The Sensitivity of Polar Ozone Recovery to Catastrophic Sea-Ice Loss in the Northern Hemisphere

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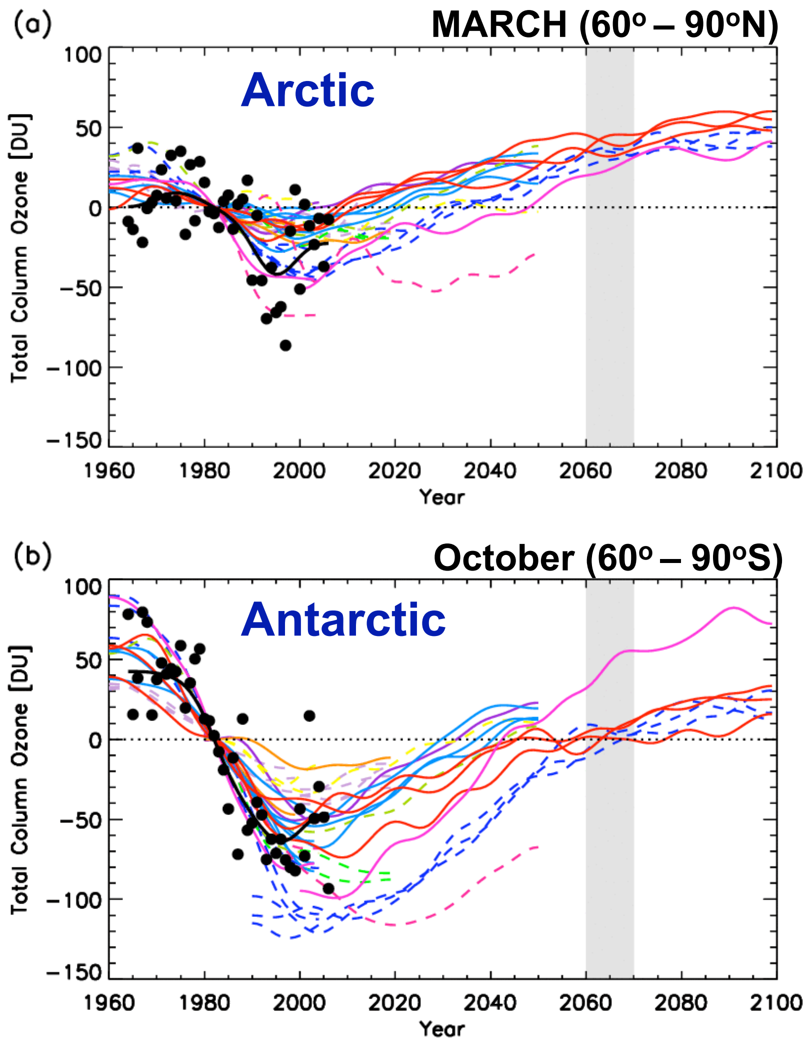
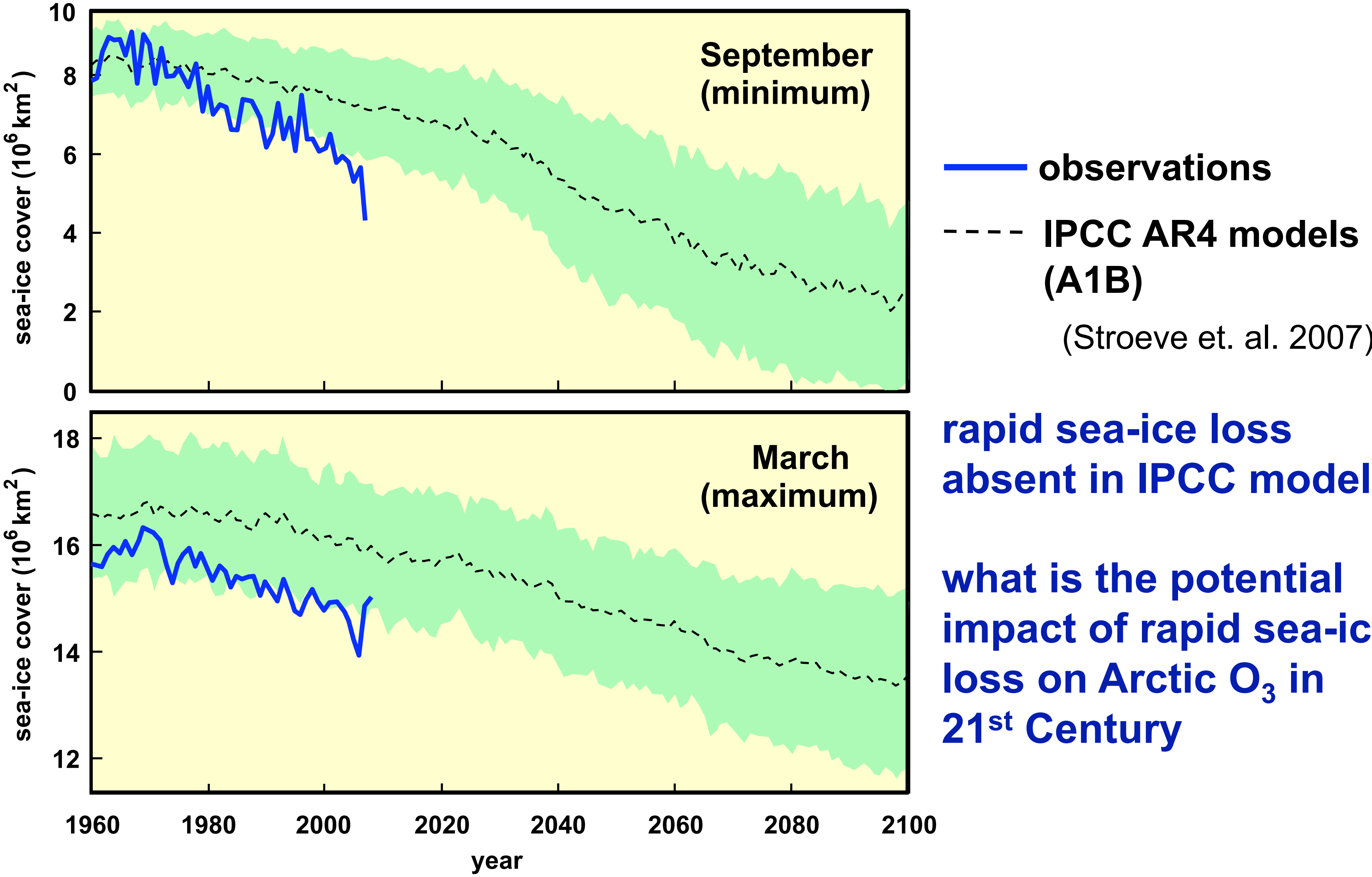
Polar Ozone Projections (total column anomalies)



