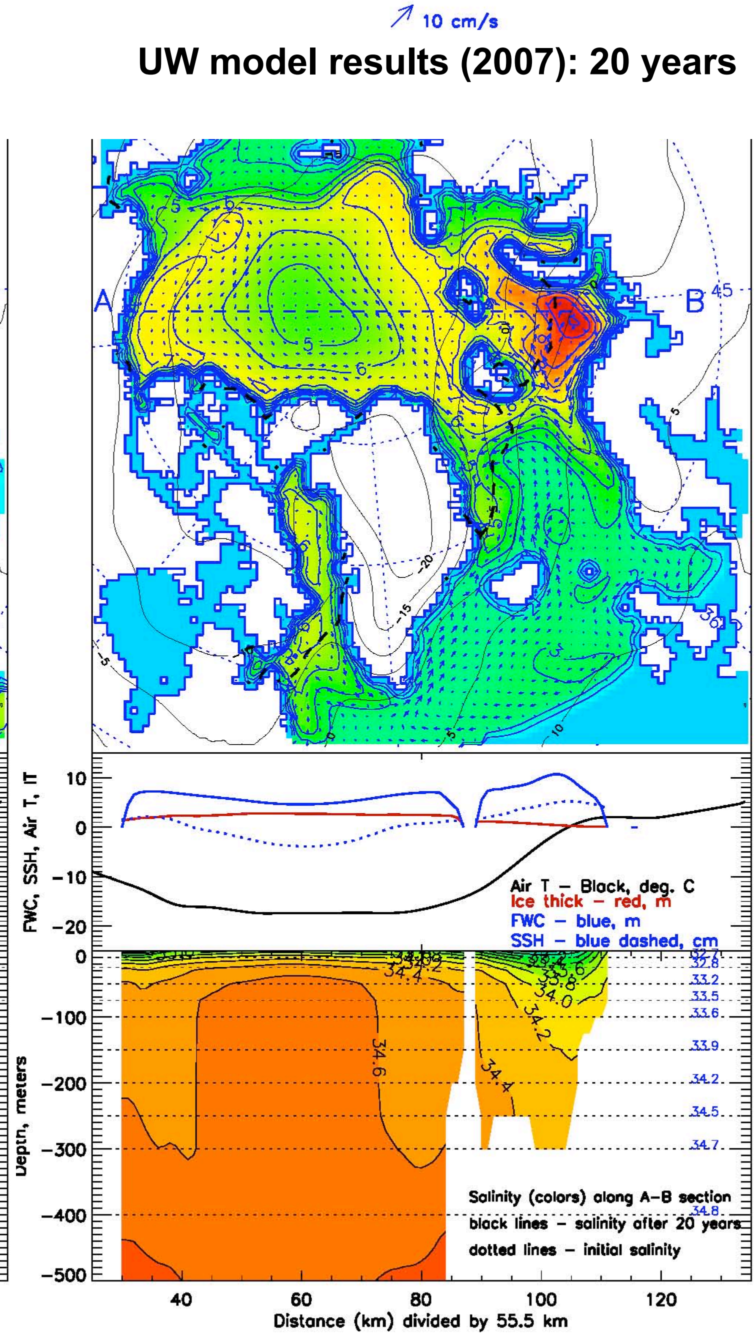


COCO model results (2007): 20 years

UW model results (2007): 20 years

years





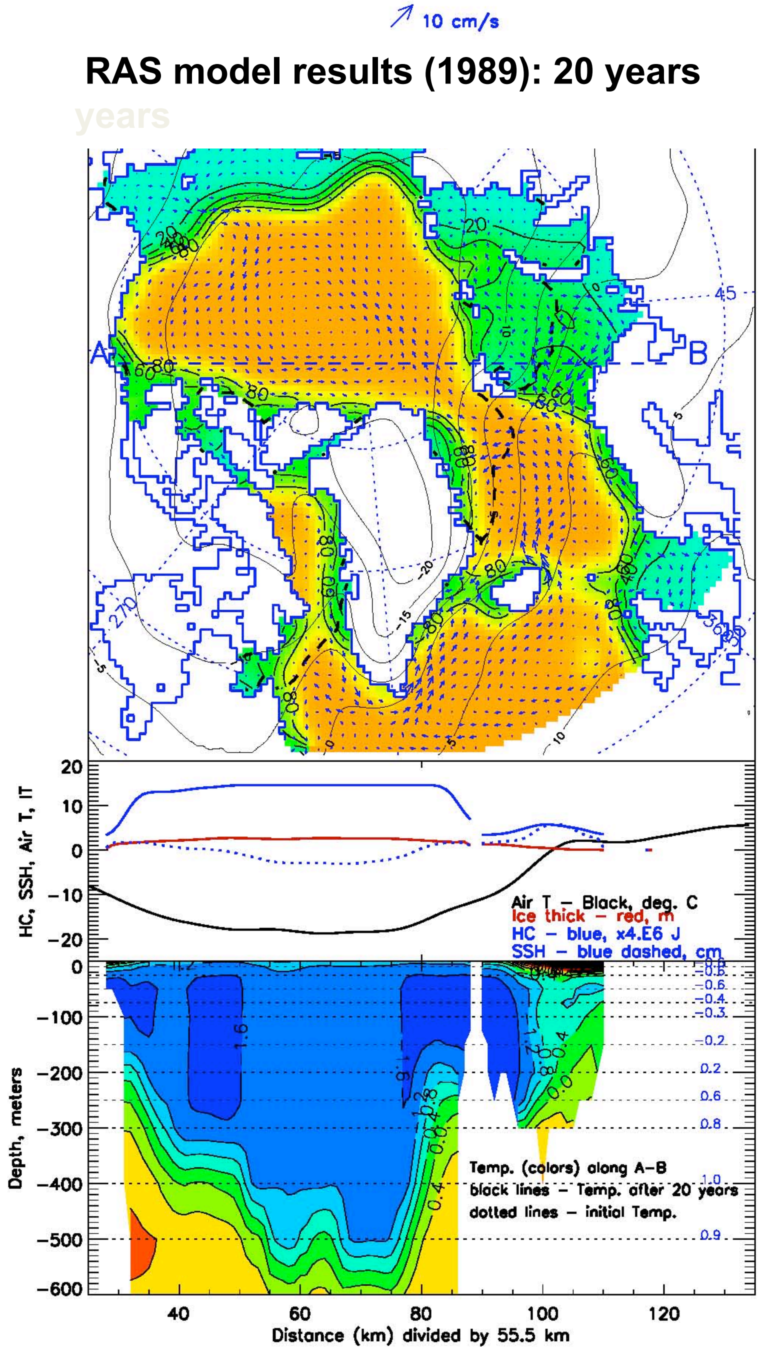
Freshwater content (m) and surface circulation

