‘Missing’ polar lows enhance deep-water formation in the Nordic Seas

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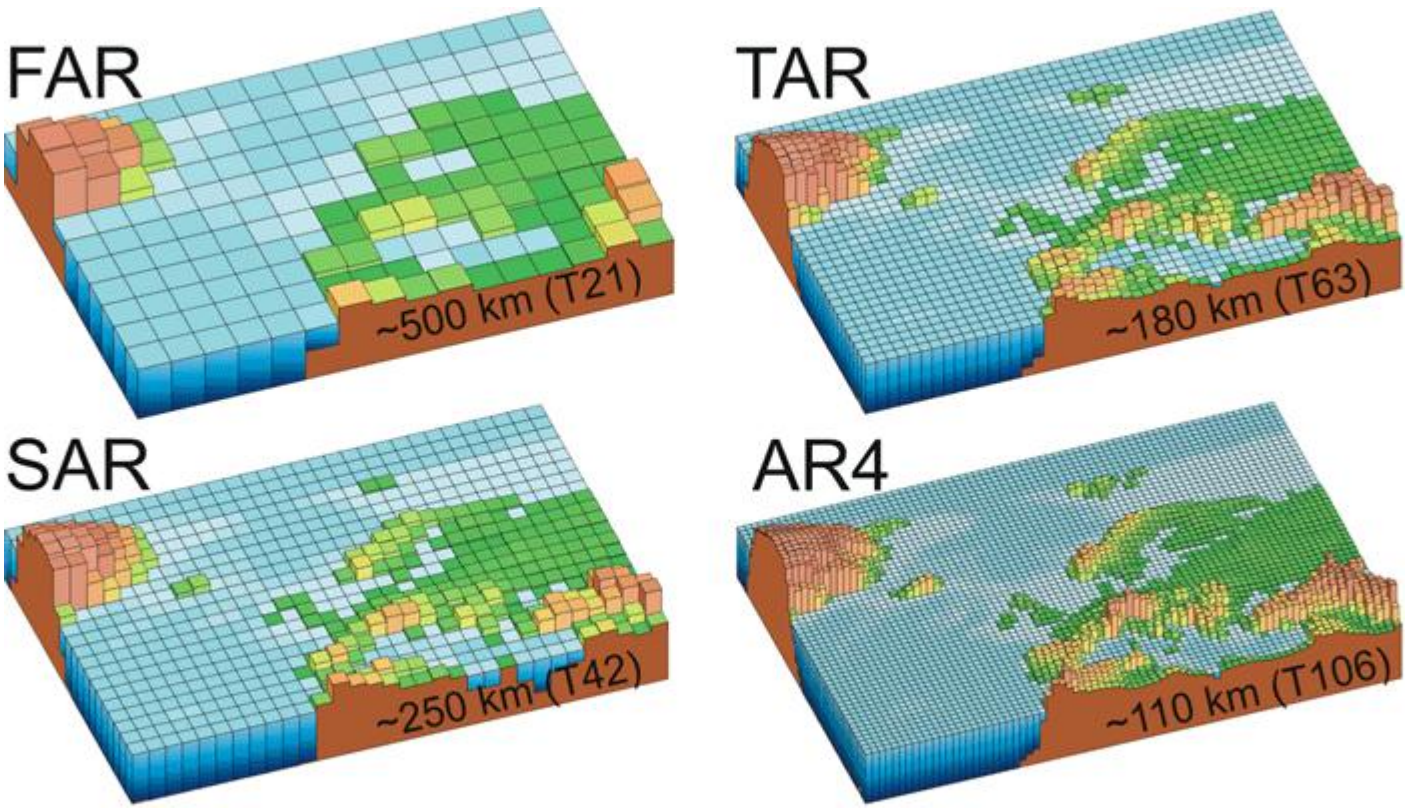
Outline

- Introduction
  - resolution
  - the Subpolar Seas
- Impact of polar lows
- Conclusions

Intro: what can atmospheric models resolve?



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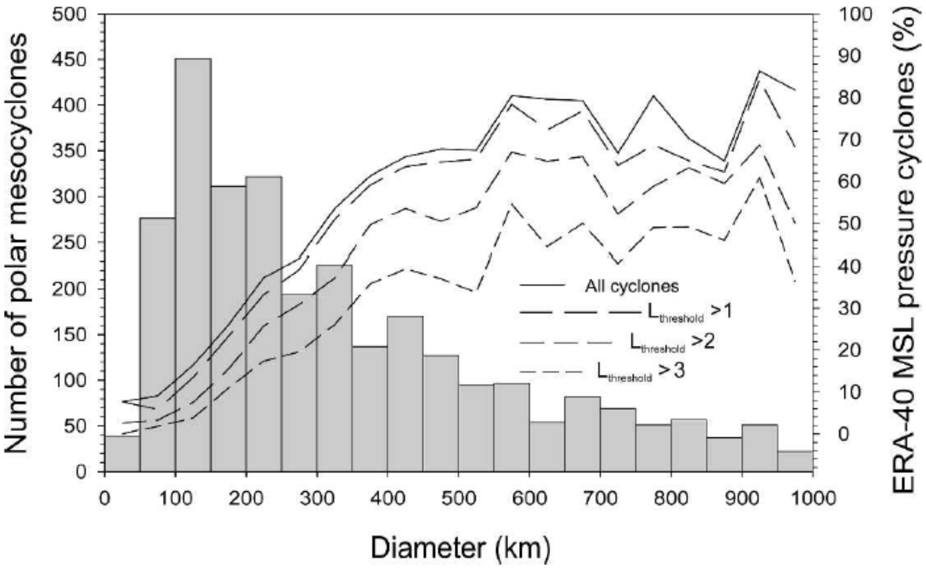

FIG. 7. Number of satellite-observed cloud vortices detected over the 2-yr climatology per 50-km size category (shaded bars). Overlaid are the percentages of cloud vortices in each size group with a cyclonic circulation in the MSL pressure reanalysis for all cyclones and those when $L_{\text{threshold}}$ is set at 1, 2, and 3 hPa $(\text{deg})^{-2}$.

From Condron et al. 2006, Mon Wea Rev

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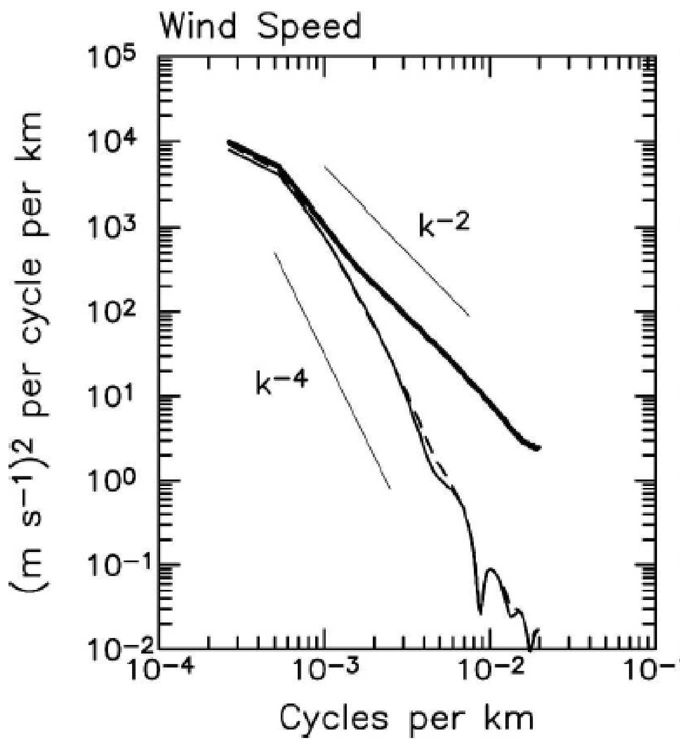
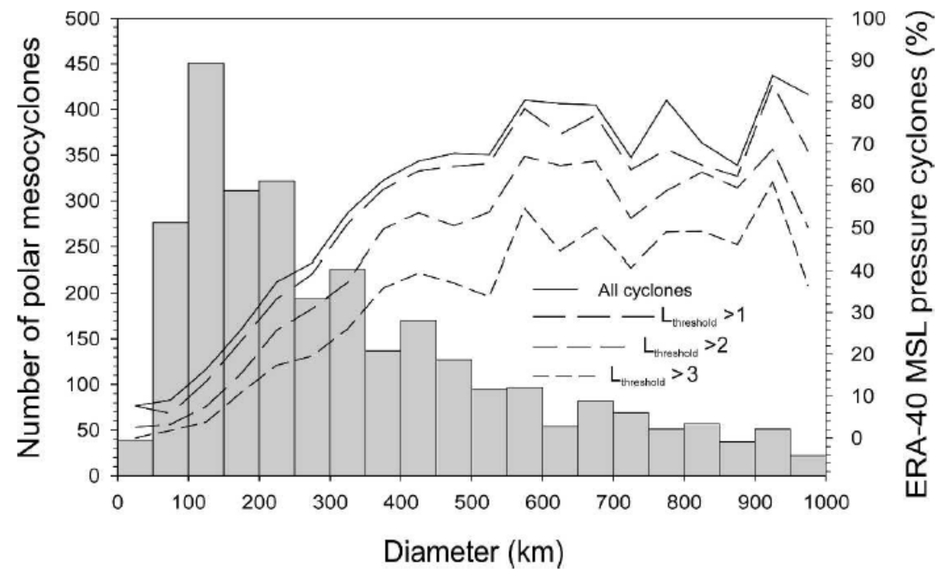


Along-track 10m wind speed spectra from QuikSCAT, ECMWF (dashed) and NCEP (thin) for the North Pacific in 2004. From Chelton et al. MWR, 2006