- **climate change**
  - radiative impact of evolving CO_2
  - changes to stratospheric wave forcing (increased BD circulation)
- **reduction of ODS**
  - return of Cl_y to 1980 values

(Eyring et al. 2007)

Arctic Sea-Ice Cover



rapid sea-ice loss absent in IPCC models

what is the potential impact of rapid sea-ice loss on Arctic O_3 in 21st Century

Model Configuration

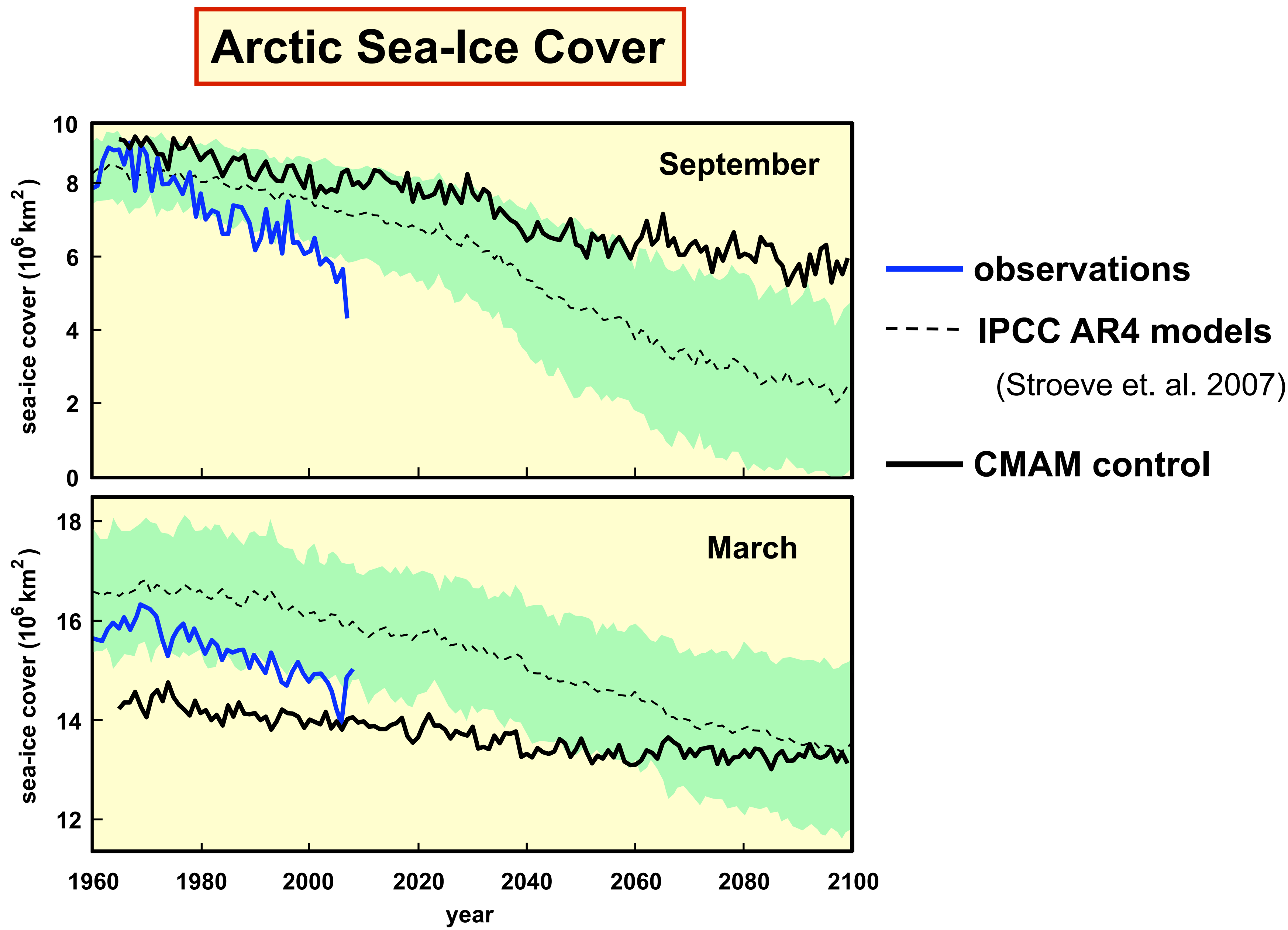
- **couple CMAM to an OGCM**

CCM: – CMAM configuration for WMO 2006 ozone assessment

OGCM:
– modified version of NCOM1.3 (Gent 1998)
– 1.86°, 29 vertical levels, Δz=50m upper ocean, Δz=300m deep ocean
– Gent McWilliams (1990) eddy mixing parameterization
– 3rd order upstream tracer advection
– modified KPP surface mixed layer param. (Large et al., 1994)
– Anisotropic horizontal viscosity (Large et al., 2001)
– Tidally-driven bottom mixing based on Simmons et al. 2004