SAT, Ice thickness, FWC and SSH along A-B

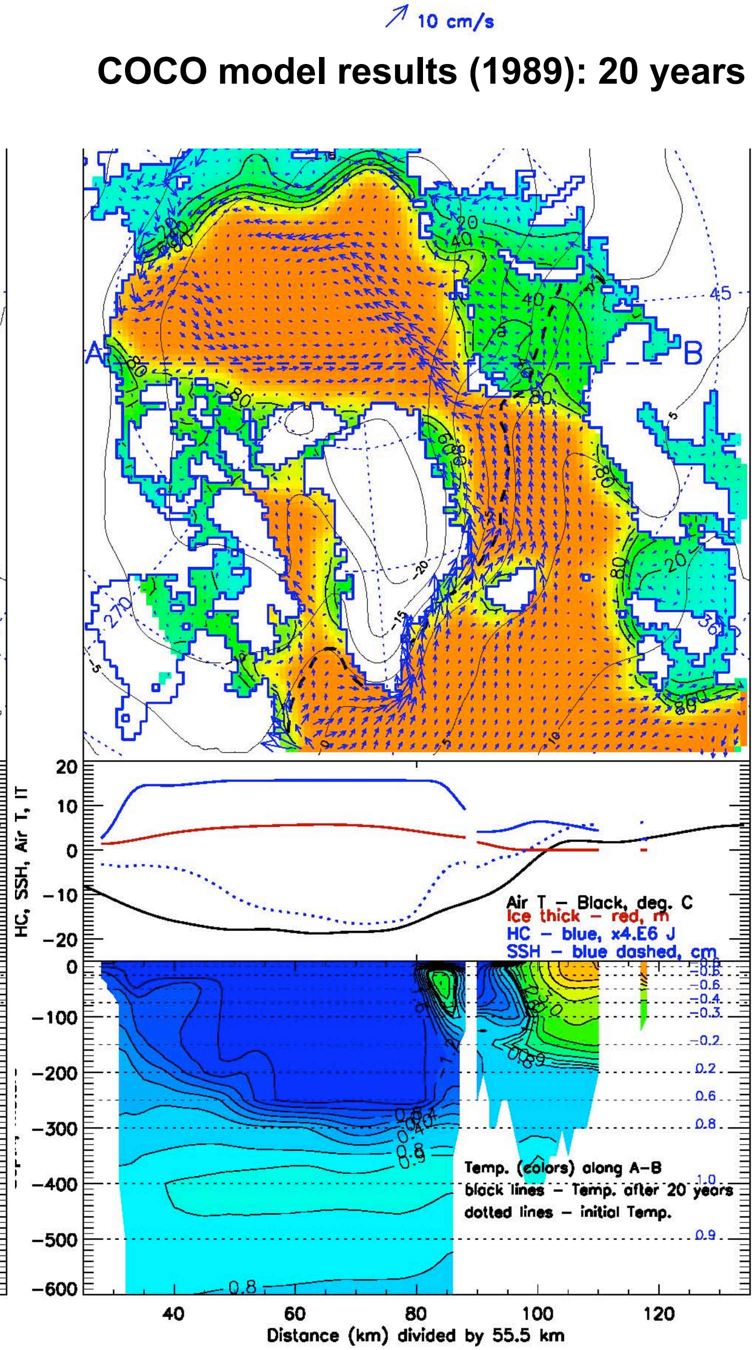
Salinity along A-B

RAS model results (1989): 20 years

years



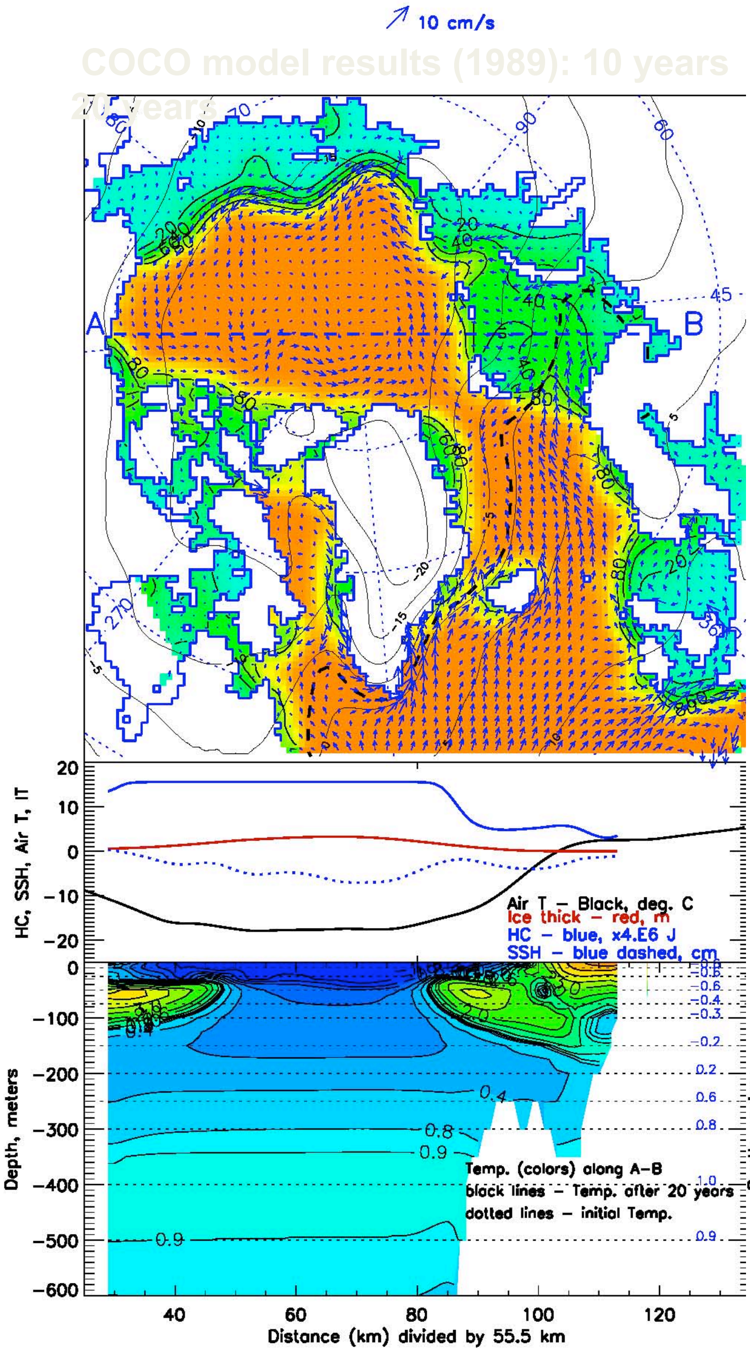
COCO model results (1989): 20 years



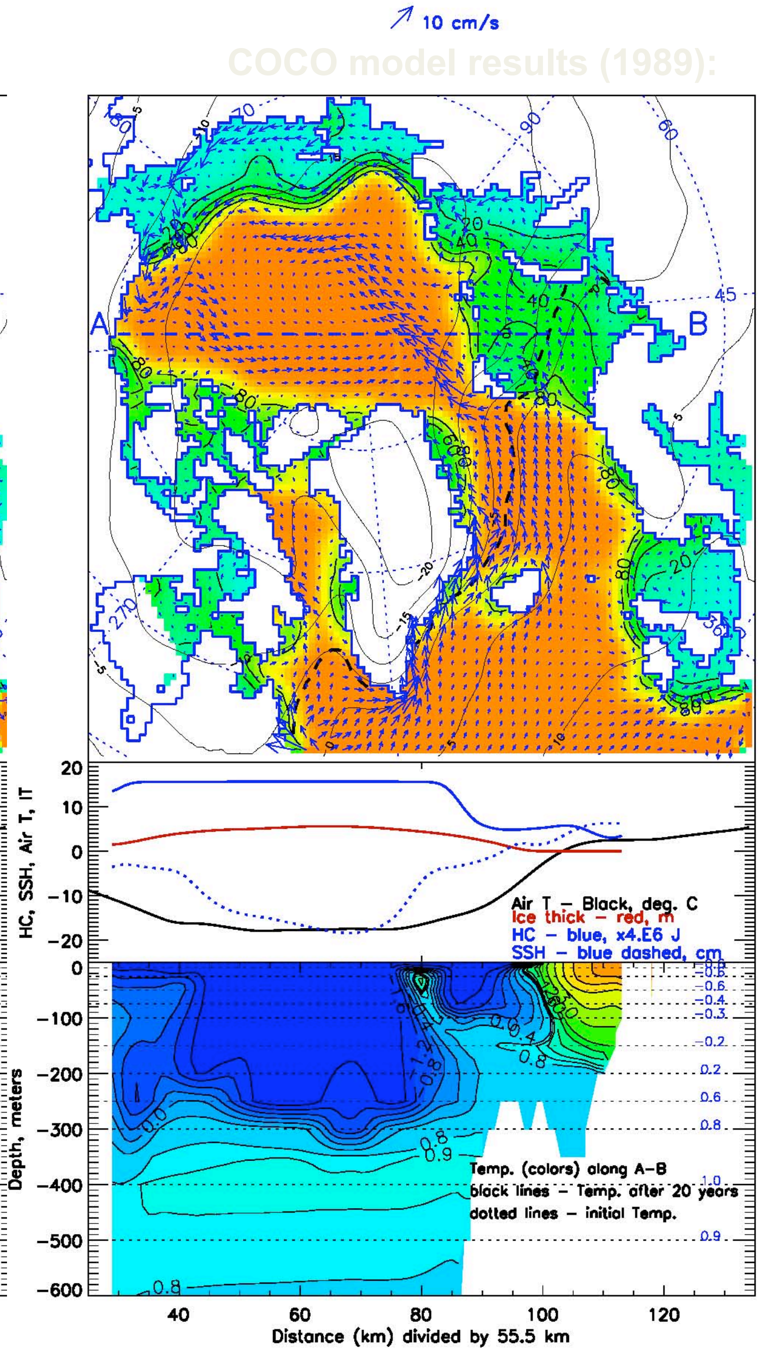
Flux of Atlantic water inflow west of Spitsbergen is well developed. There is a lot of heat of AW layer in the RAS model but most of heat in COCO model is disappeared and ice is much thicker in the COCO model