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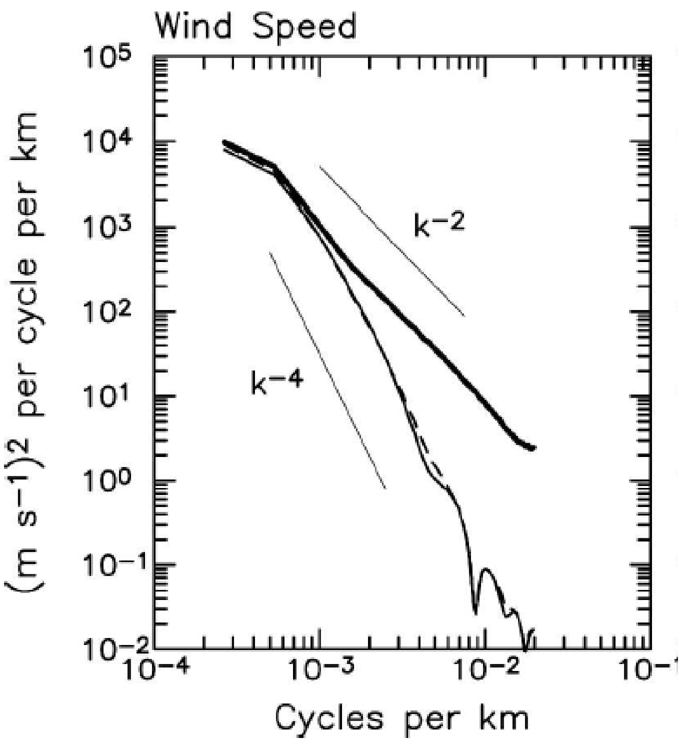

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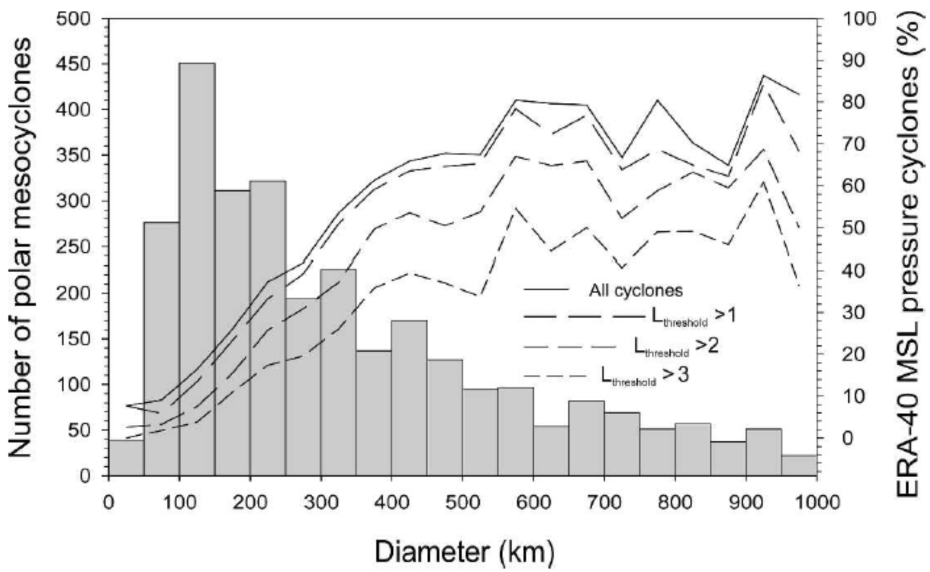

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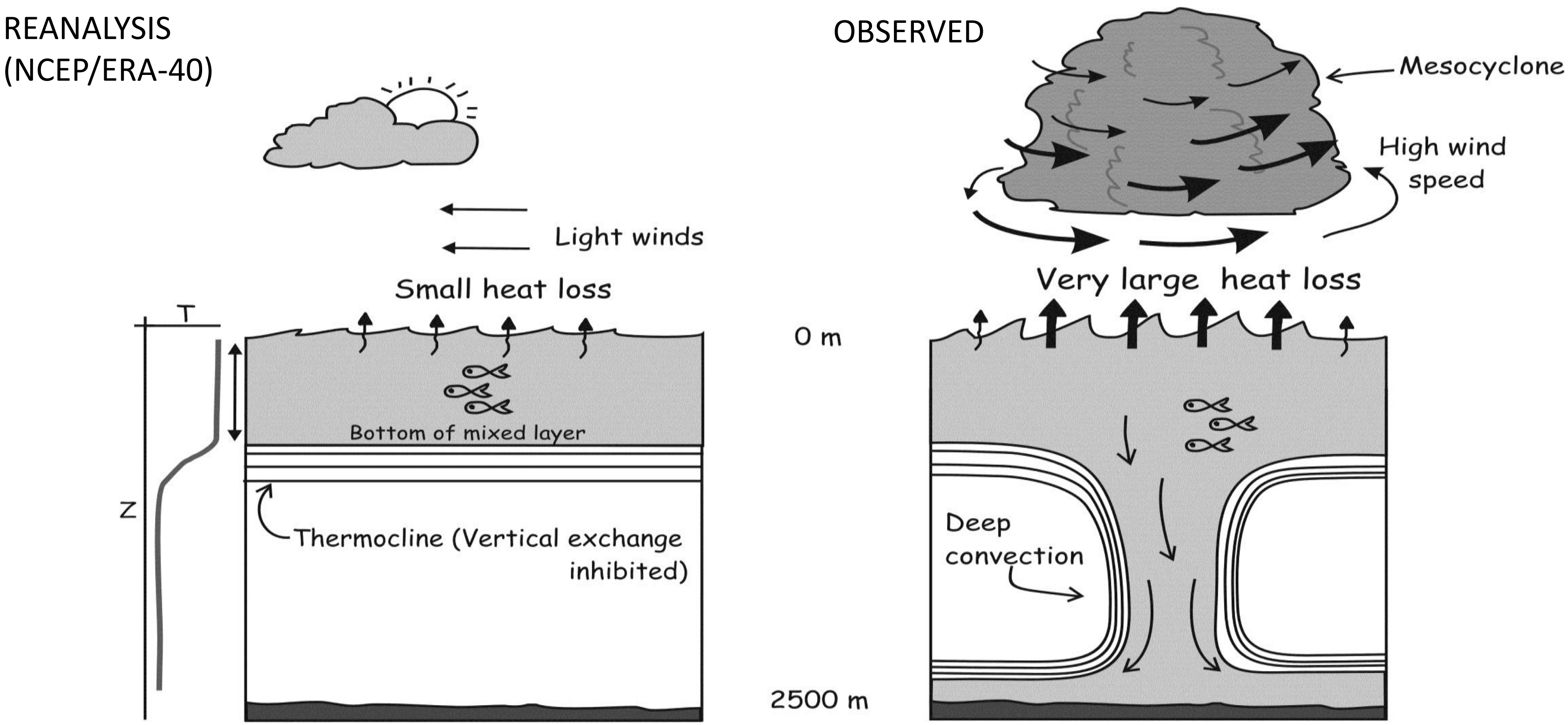
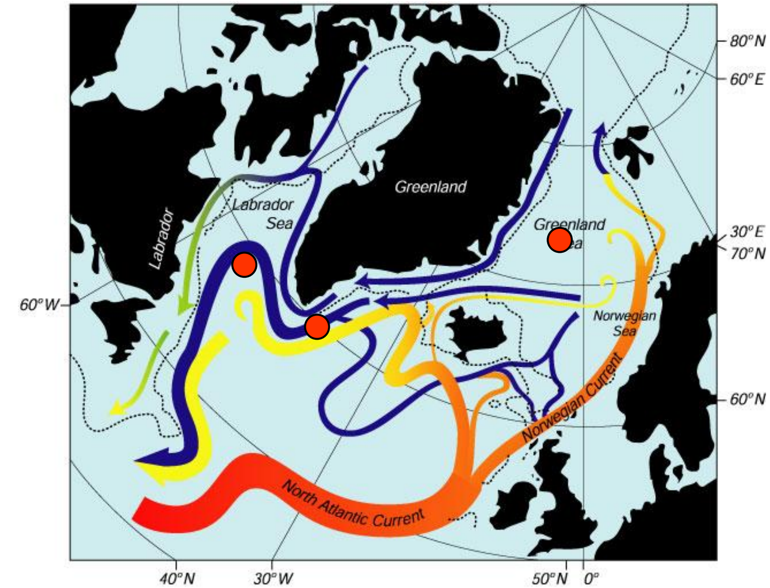
- Meteorological analyses (and climate models) have large amount of power "missing" in the atmospheric mesoscale
- Does this matter for ocean circulation?

Are ocean models under-forced at the mesoscale scale?