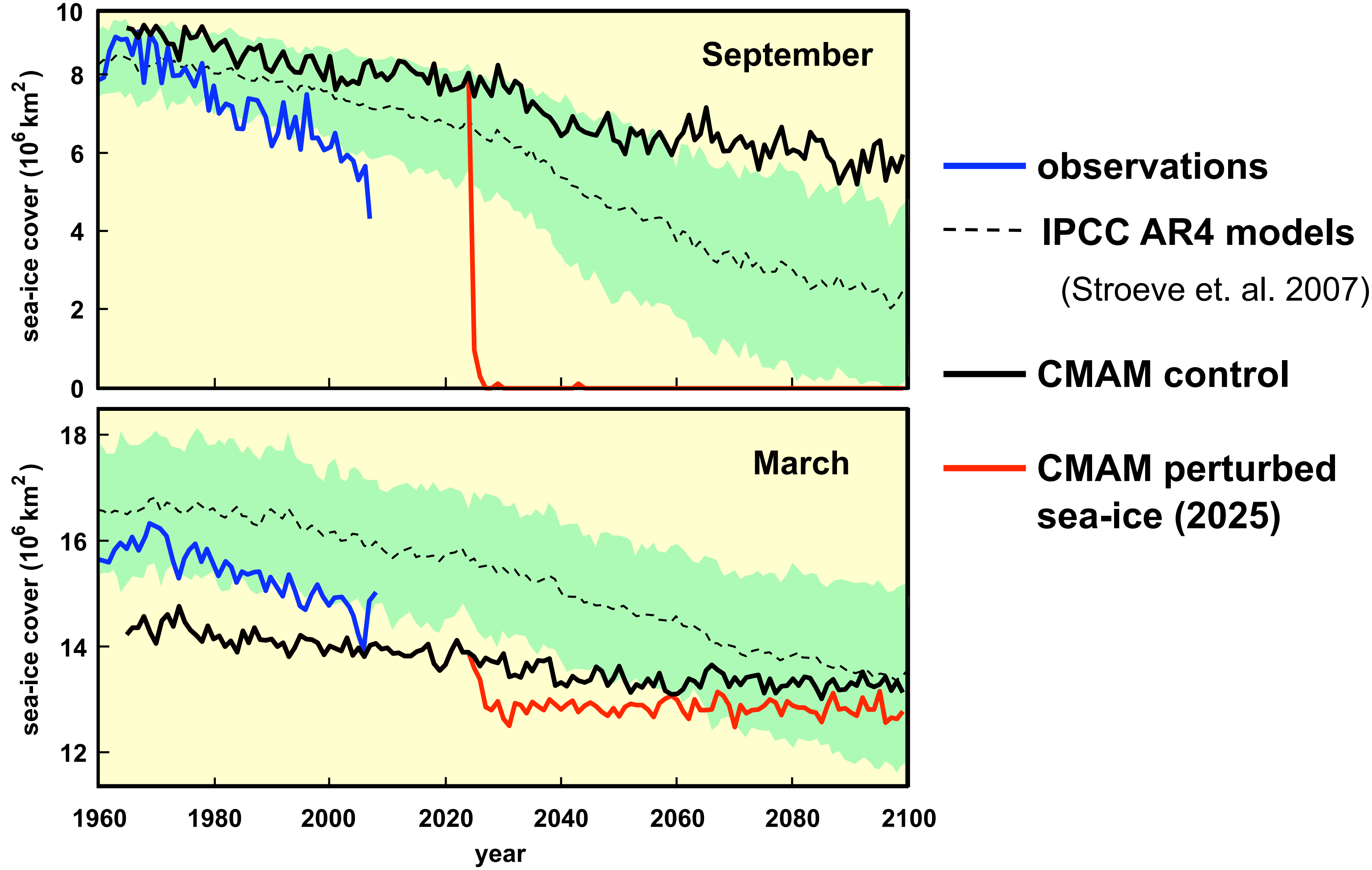
- **control: ensemble (3) following CCMVal REF2 1950-2100 scenario**
- **experiment: ensemble (3) perurb sea-ice (2025) to induce rapid loss**