Note AW boundary flow

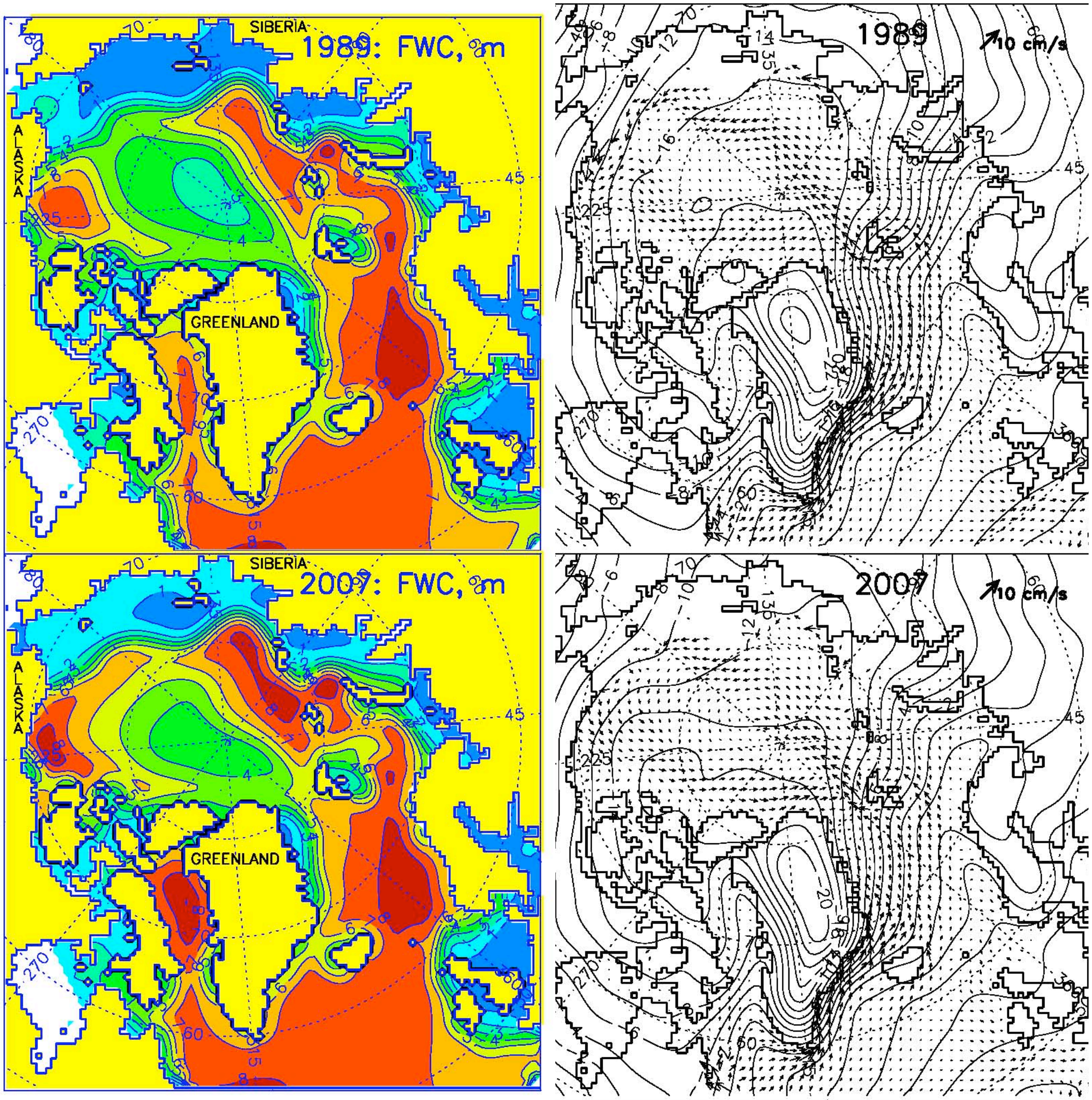
COCO model results (1989): 10 years



COCO model results (1989): 20 years

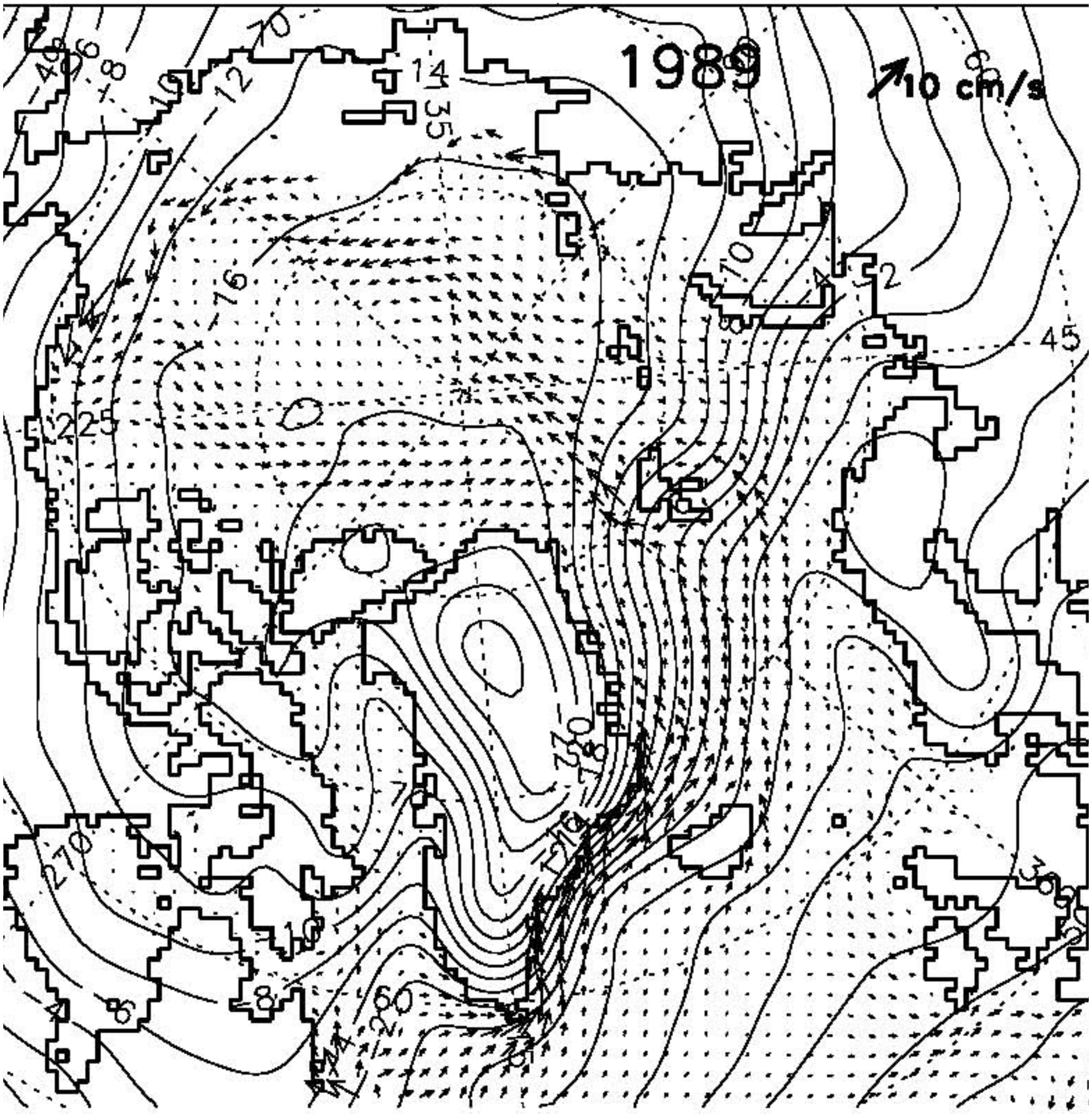


Evolution of AW flow and its changes at section between Alaska and the White Sea during 10 years. After 20 years circulation became stronger but a lot of heat has disappeared due to continuation of ice growth.

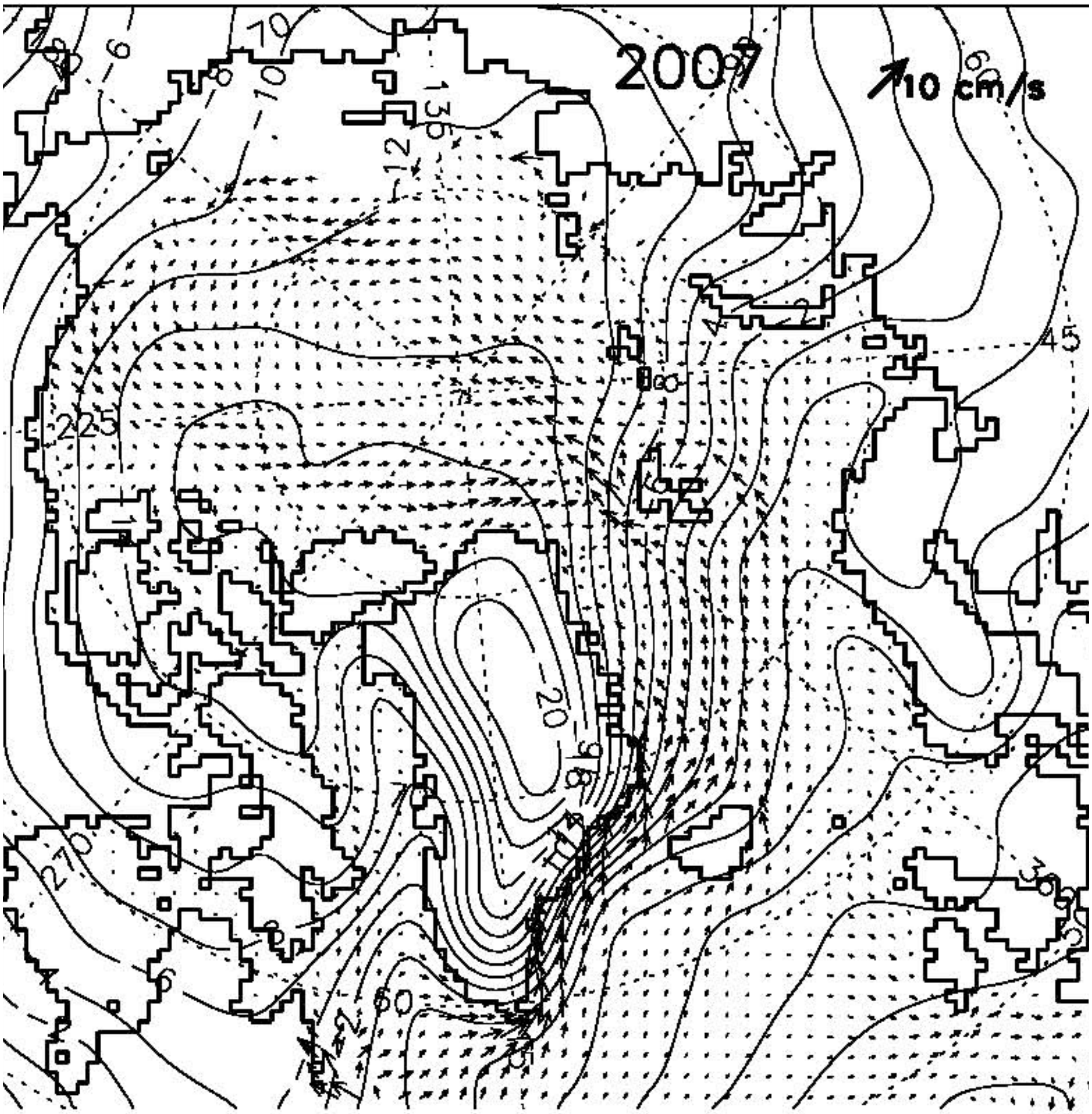


Left panels: redistribution of the oceanic fresh water due to ice formation under influence of only thermal forcing in 1989 and 2007. Note accumulation of freshwater along continental slopes and formation of a small BG FW reservoir.