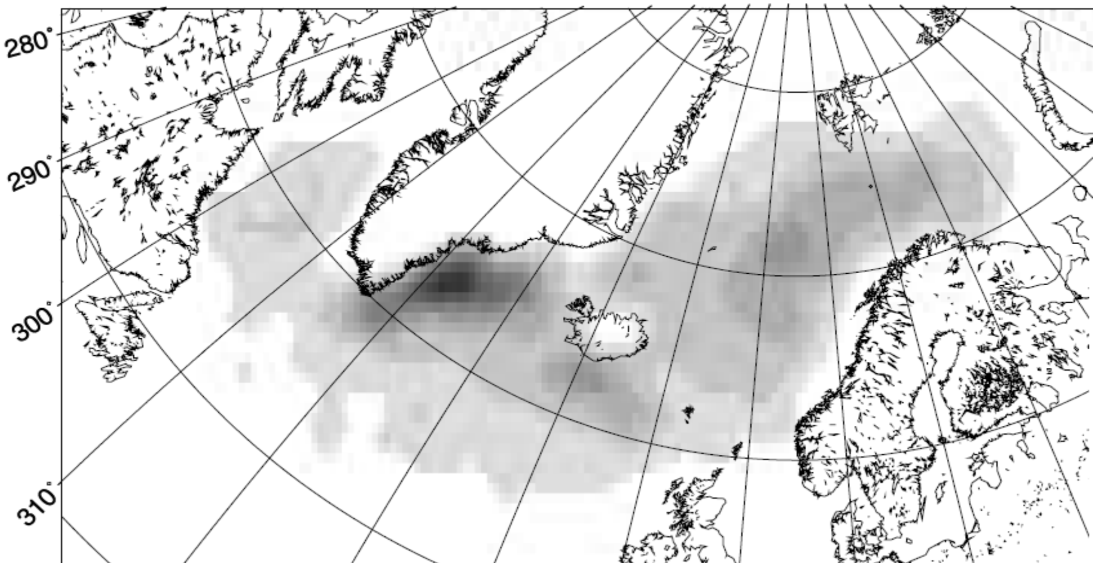
Under-representation of sub-synoptic mesoscale cyclones in atmospheric forcing datasets → inaccurately forcing the ocean

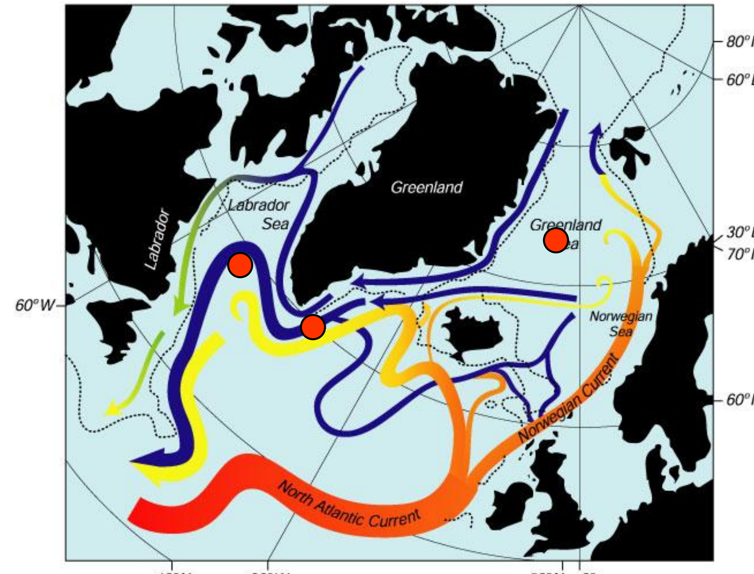
Intro: Subpolar Seas of North Atlantic

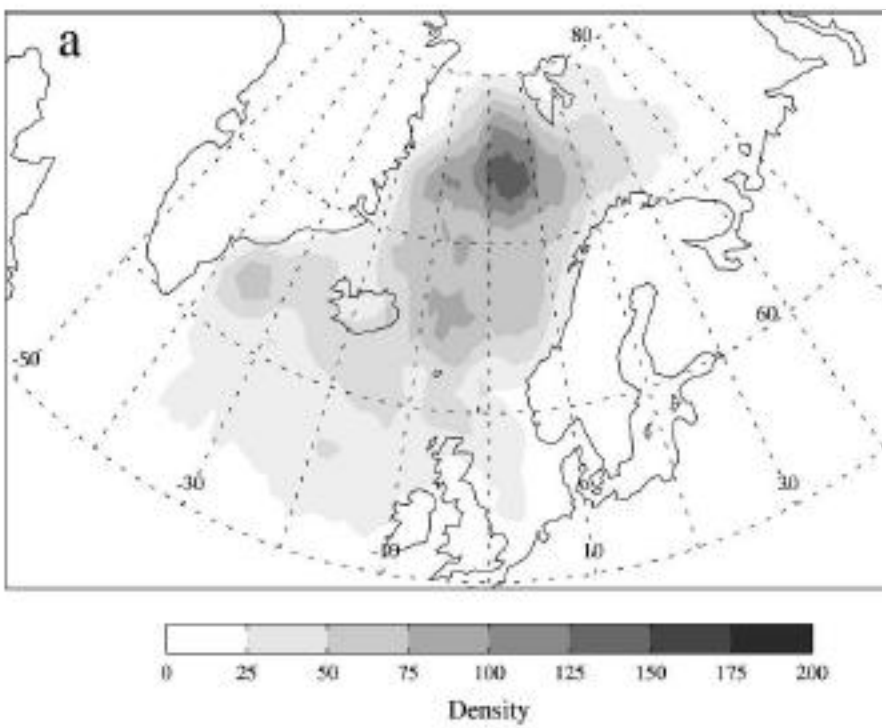


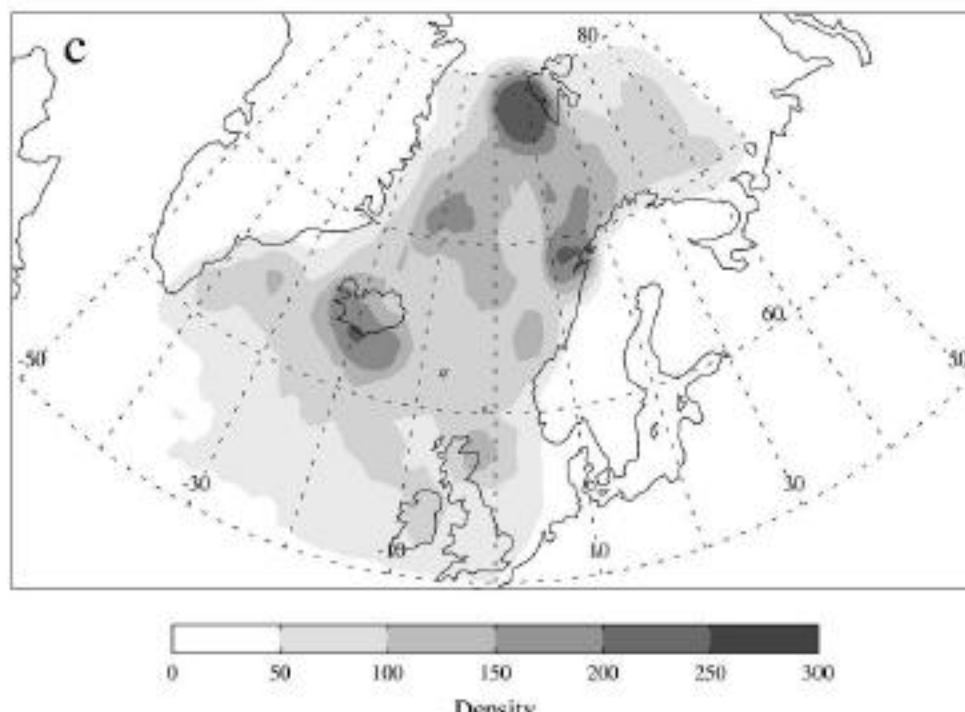
● site of deep convection

Polar mesoscale cyclone density, from (top) dynamical downscaling (Zahn & von Storch 2008);
(br) satellite (Harold et al.) , (bl) ERA40 reanalyses (Condron et al. 2006).