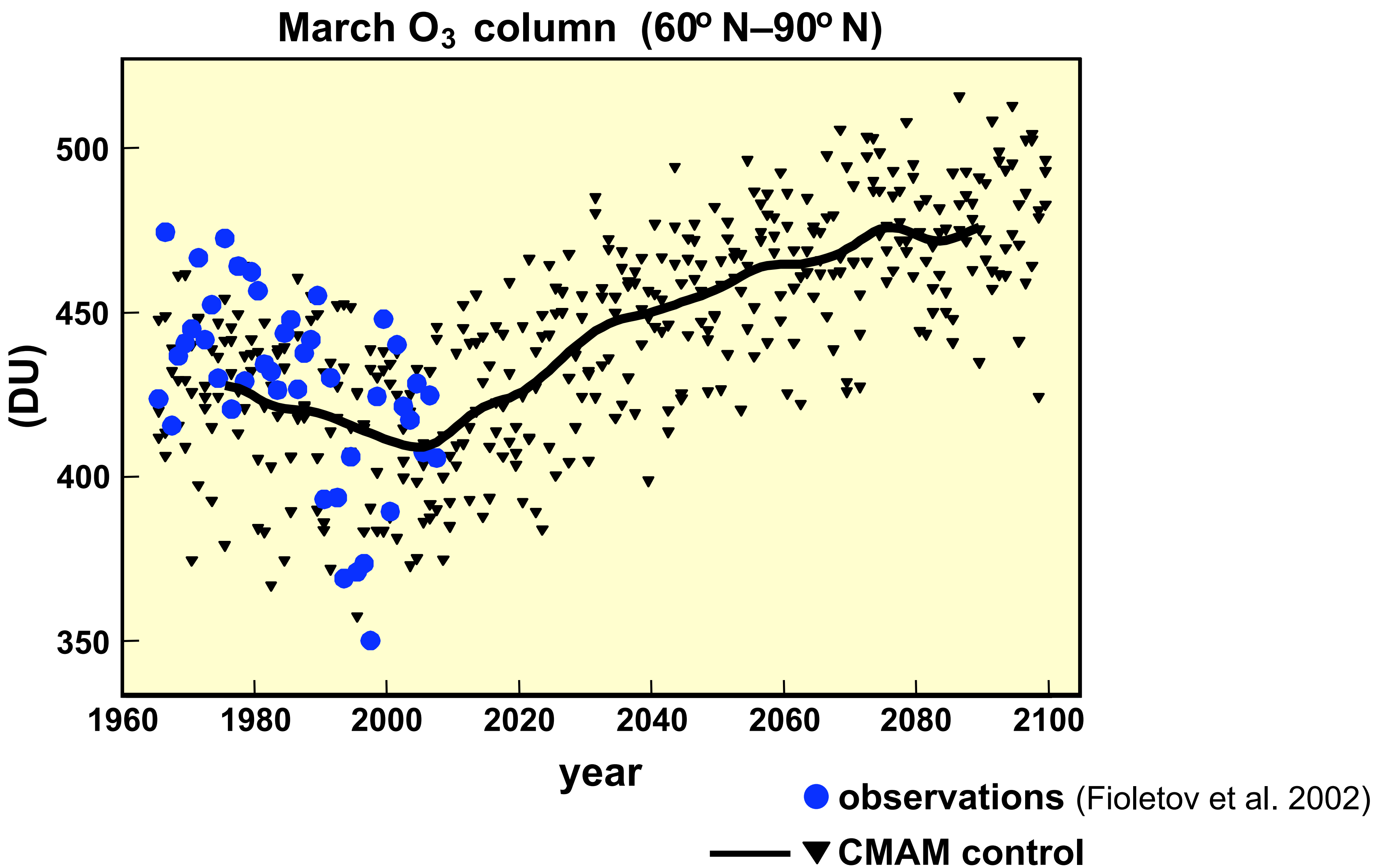
– change (reduce) albedo of NH sea ice

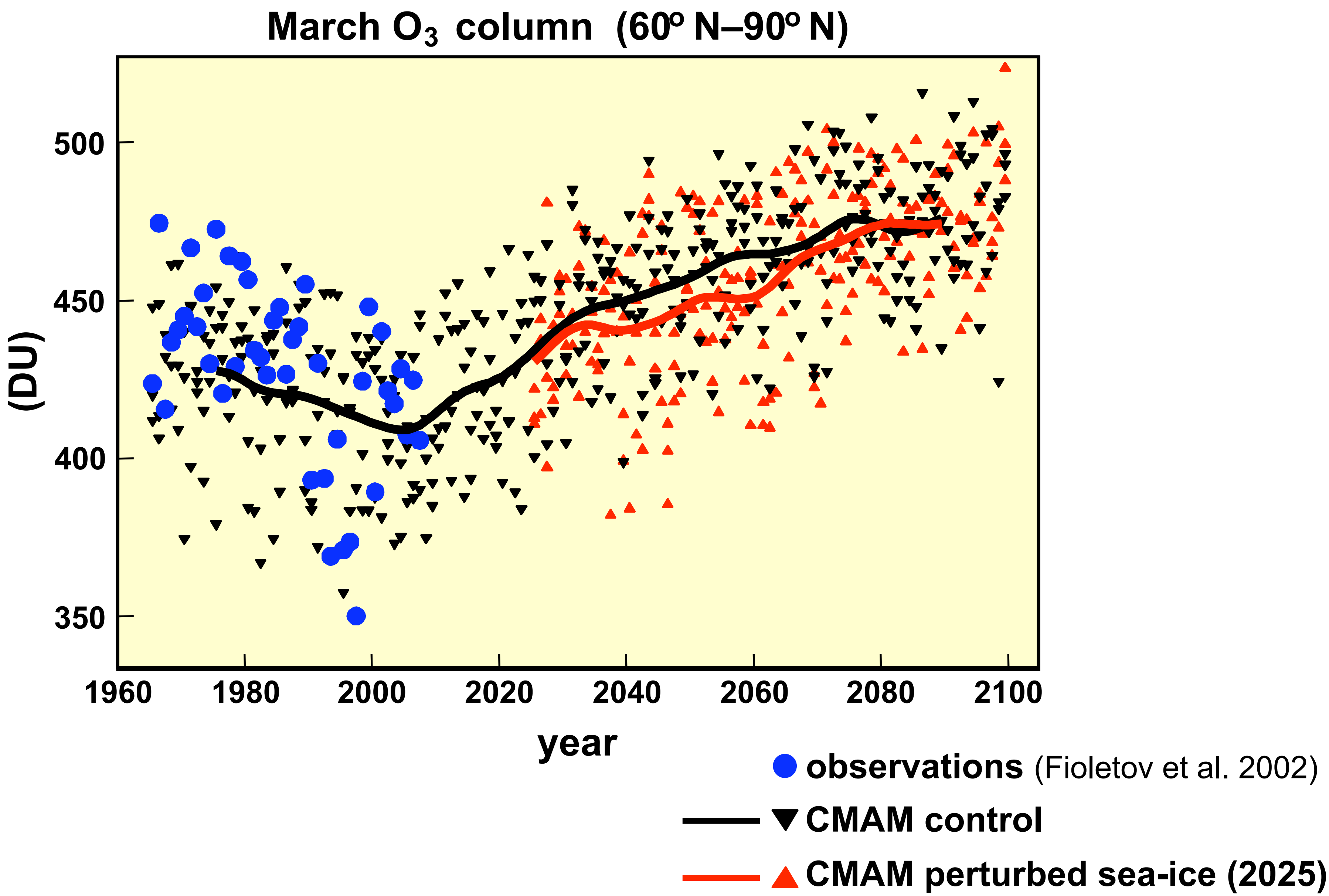


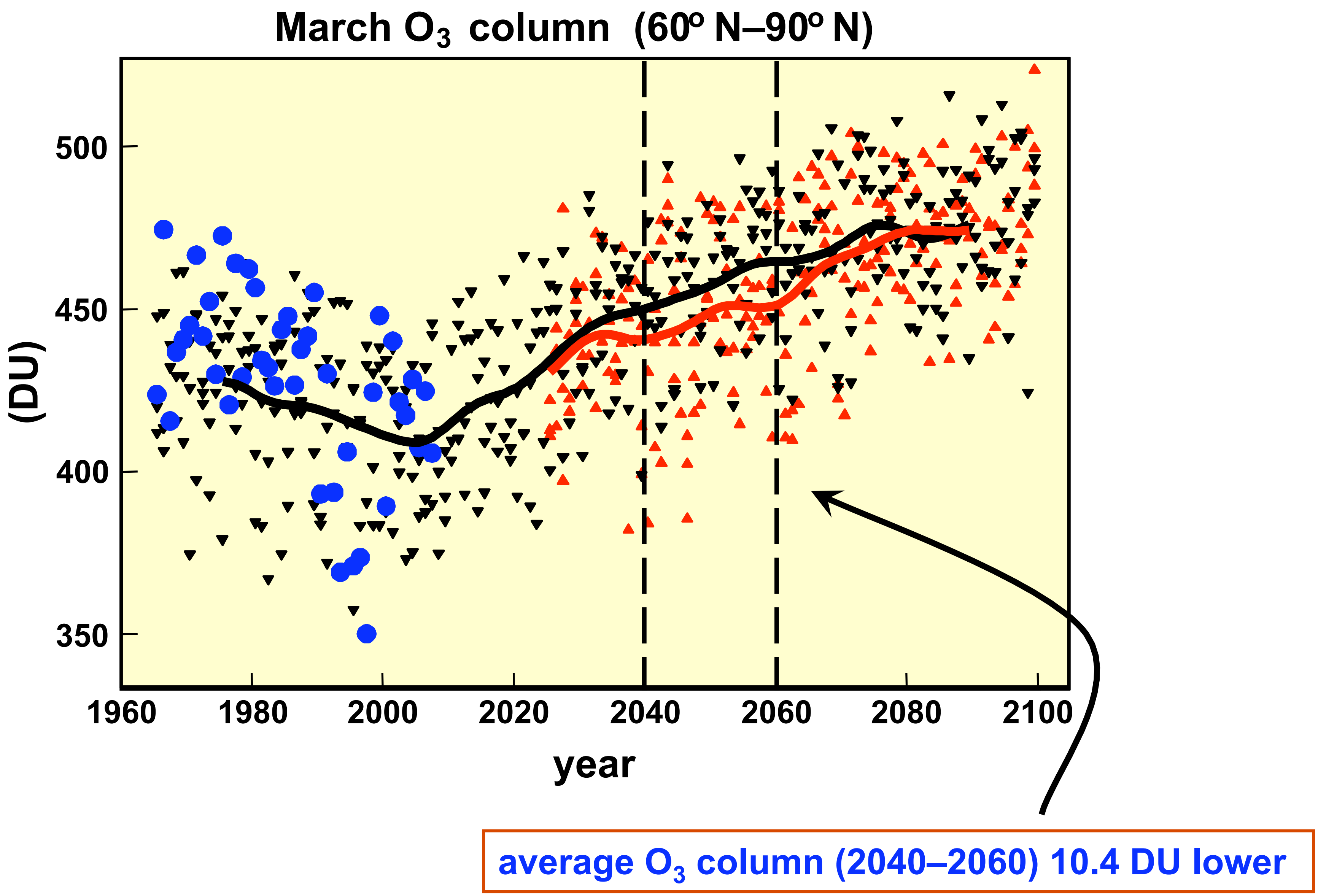
Arctic Sea-Ice Cover
September
March
sea-ice cover (10^6 km^2)
10
8
6
4
2
0
18
16
14
12
1960
1980
2000
2020
2040
2060
2080
2100
year
observations
IPCC AR4 models
(Stroeve et. al. 2007)
CMAM control