Right panels: Mean currents (cm/s) in the upper 200-m water layer forced by only thermal forcing in 1989 and 2007



Mean currents in the upper 200m layer: COCO model, 1989 thermo-experiment

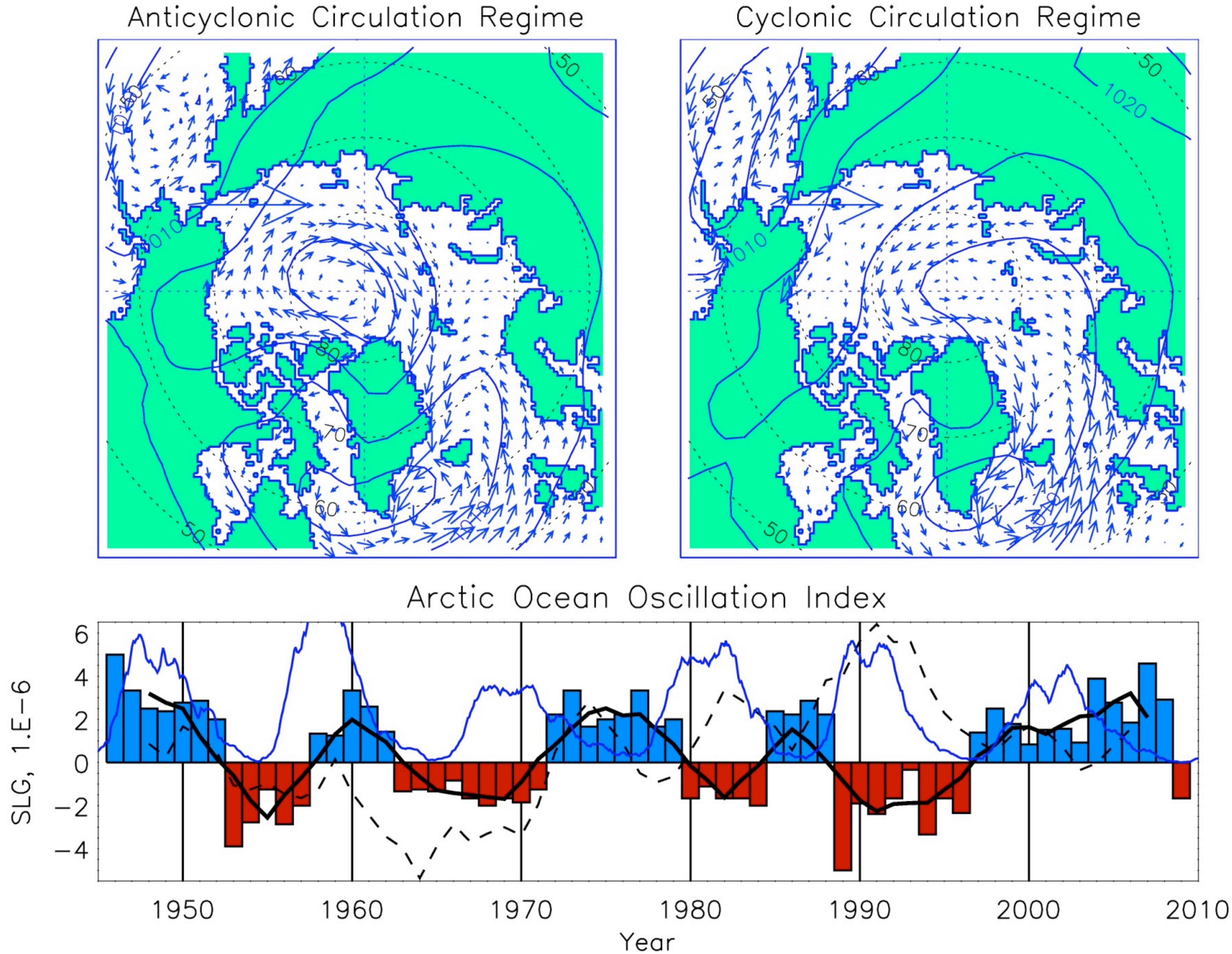


Mean currents in the upper 200m layer: COCO model, 2007 thermo-experiment

Concluding remarks

Surface layer waters in the BG region in the 2000s are much fresher than in the 1970s. In total, during 2003-2009 the Beaufort Gyre has accumulated approximately 5,000 km^3 of freshwater (from 17,300 km^3 in 2003 to 22,300 km^3 in 2009), which is 5,800 km^3 larger than in climatology of the 1970s.

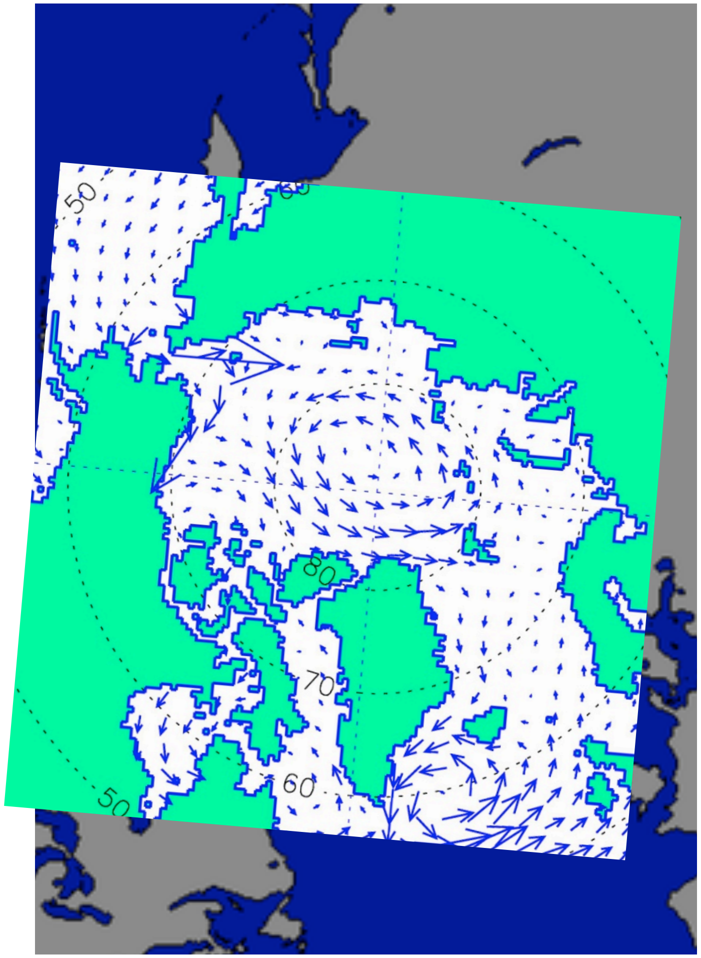
The release of this FW to the North Atlantic can significantly influence climate via reduction of the ocean meridional overturning circulation. In this sense the BG as a major FW reservoir is “a ticking time bomb” for Atlantic Ocean climate.



Bars and solid black line – AOO index; dashed – 5-year running mean AO index;