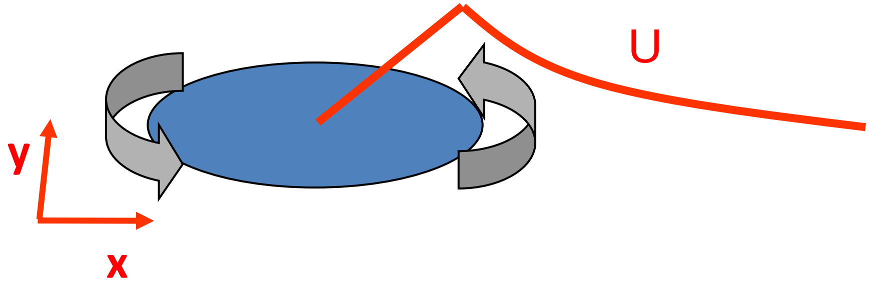








Parameterizing Polar Lows

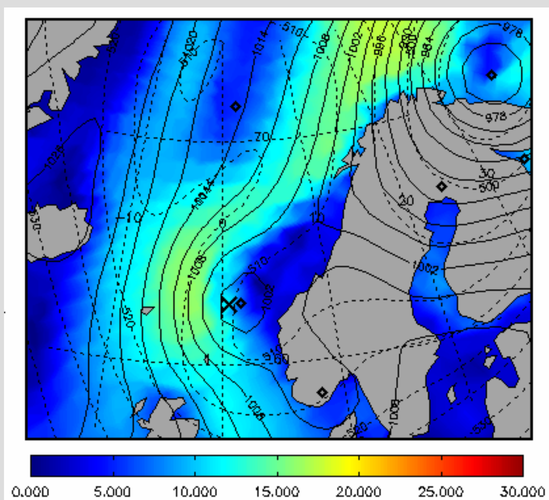


Rankine vortices of correct size & strength "bogussed in" to forcing fields

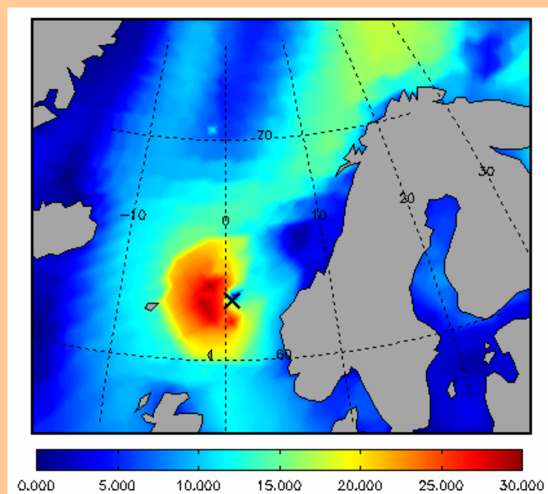
ERA-40 WIND SPEED

OBSERVED WIND SPEED

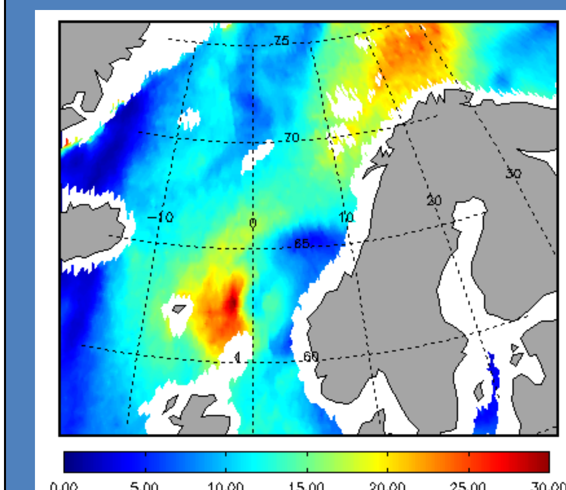
Standard

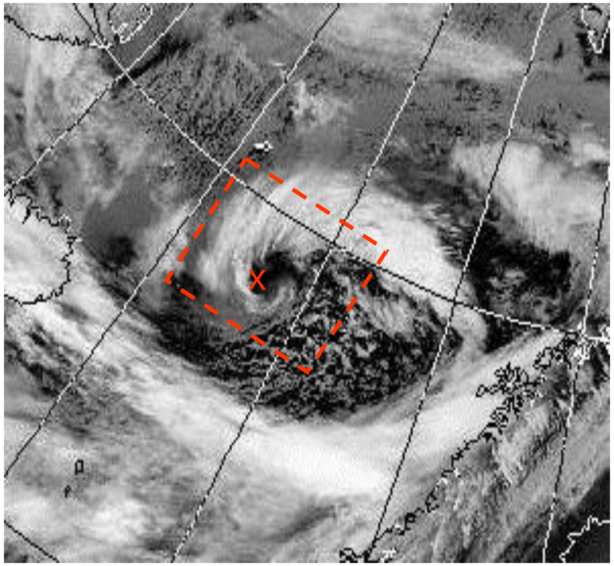


Parameterized



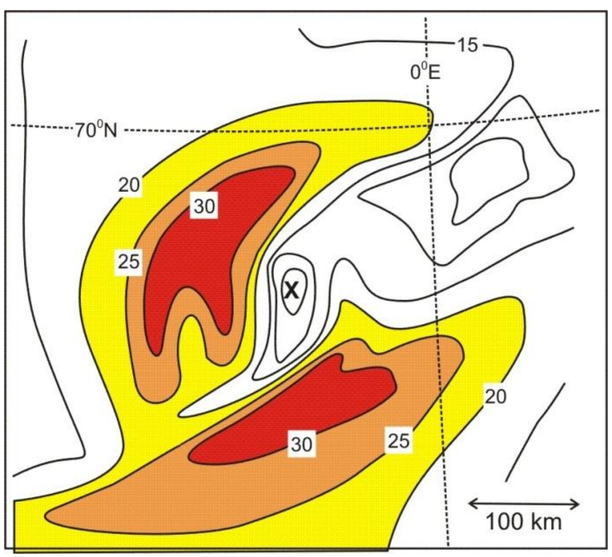
SATELLITE (QUIKSCAT)



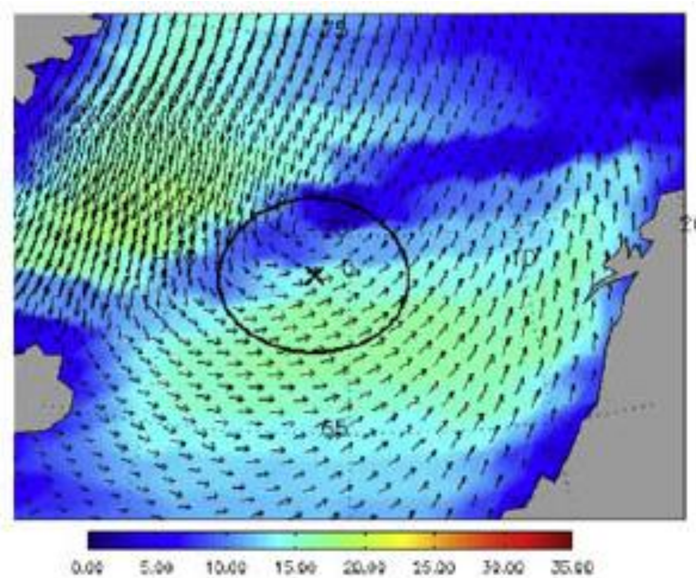


Above: 13:41 GMT 27 February 1984

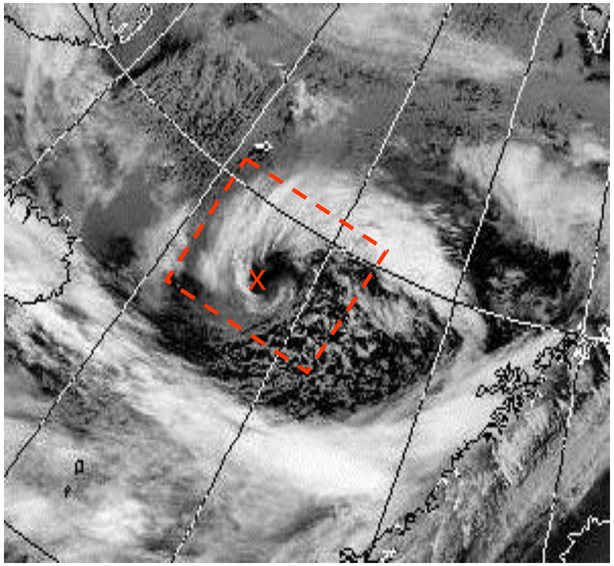
- 26-27th February, 1984 (Shapiro et al.1987)
- ~400 km diameter
- Max wind speed: 35 m/s in main cloud band



Above: airborne wind speed observations



Above: ERA-40 12 UTC 27 February 1984



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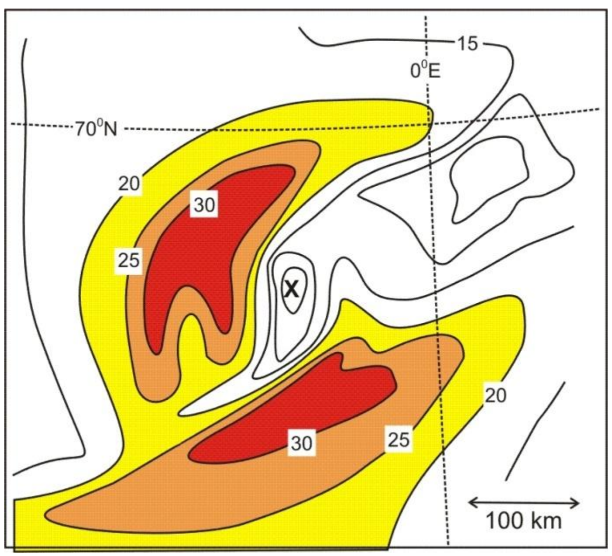

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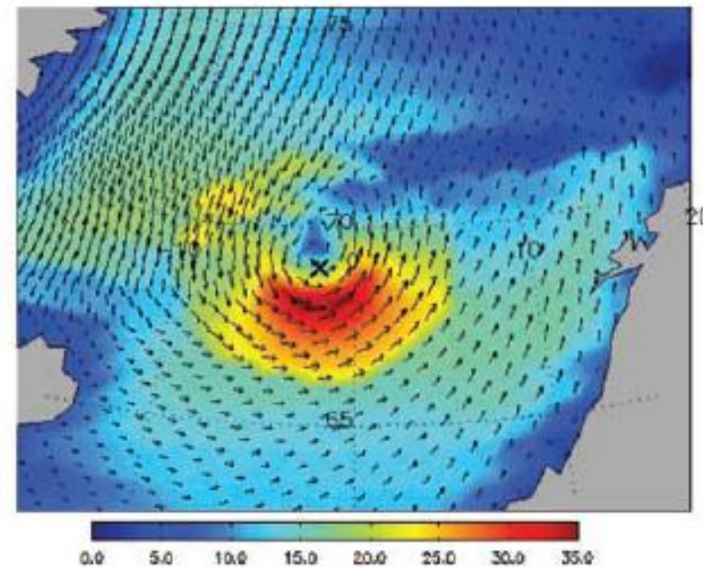