Arctic Sea-Ice Cover

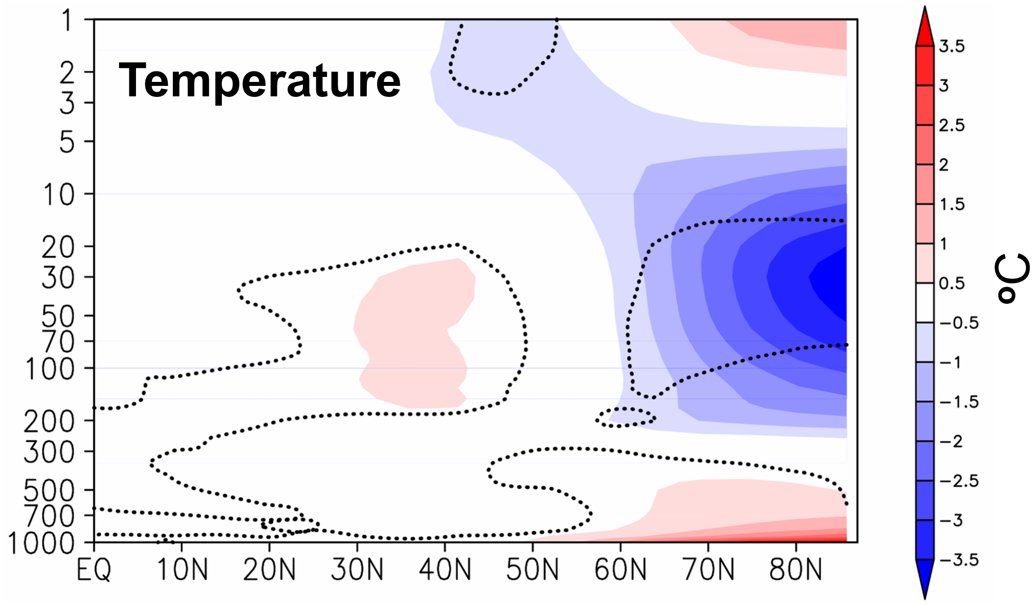



March O3 column (60º N–90º N)
(DU)
500
450
400
350
1960
1980
2000
2020
2040
2060
2080
2100
year
observations (Fioletov et al. 2002)
CMAM control


March O_3 column (60° N–90° N)
(DU)
500
450
400
350
1960
1980
2000
2020
2040
2060
2080
2100
year
observations (Fioletov et al. 2002)
CMAM control
CMAM perturbed sea-ice (2025)



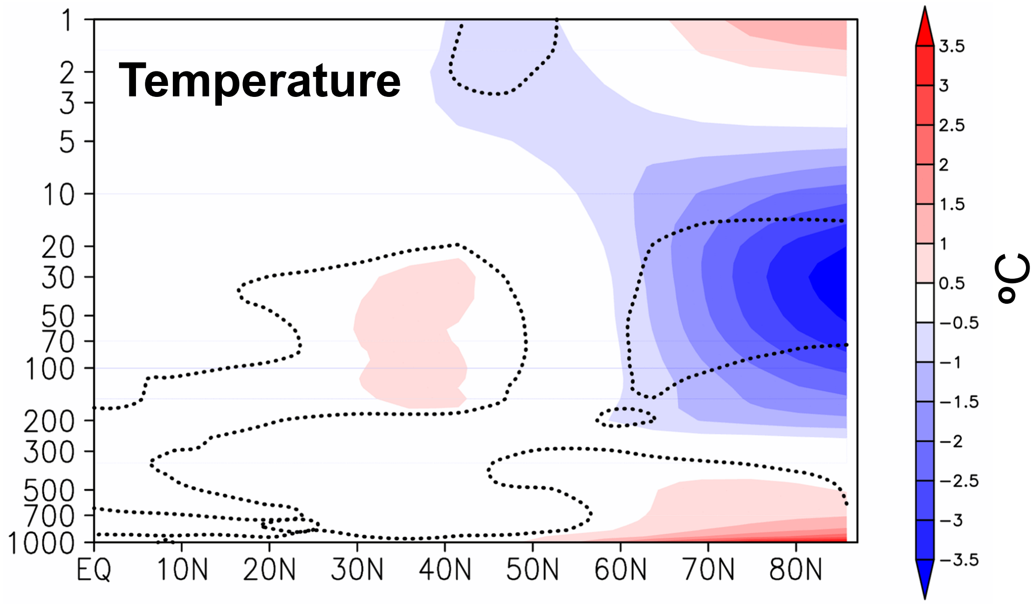
March O_3 column (60° N–90° N)
(DU)
500
450
400
350
1960
1980
2000
2020
2040
2060
2080
2100
year
average O_3 column (2040–2060) 10.4 DU lower



CMAM T anomaly

(sea-ice perturbation – control)

March (2040 – 2060)