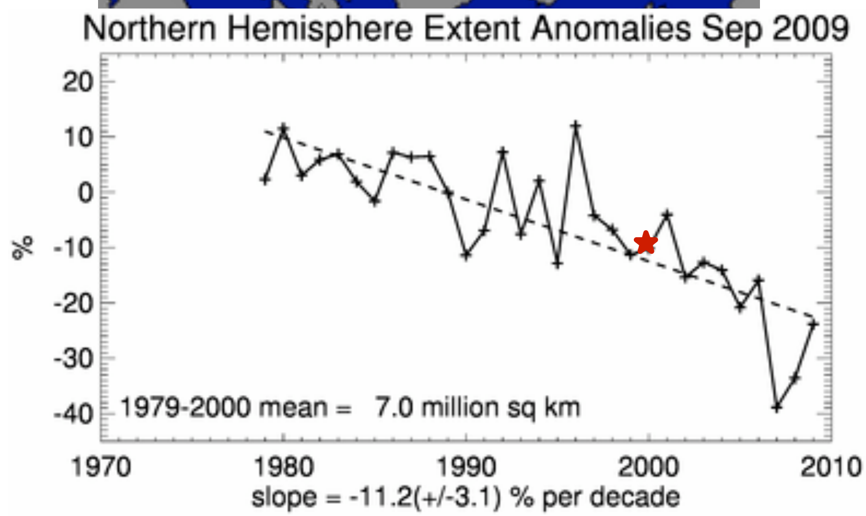
Blue solid line – area of sun spots

MJJAS drift and currents



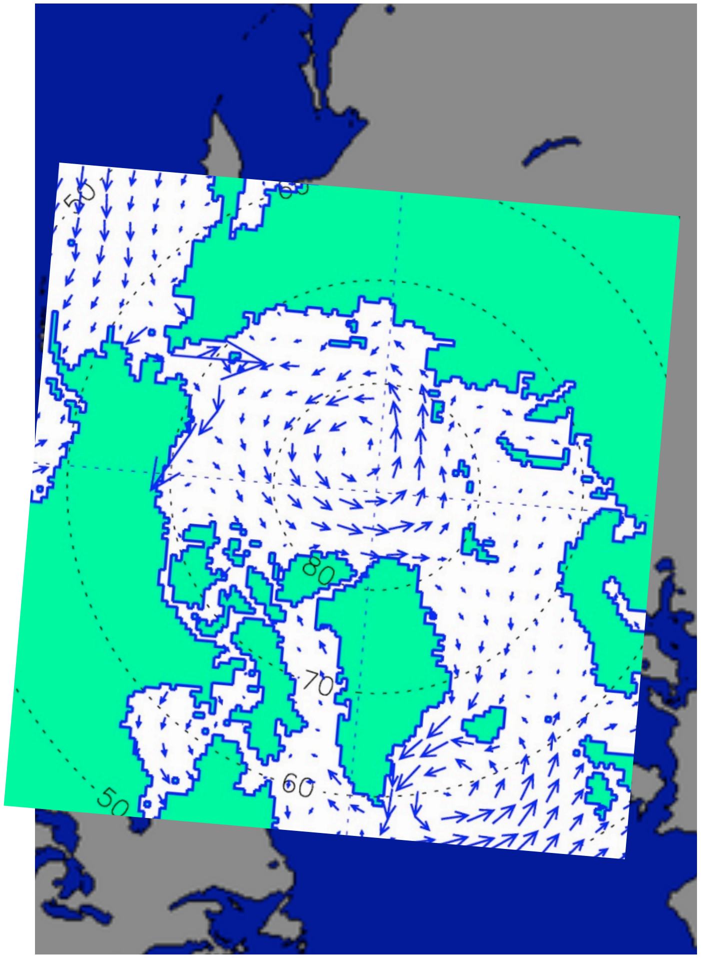
September

2000



Low

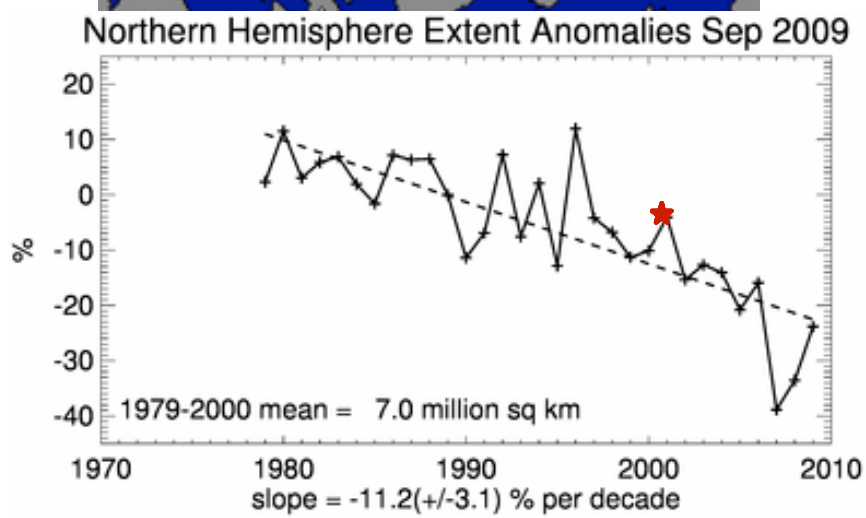
MJJAS drift and currents



High

September

2001



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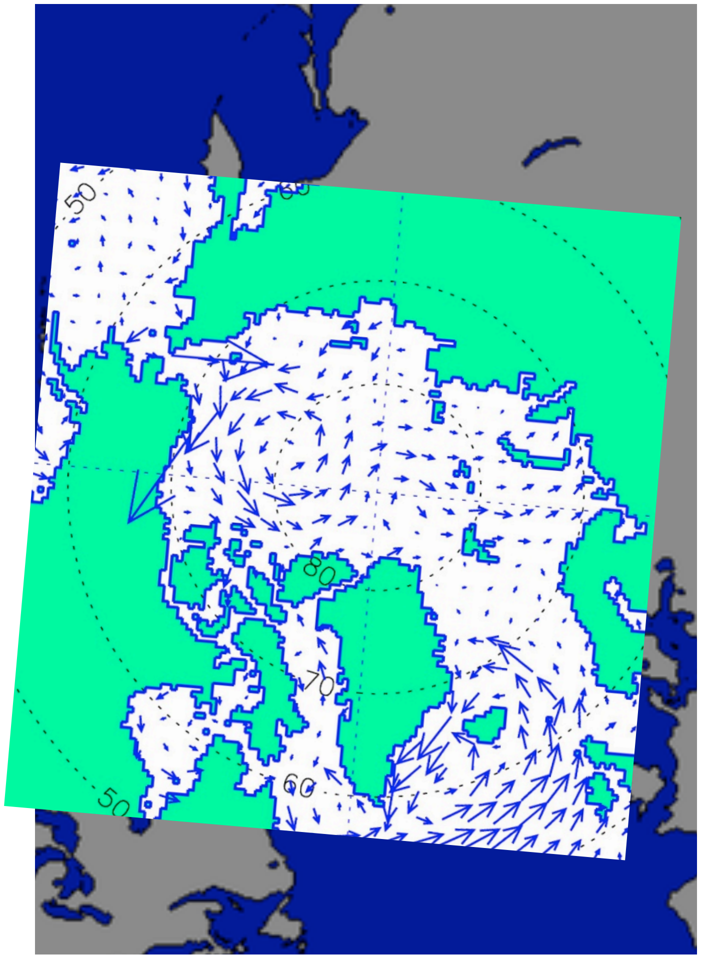
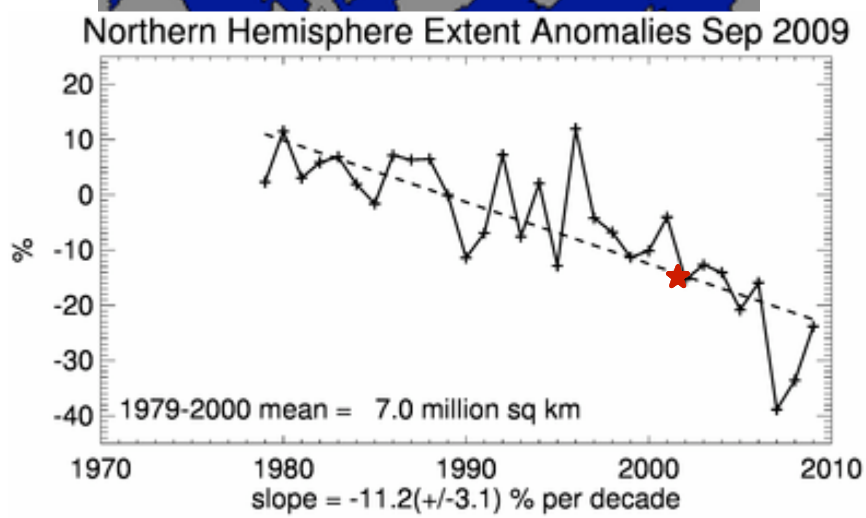


Low

September

2002



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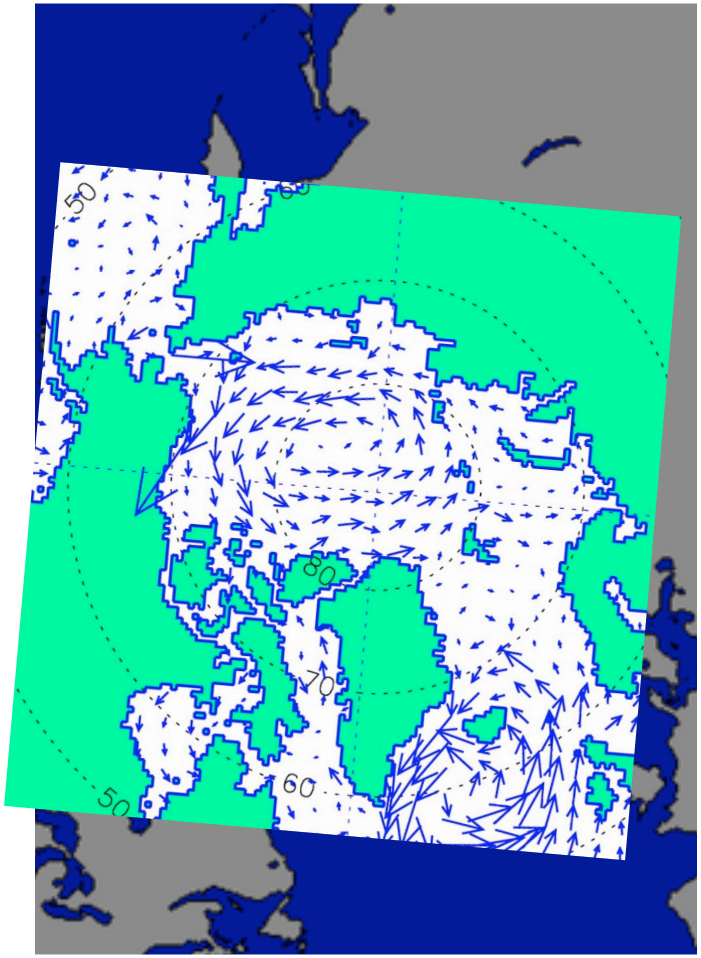