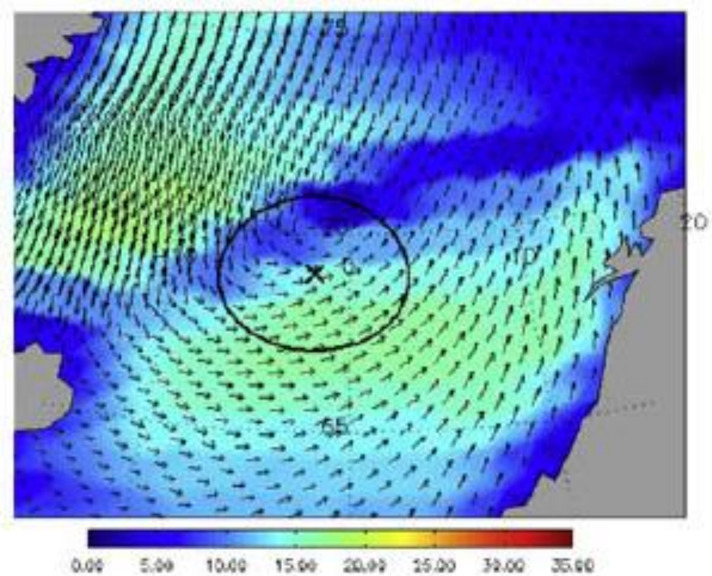

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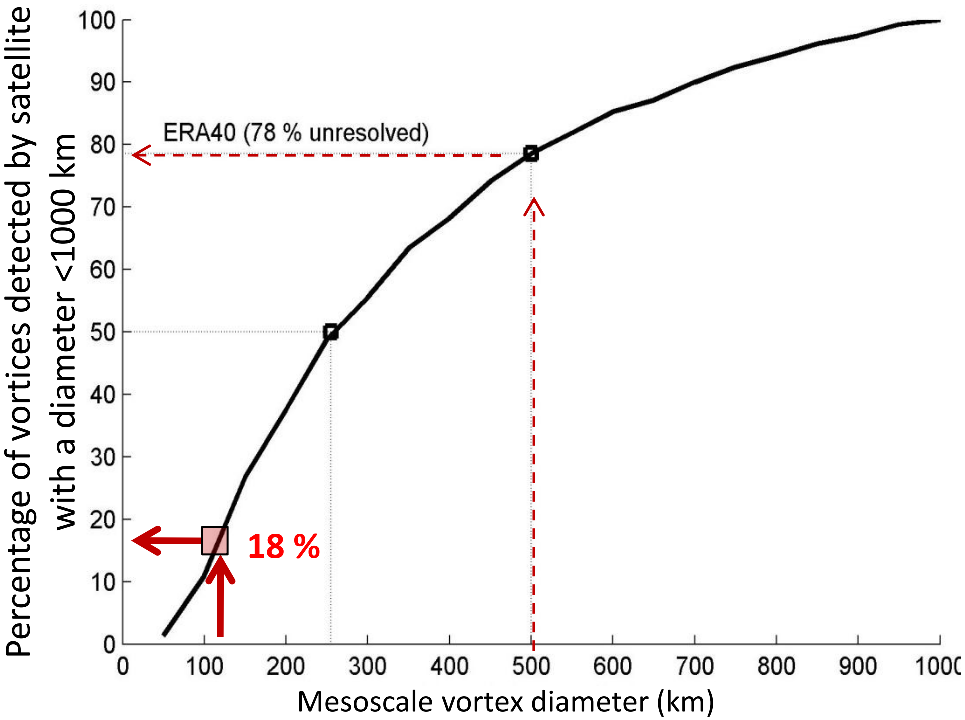
Parameterizing Polar Lows

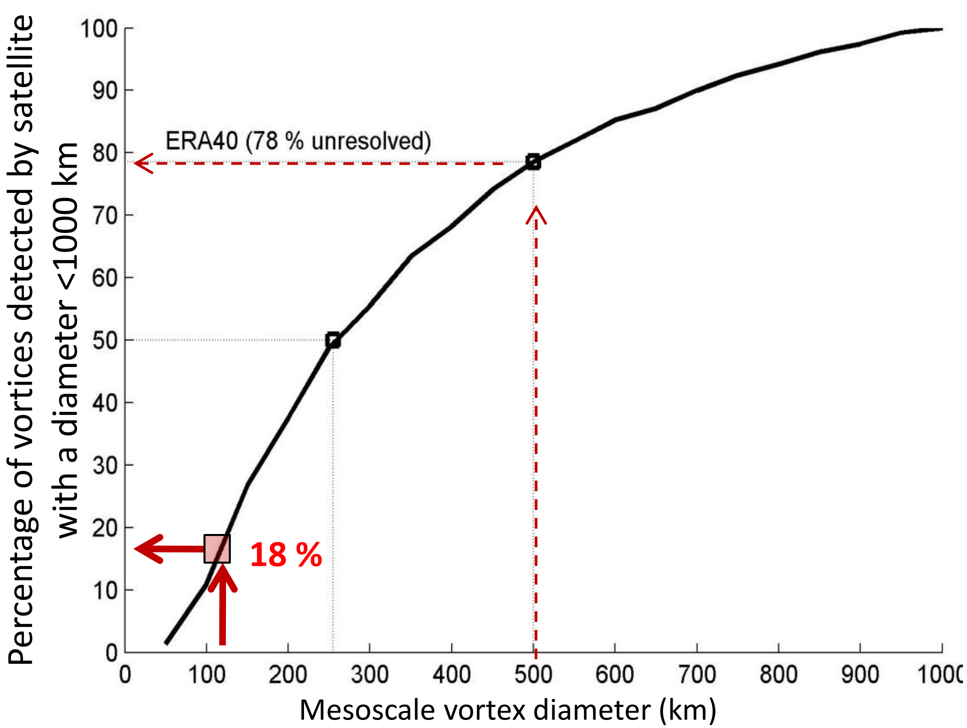
- **Experiment I**
- PL from satellite database
- Regrid + Parameterization -> only 18% unresolved
- 2 Year Ocean GCM run (FRUGAL)

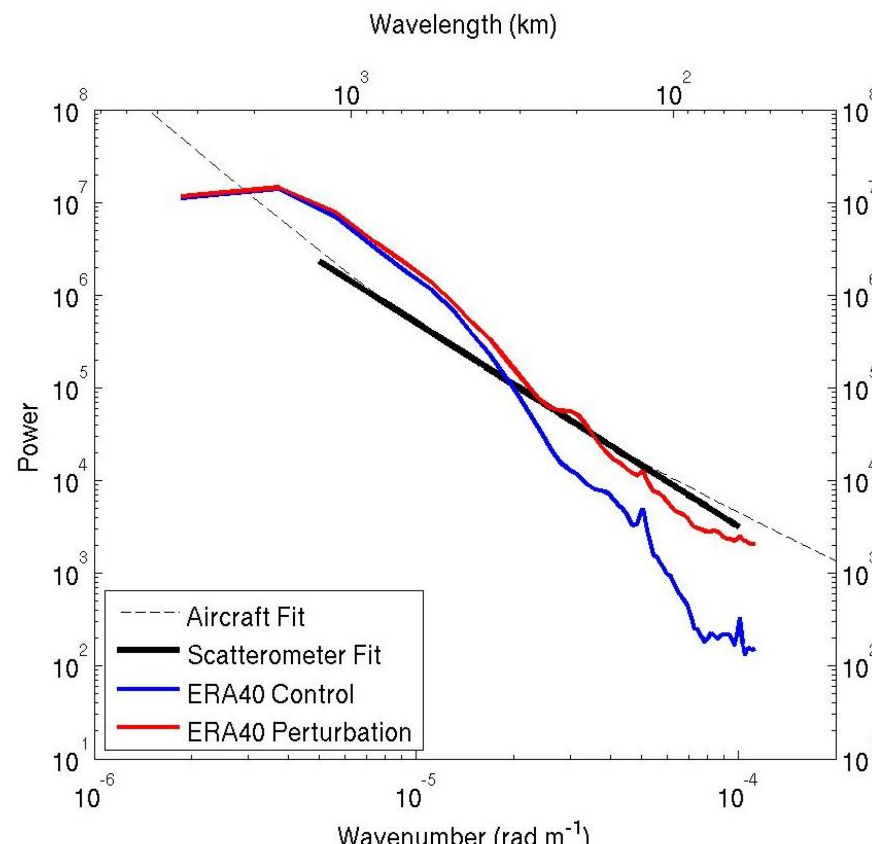


Parameterizing Polar Lows

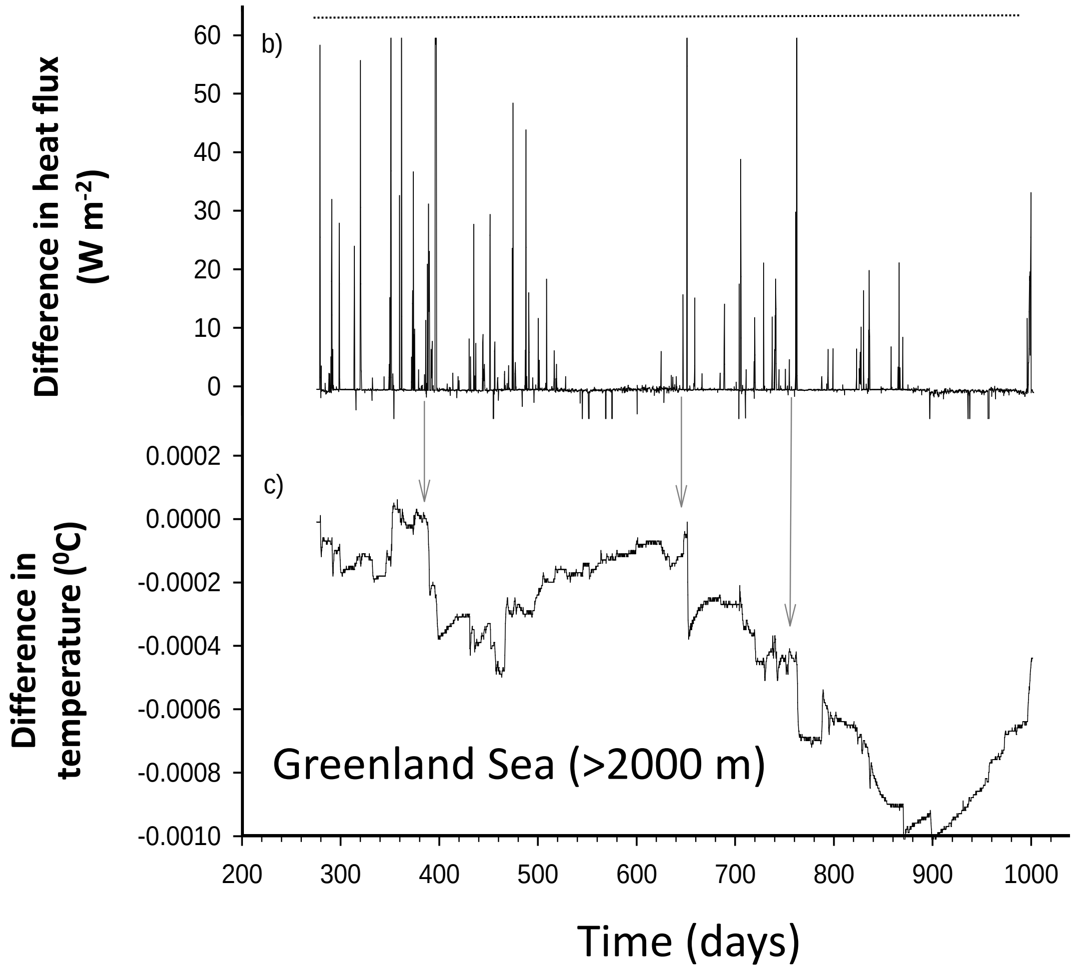
- **Experiment I**
- PL from satellite database
- Regrid + Parameterization -> only 18% unresolved
- 2 Year Ocean GCM run (FRUGAL)