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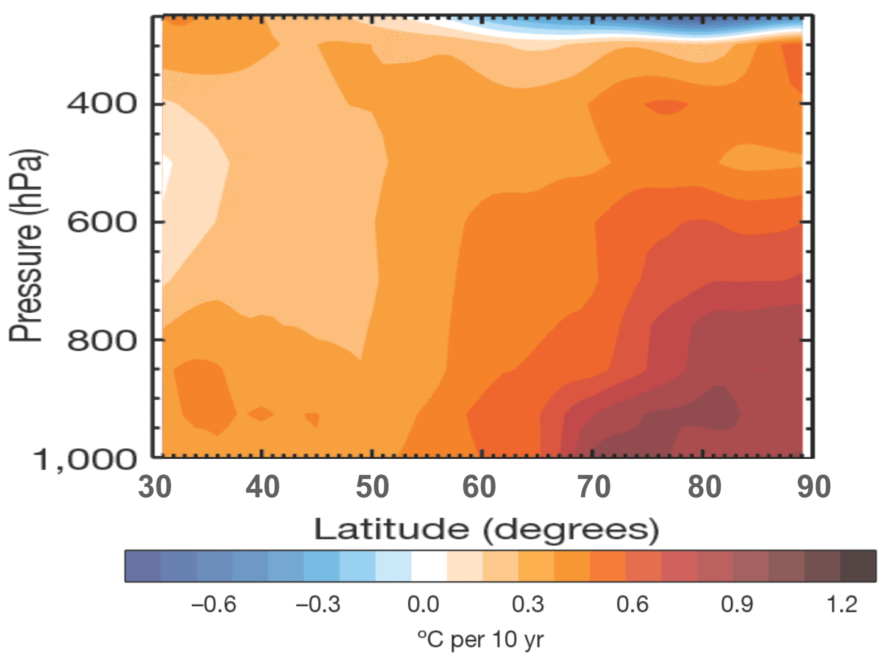
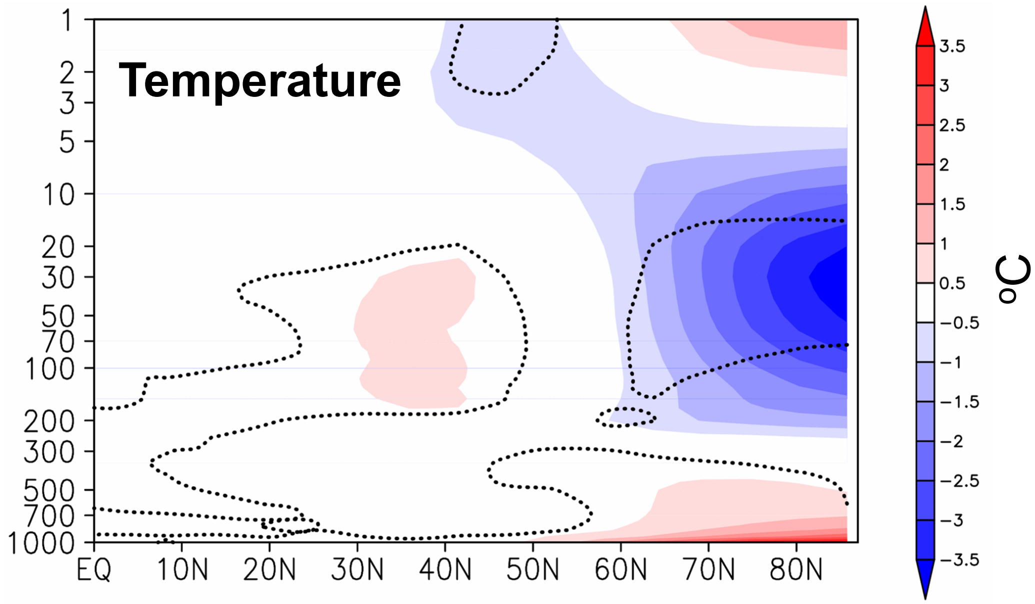


ERA40 T trend

March-May (1979 – 2001)

“Arctic amplification”

(Graversen et al. 2008)



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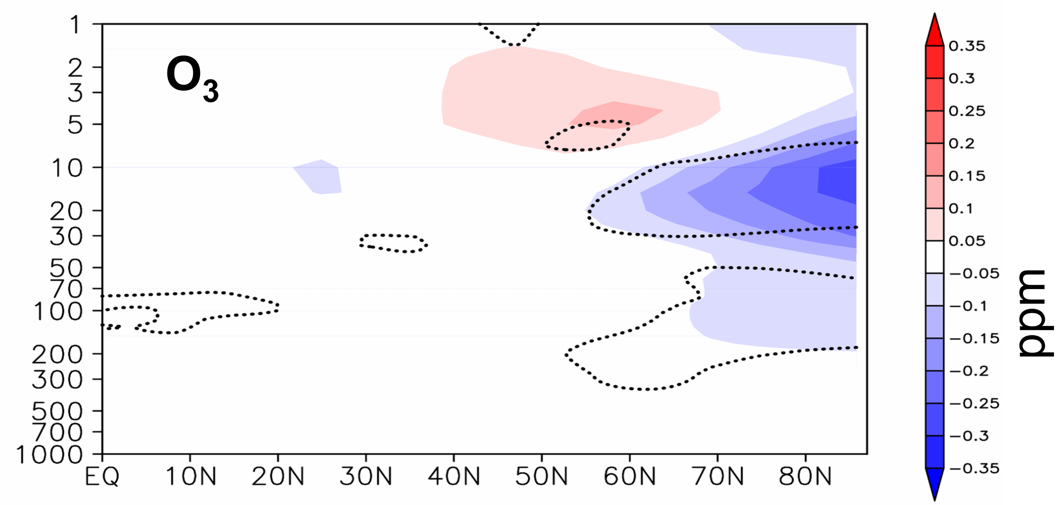
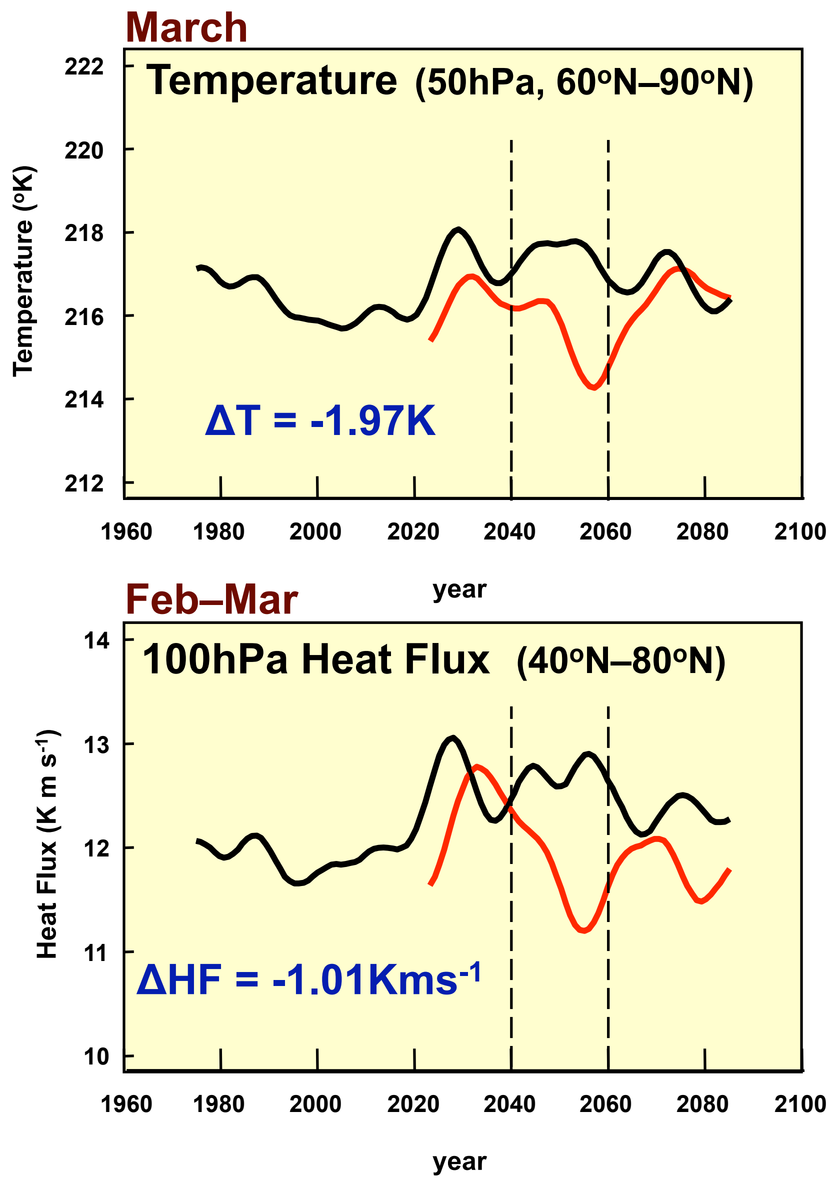