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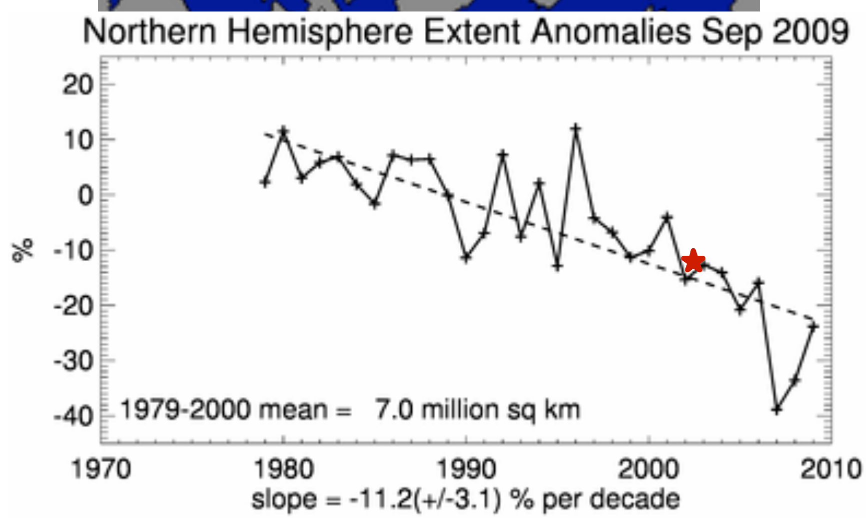
September

2003



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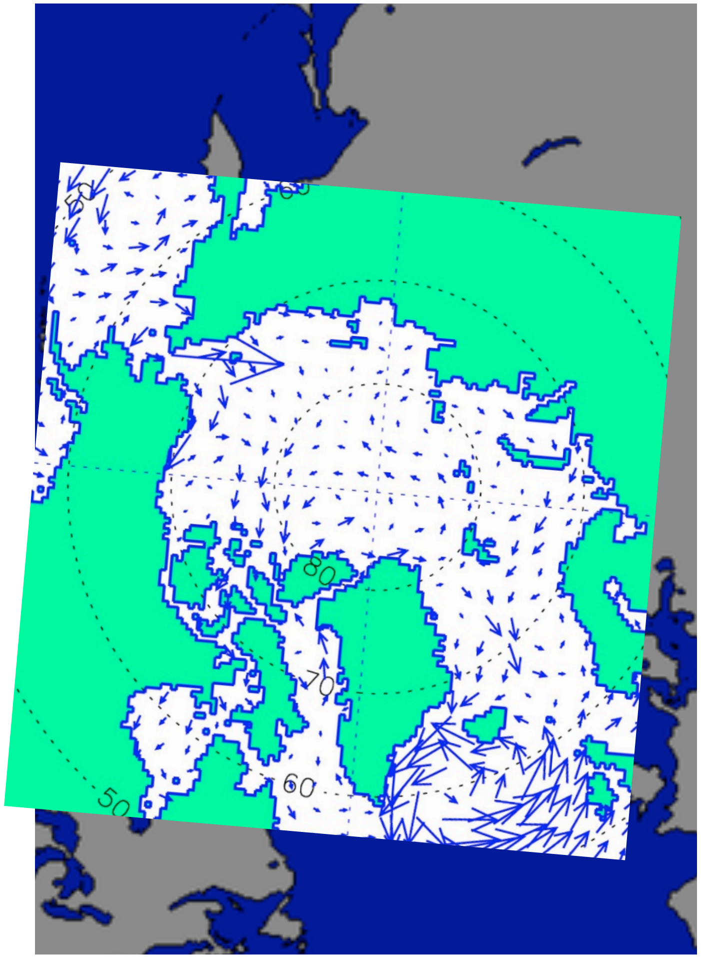

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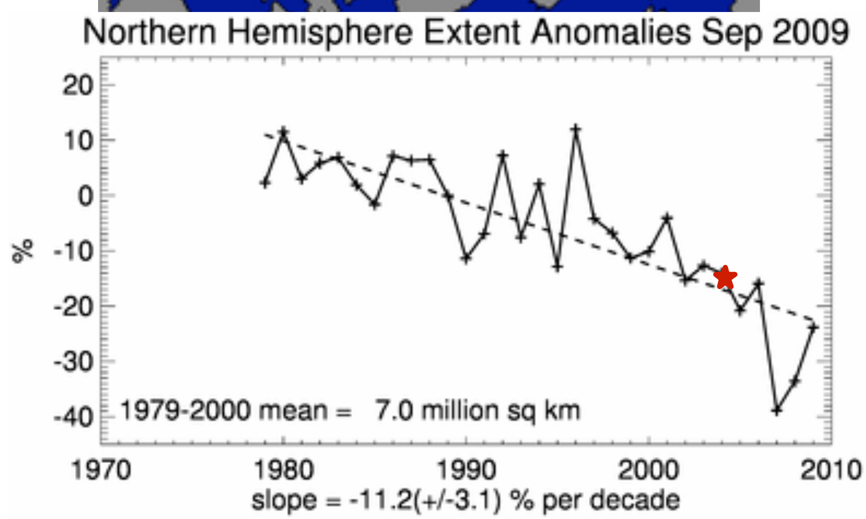
September

2004



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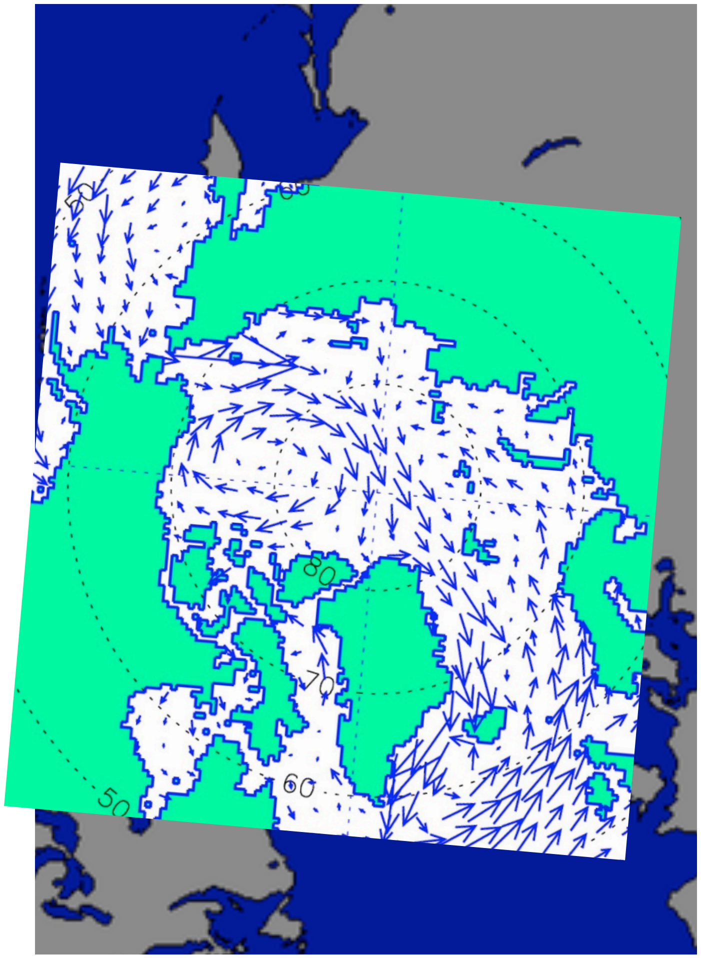
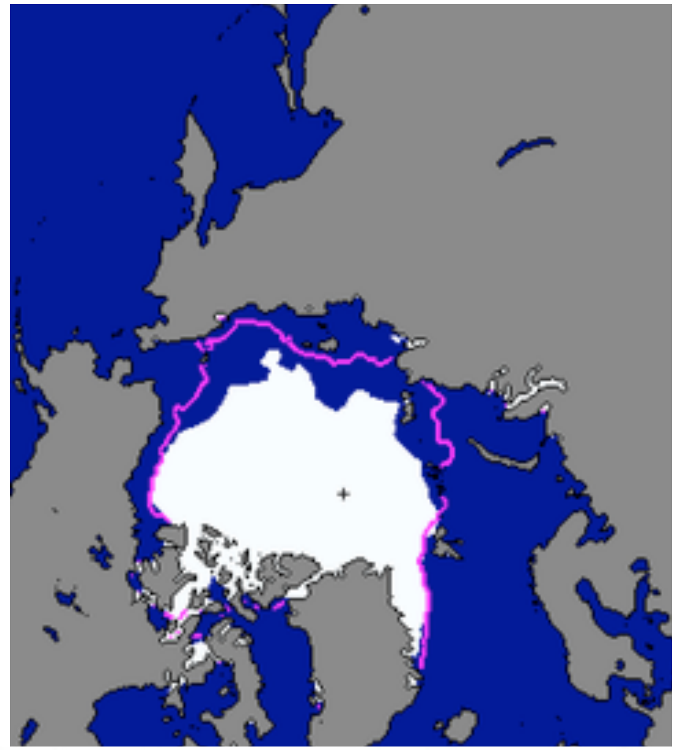
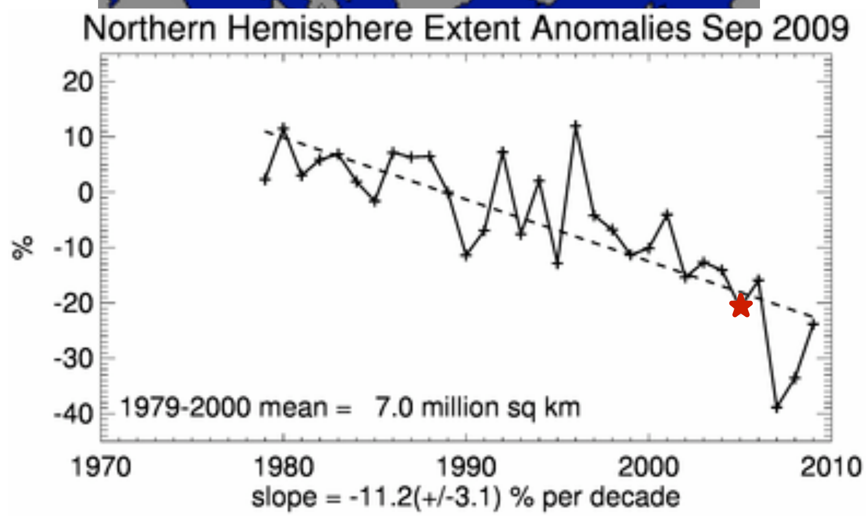