- **Experiment II**
- PL from cyclone detection algorithm
- Regrid + Parameterization -> improvement in wind speed spectra
- 20 Year Ocean GCM run (MITgcm)





Experiment I: Changes in the Nordic Seas



- Increased surface heat flux → Cooling/densification of the deep water (>2100 M) in the Greenland sea.
- Impact of individual storms observed to cause localized deep convection
- General spin up of Nordic Seas gyre

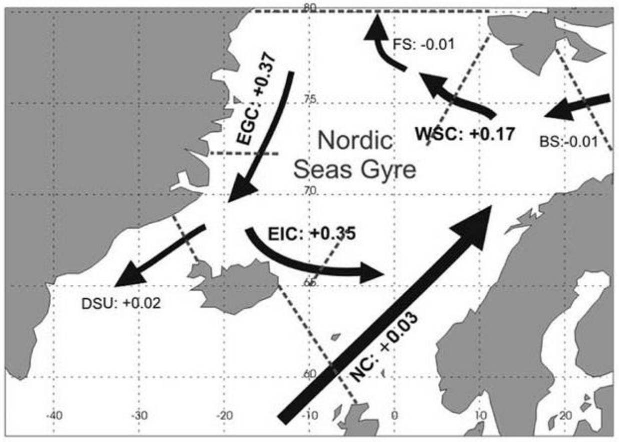
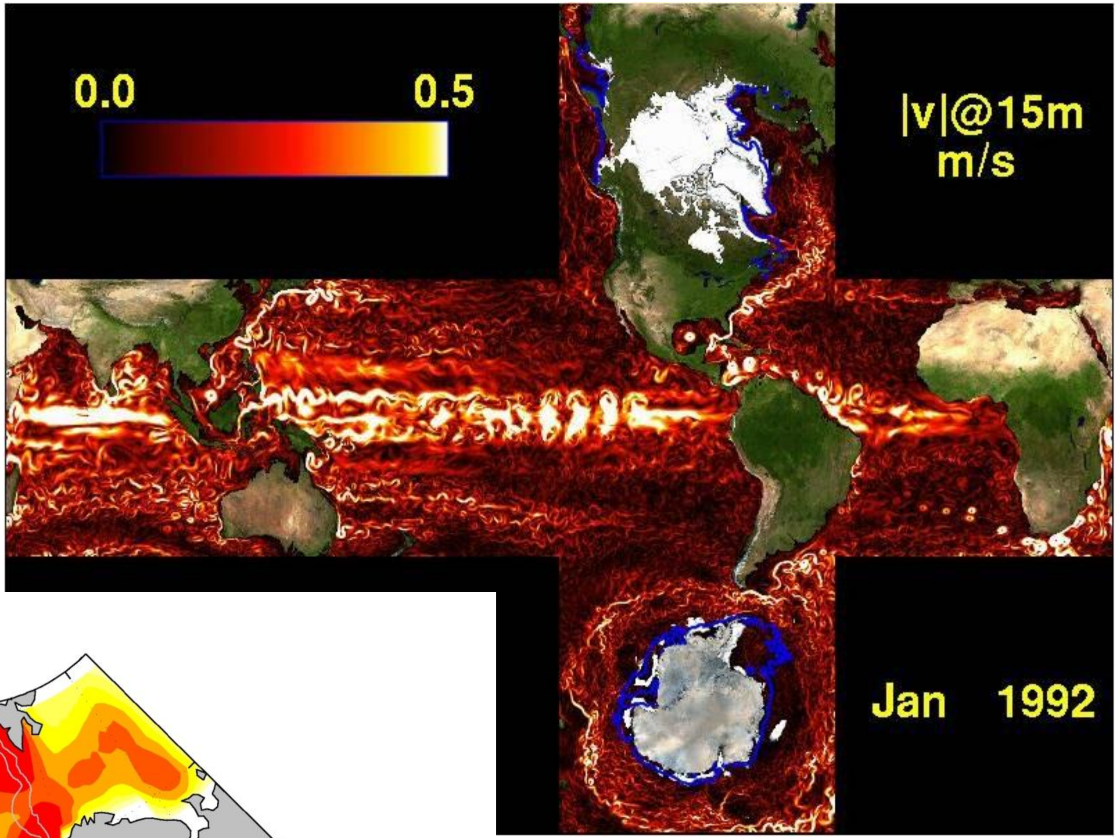


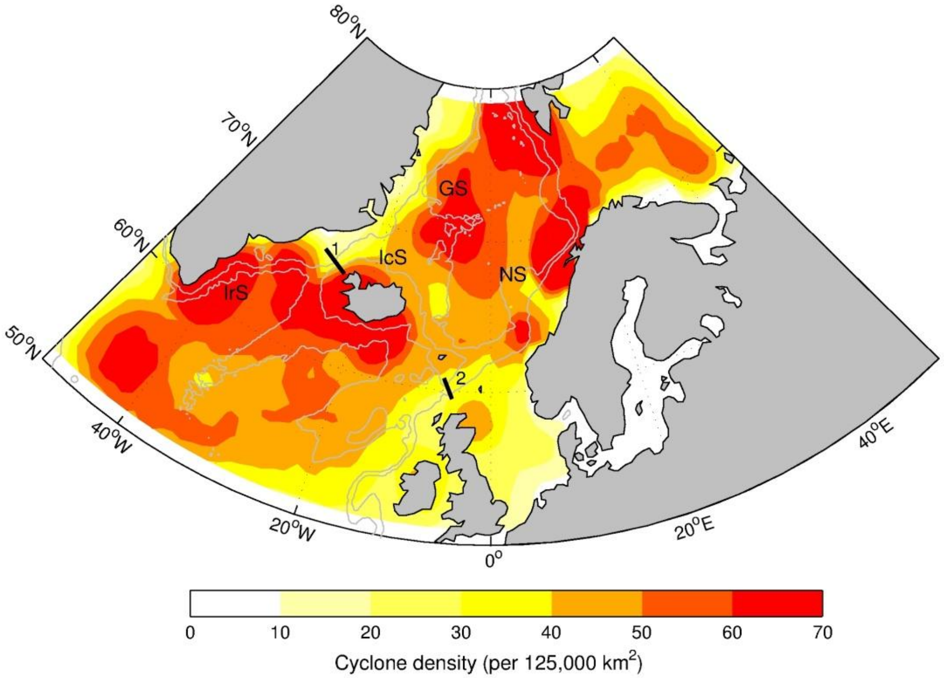
Figure 9. A schematic illustrating the spin up of the Nordic Seas gyre during the second winter (DJFM) in the perturbed run, as a result of increased volume transports in the Norwegian Current (NC), West Spitzbergen Current (WSC), East Greenland Current (EGC), and East Icelandic Current (EIC). Positive values indicate an increase in volume transport (in the direction of the arrow) in the perturbed run, compared to the control run, with the volume changes indicated in Sverdrups (Sv).

From Condron, Bigg & Renfrew 2008, JGR

Experiment II: MIT gcm at 1/6° (20 Year run)

- MITgcm ocean sea-ice model
- Eddy permitting resolution (1/6 degree)
- Global, cube-sphere configuration