CMAM O_3 anomaly

(sea-ice perturbation – control)

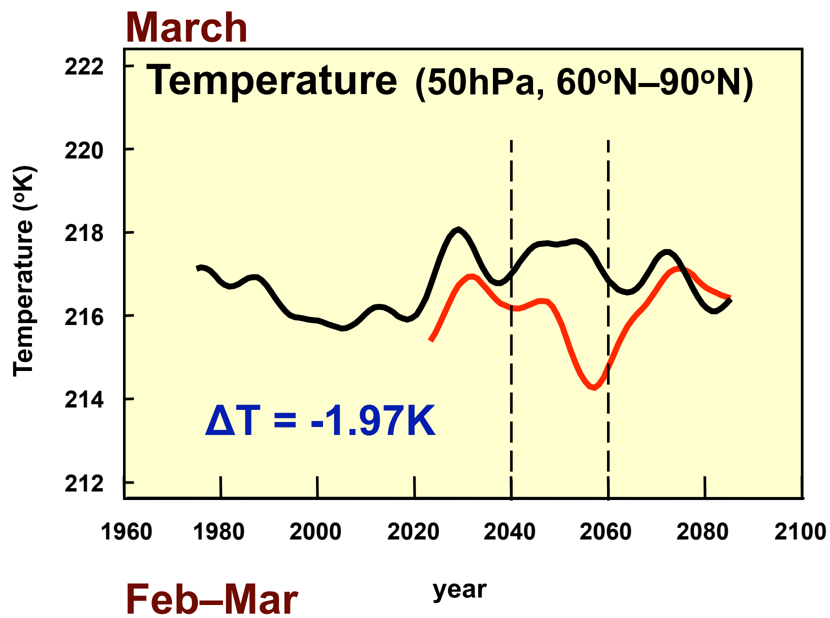
March (2040 – 2060)

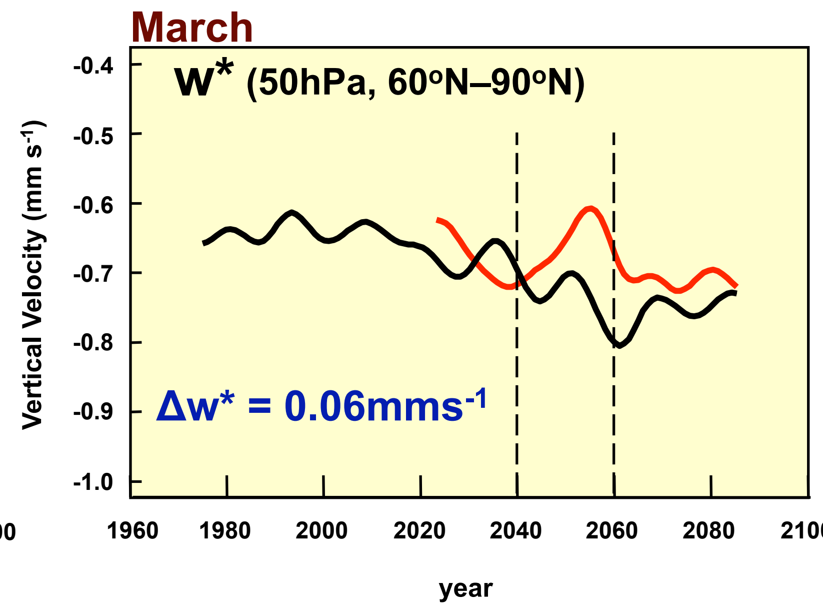


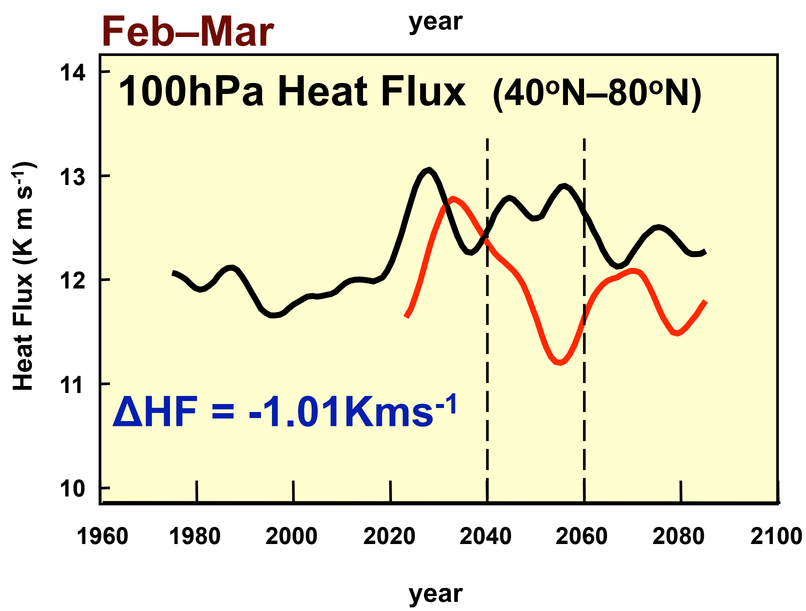
- March polar temperatures nearly 2° colder during the period (2040-2060)

- associated with roughly an 8% reduction of wave forcing during (2040-2060)

CMAM control   CMAM perturbed sea-ice (2025)