Low

September

2005





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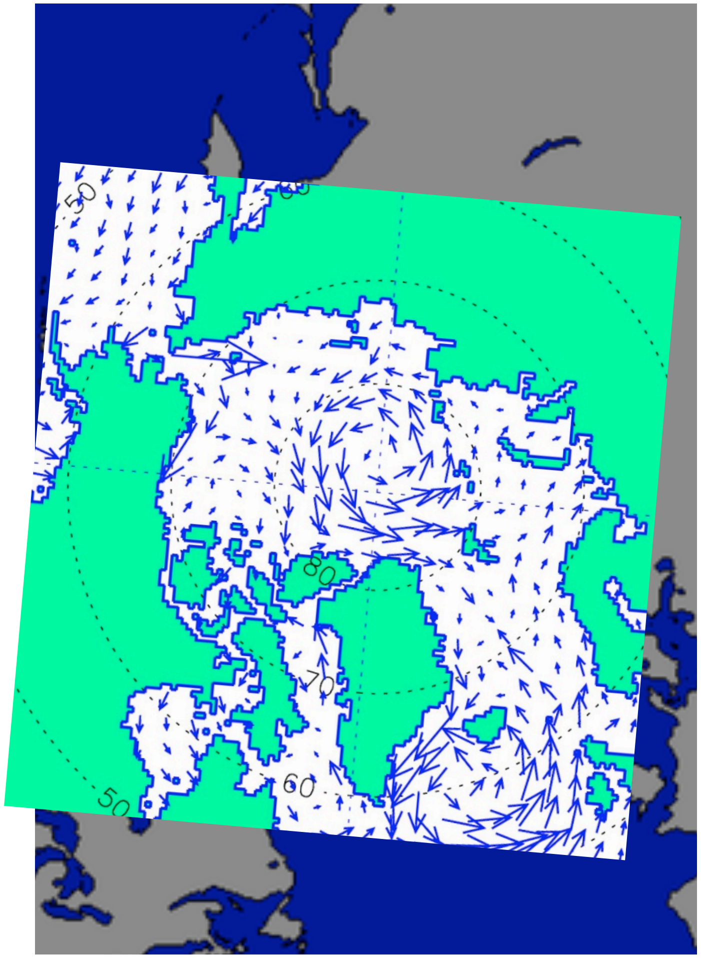
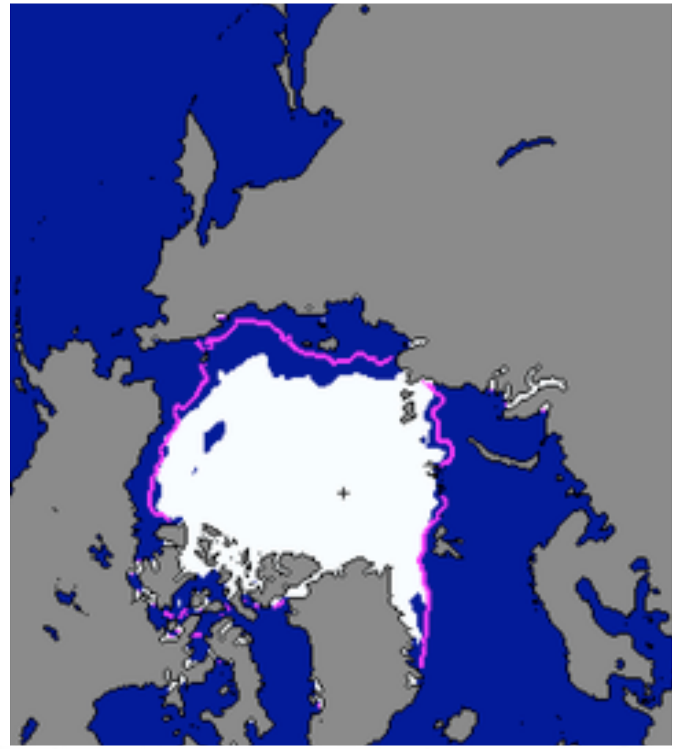
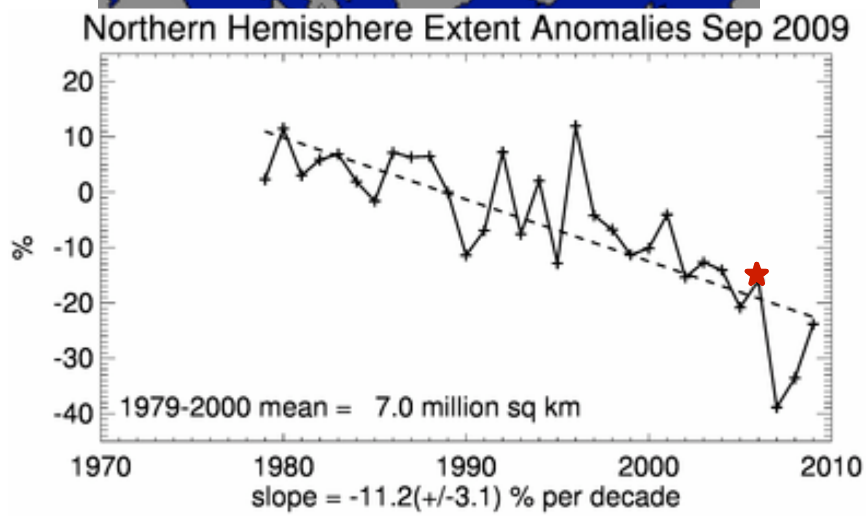


High

September

2006





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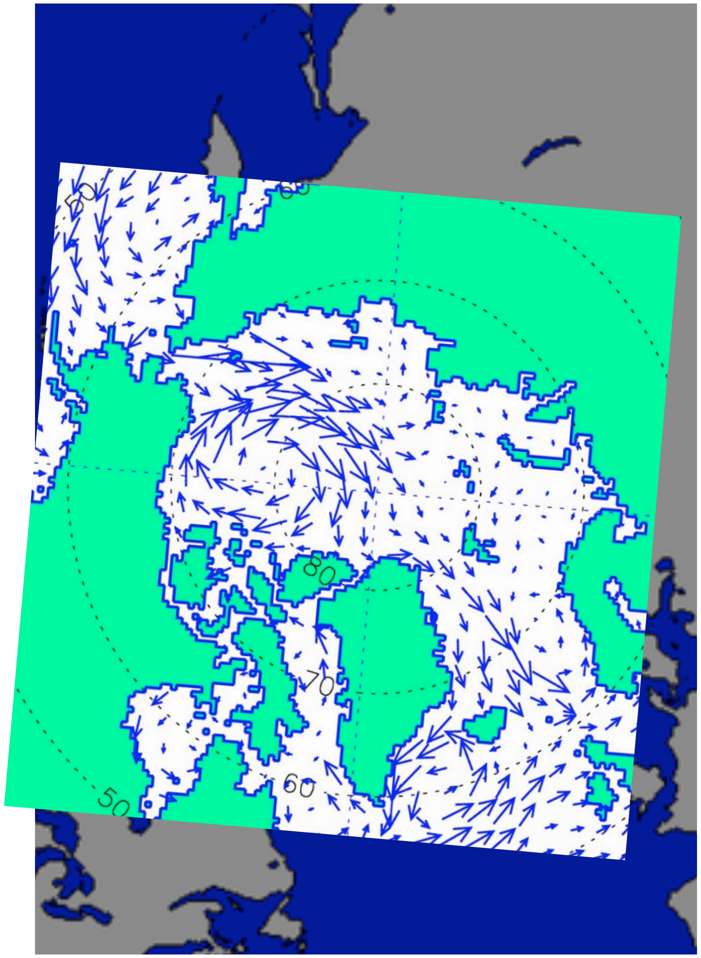
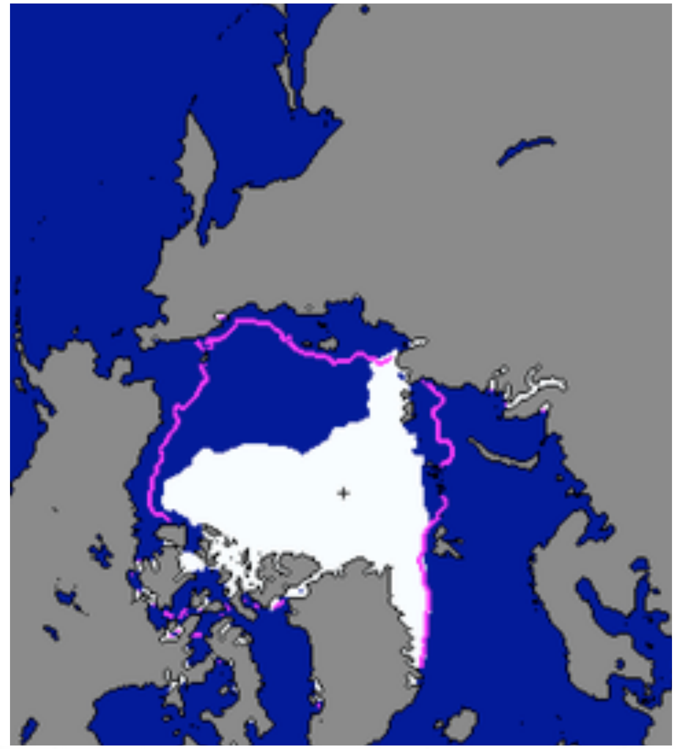
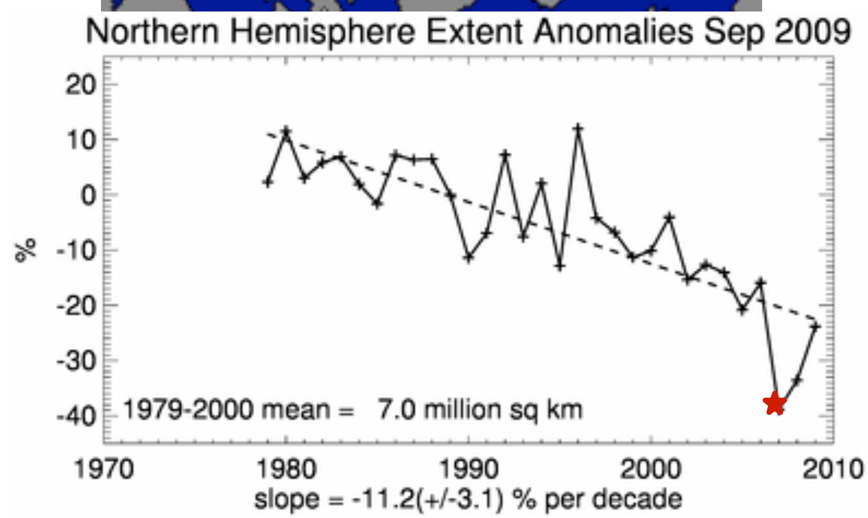