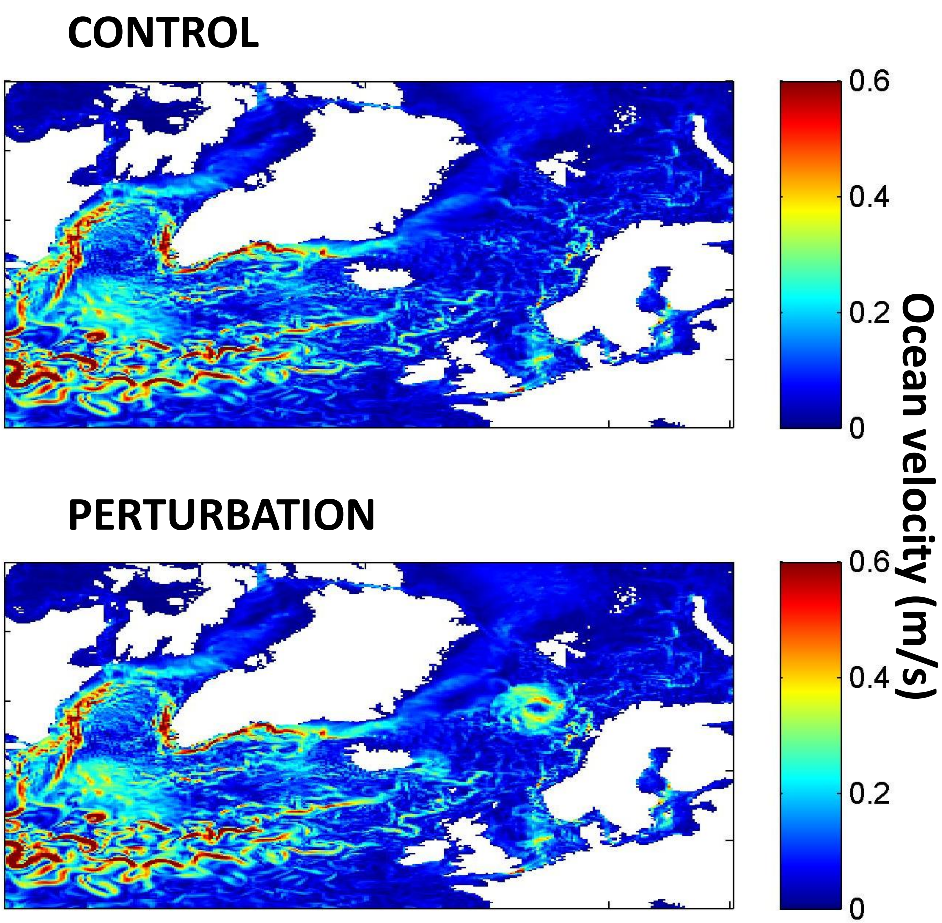


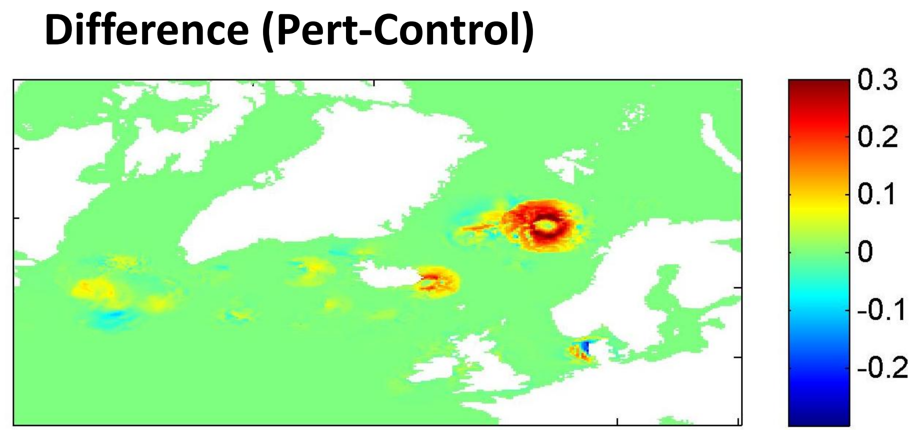


- Annual mean density of polar mesoscale cyclones added to the atmospheric forcing fields
- In good agreement (r = 0.75) with satellite data base

Experiment II: MIT gcm at 1/6^{o} (20 Year run)

Localized stirring in the upper ocean





Passage of intense mesoscale storms can leave a cyclonic signature in the surface ocean velocity field.

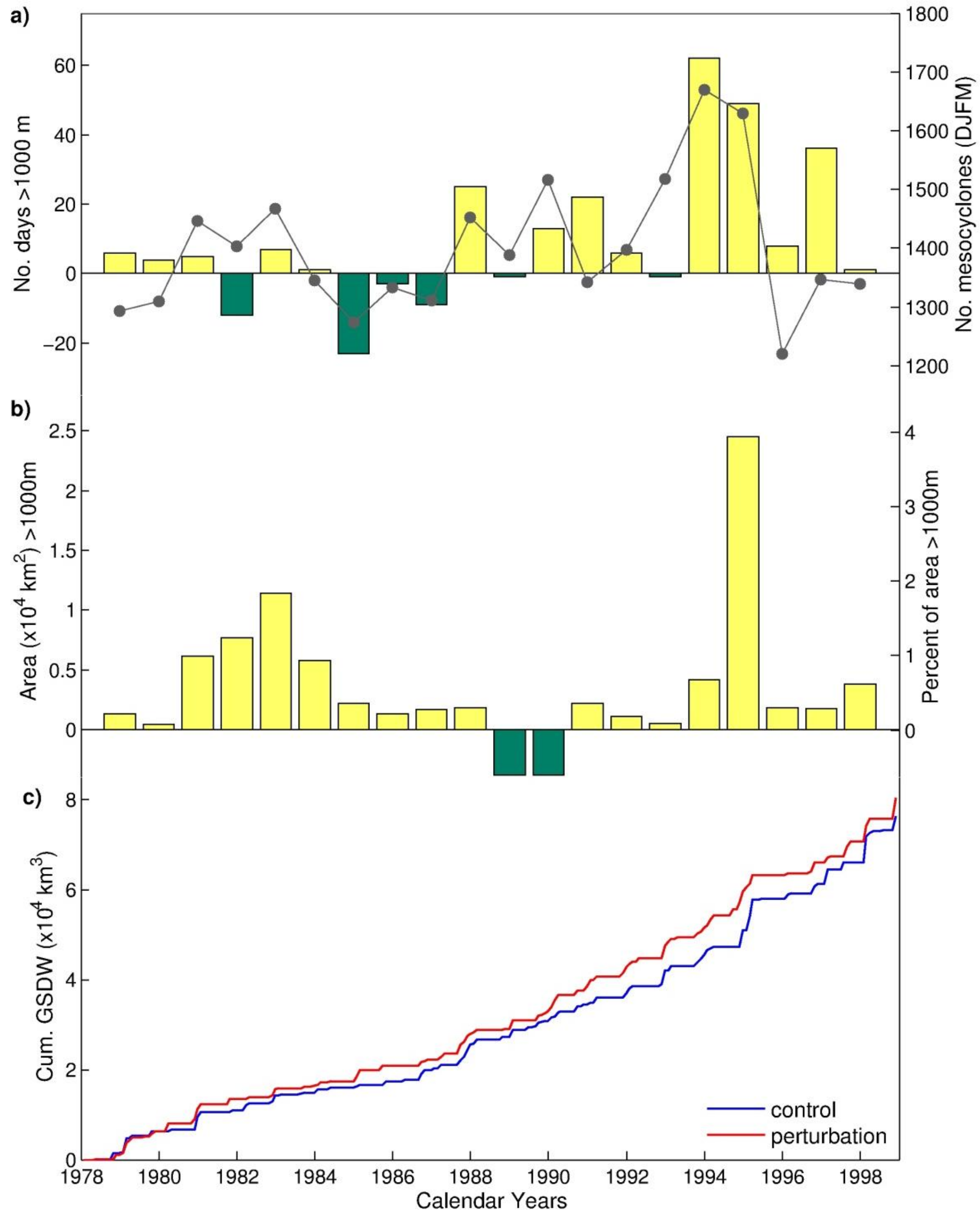
Experiment II: MIT gcm at 1/6° (20 Year run)

Impact on deep convection in the Greenland Sea

(a) The difference in the number of days each year with open-ocean convection exceeding 1000 m, plus the number of polar lows;

(b) The difference in area of the Greenland Sea over which open-ocean convection exceeds 1000 m;

(c) The cumulative volume of GSDW formed. Note that the total production of GSDW increases by 4.1 x 10^3 km^3 (5.3 %) in the experiment with parameterized polar lows.



Experiment II: MIT gcm at 1/6° (20 Year run)

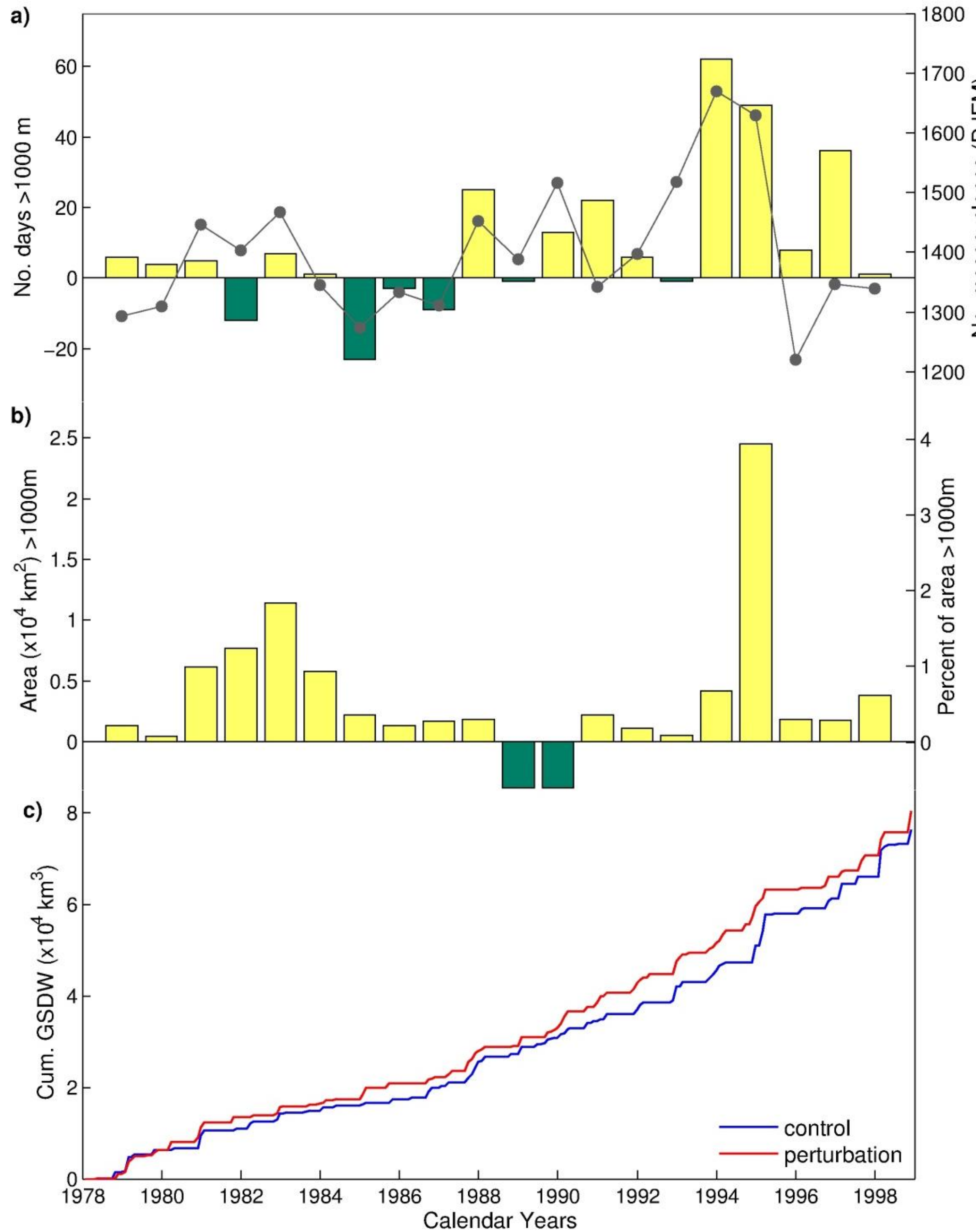
Impact on deep convection in the Greenland Sea