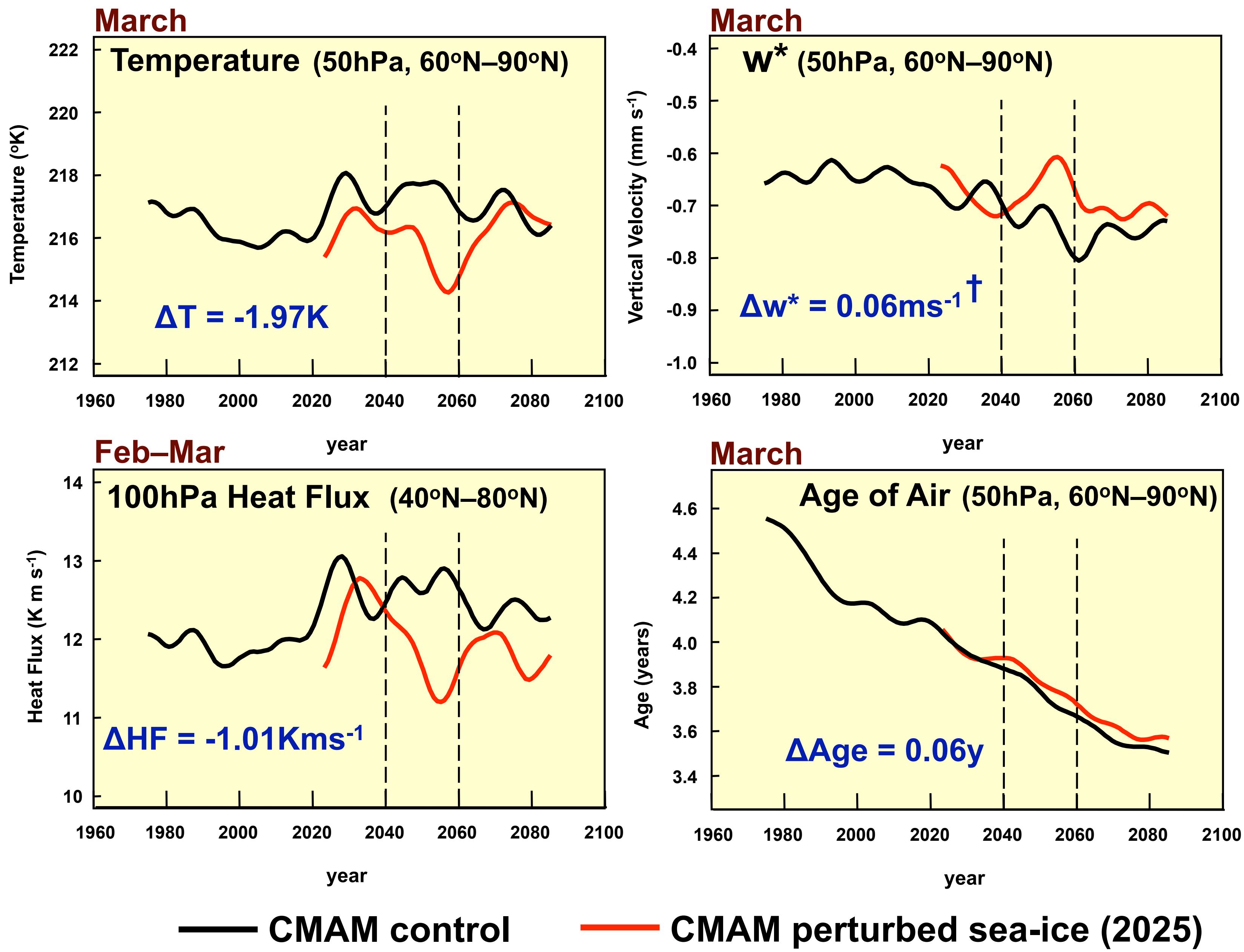






- weaker downwelling over the pole during (2040-2060)
- reduced of BD circulation trend

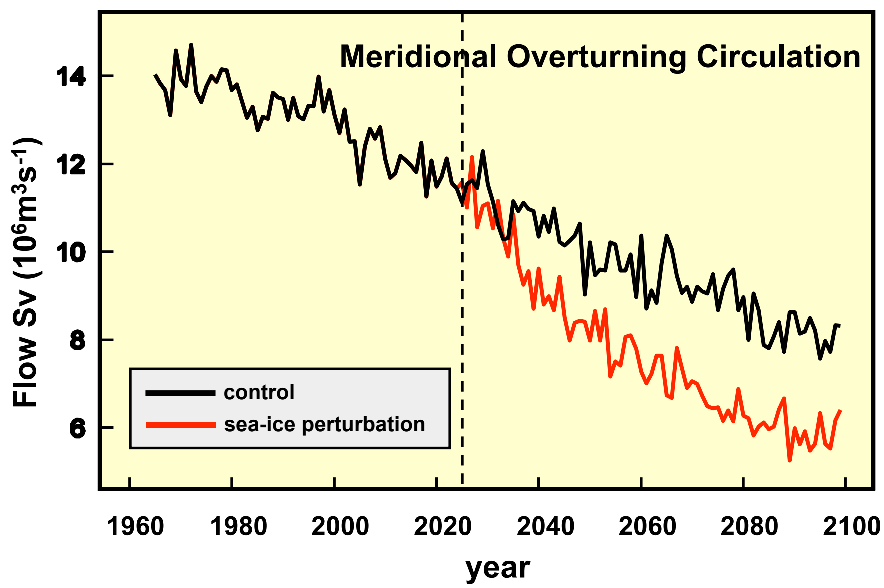
CMAM control — CMAM perturbed sea-ice (2025)



March
Temperature (50hPa, 60°N–90°N)
Temperature (°K)
ΔT = -1.97K
year
March
w* (50hPa, 60°N–90°N)
Vertical Velocity (mm s-1)
Δw* = 0.06ms-1 †
year
Feb–Mar
100hPa Heat Flux (40°N–80°N)
Heat Flux (K m s-1)
ΔHF = -1.01Kms-1
year
March
Age of Air (50hPa, 60°N–90°N)
Age (years)
ΔAge = 0.06y
year
CMAM control
CMAM perturbed sea-ice (2025)

conclusions

- **REF2 perturbative response to rapid Arctic sea-ice loss (2025)**
  - **reduced spring-time (March) ozone column (~10.5DU) for several decades**
  - **associated with reduced temperature (50hPa), reduced late-winter wave flux, slowing of BD circulation trend, and increased age of air.**
- **open questions:**
  - **cause of reduced wave flux from troposphere to stratosphere**
  - **reason for delay in the response to sea-ice loss (fresh-water influx)**



conclusions

- REF2 perturbative response to rapid Arctic sea-ice loss (2025)
  - reduced spring-time (March) ozone column (~10.5DU) for several decades
  - associated with reduced temperature (50hPa), reduced late-winter wave flux, slowing of BD circulation trend, and increased age of air.
- open questions:
  - cause of reduced wave flux from troposphere to stratosphere
  - reason for delay in the response to sea-ice loss (fresh-water influx)
  - timing of sea-ice loss relative to halogen loading
  - rate of sea-ice loss
  - what is the relative role of chemistry vs transport