Low

September

2007





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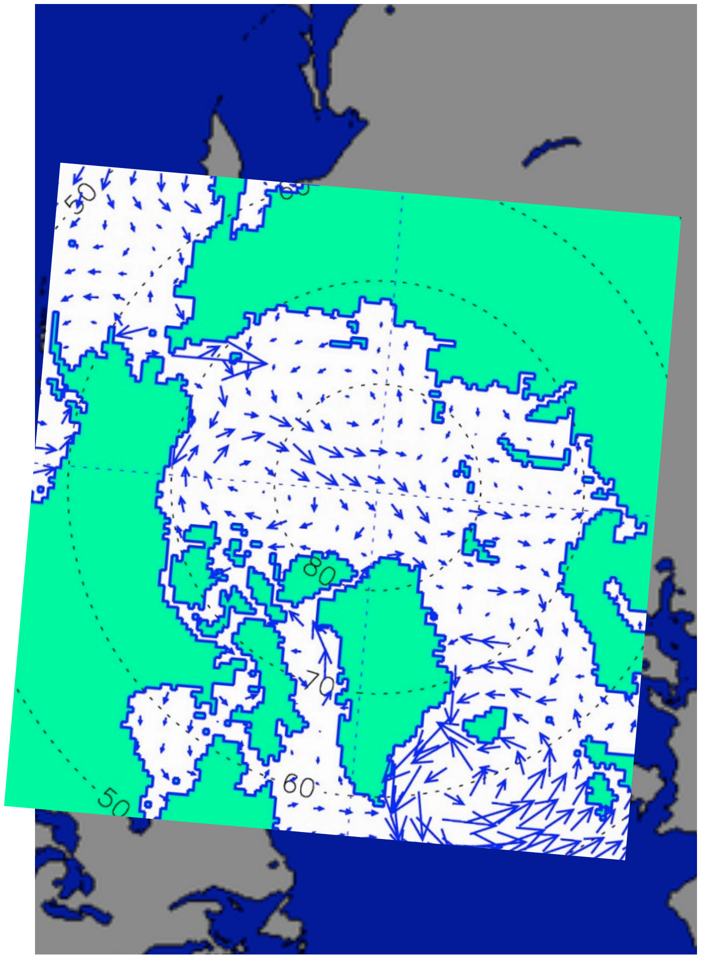

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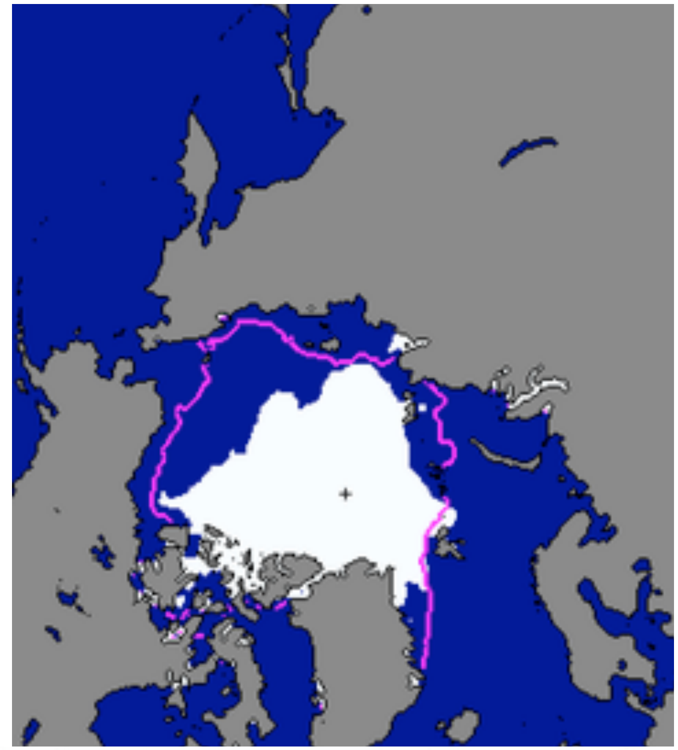
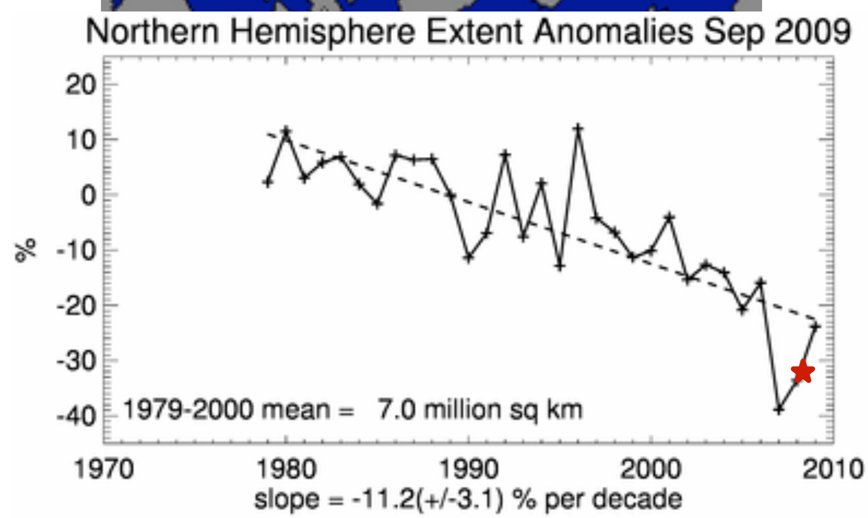
September

2008





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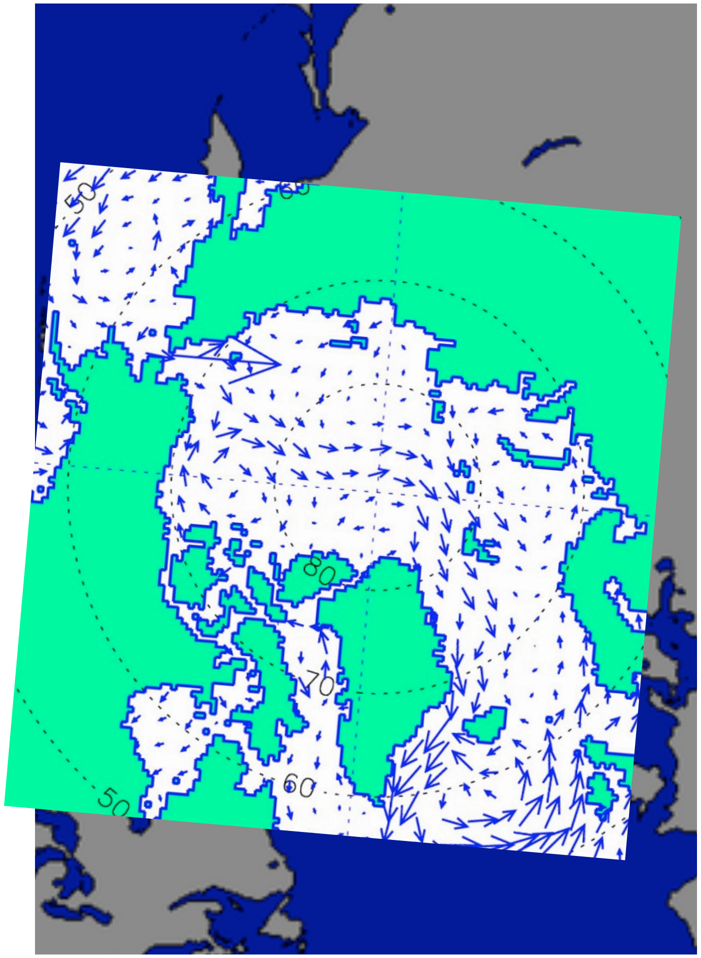

High

September

2009