- Increase in maximum convective depth of 108 m (13%)

- Increase in the average MLD of 12 m (9%)

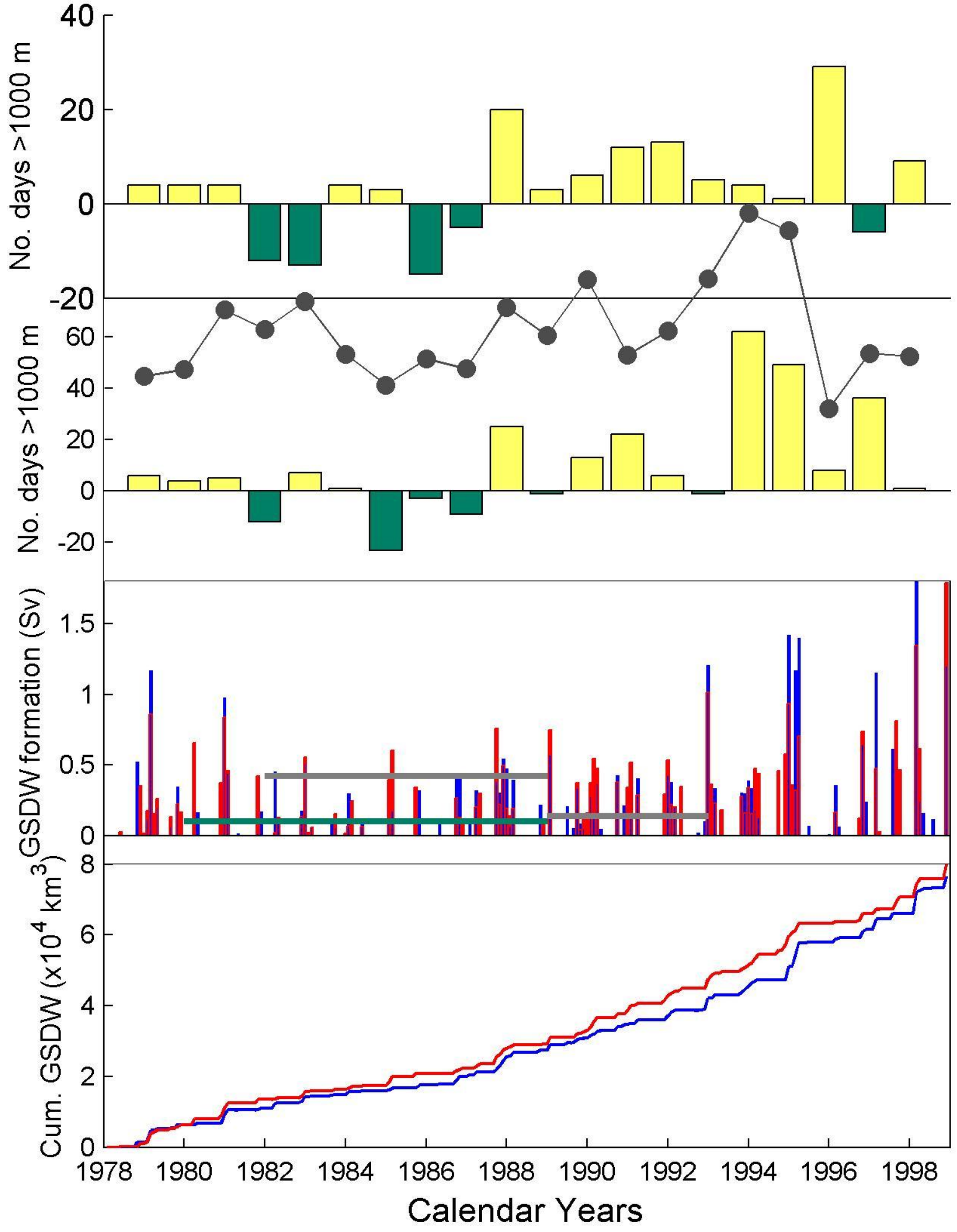
- Both statistically significant at 99% confidence level

- Increase in frequency of deep convection by 14.7 days on average (8%)



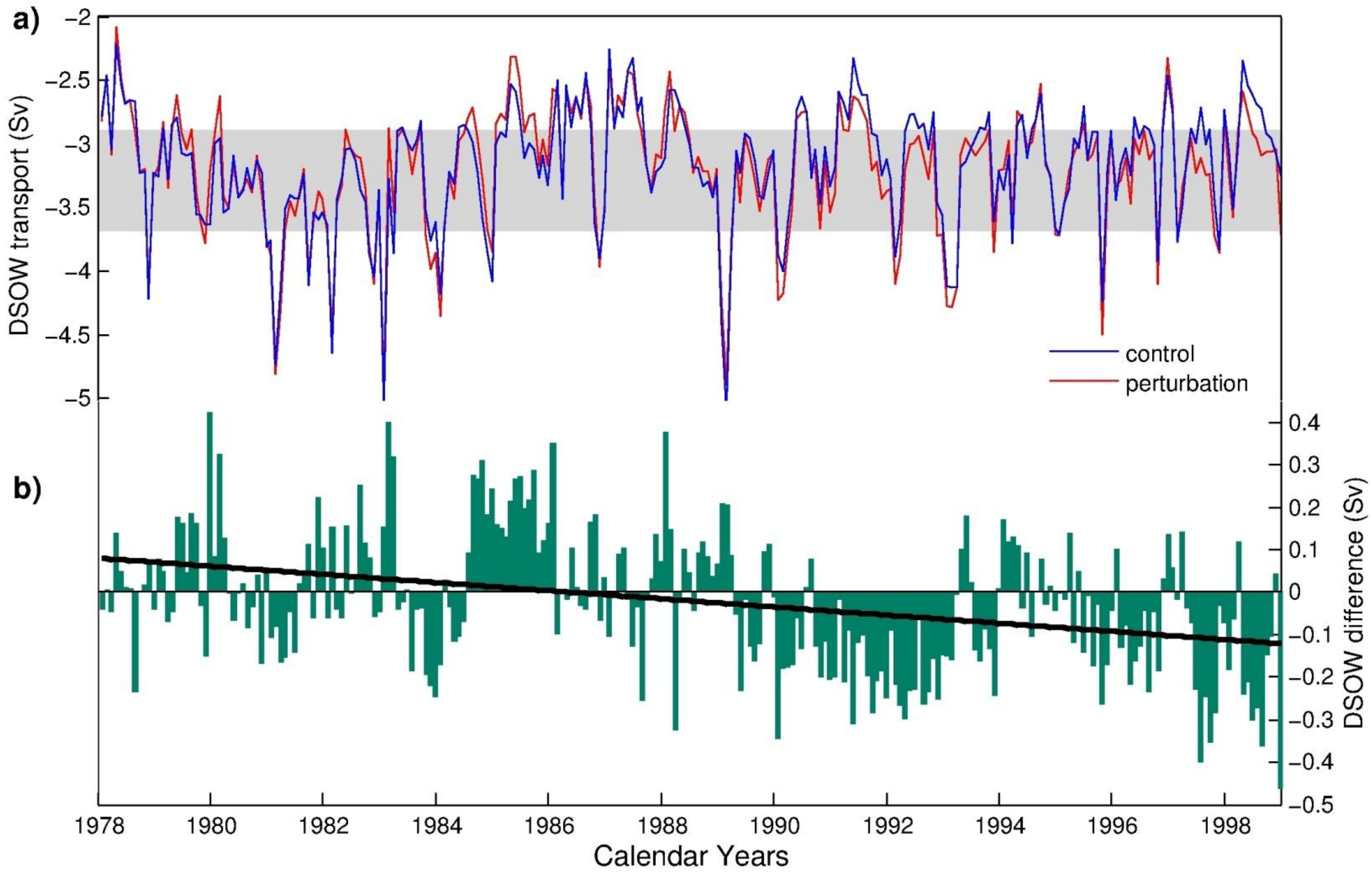
Experiment II: MIT gcm at 1/6°

Impact on deep convection in the Irminger Sea



Experiment II: MIT gcm at 1/6^{o} (20 Year run)

Impact on dense water overflowing Denmark Strait



(a) Monthly transports through Denmark Strait. The mean transport of -3.2 Sv in the Control experiment compares very well to the observational range of -2.9 to -3.5 Sv (Grey shading);

(b) The difference in the volume of DSOW at Denmark Strait. There is a sustained increase in the volume of DSOW in the Perturbation experiment after 10 years, leading to an additional 3.1 x 10^4 km^3 (3 %) of deepwater reaching the North Atlantic.

Conclusions

- Mesoscale cyclones extract large amounts of heat from the ocean → climatically significant.
- Reanalysis data fail to capture a large fraction of these vortices → under-represent air-sea heat and momentum flux.
- Parameterizing cyclones as Rankine vortices results in a considerably more realistic forcing field.
- The ocean responds to this forcing, especially when modelled at an eddy resolving resolution.
  - Deeper and more frequent convection, more deep water formation (both Greenland Sea and Irminger Sea)
  - Increase in dense water out of Nordic Seas
  - Increase in poleward heat transport

- Condron, A., G. R. Bigg, and I. A. Renfrew, 2008: Modeling the impact of polar mesocyclones on ocean circulation, *J. Geophys. Res.*, 113, C10005, doi:10.1029/2007JC004599.
- Condron, A. and I. A. Renfrew, 2012: ‘Missing’ polar lows enhance deep water formation in the Nordic Seas, *Nature Geoscience,* **under review.**

Experiment I: Wind speed spectra over Nordic Seas