



Camp Pond, 14 Jul 1979



C.H. Lagoon, 17 Aug 1987



Camp Pond, 12 Jul 2006



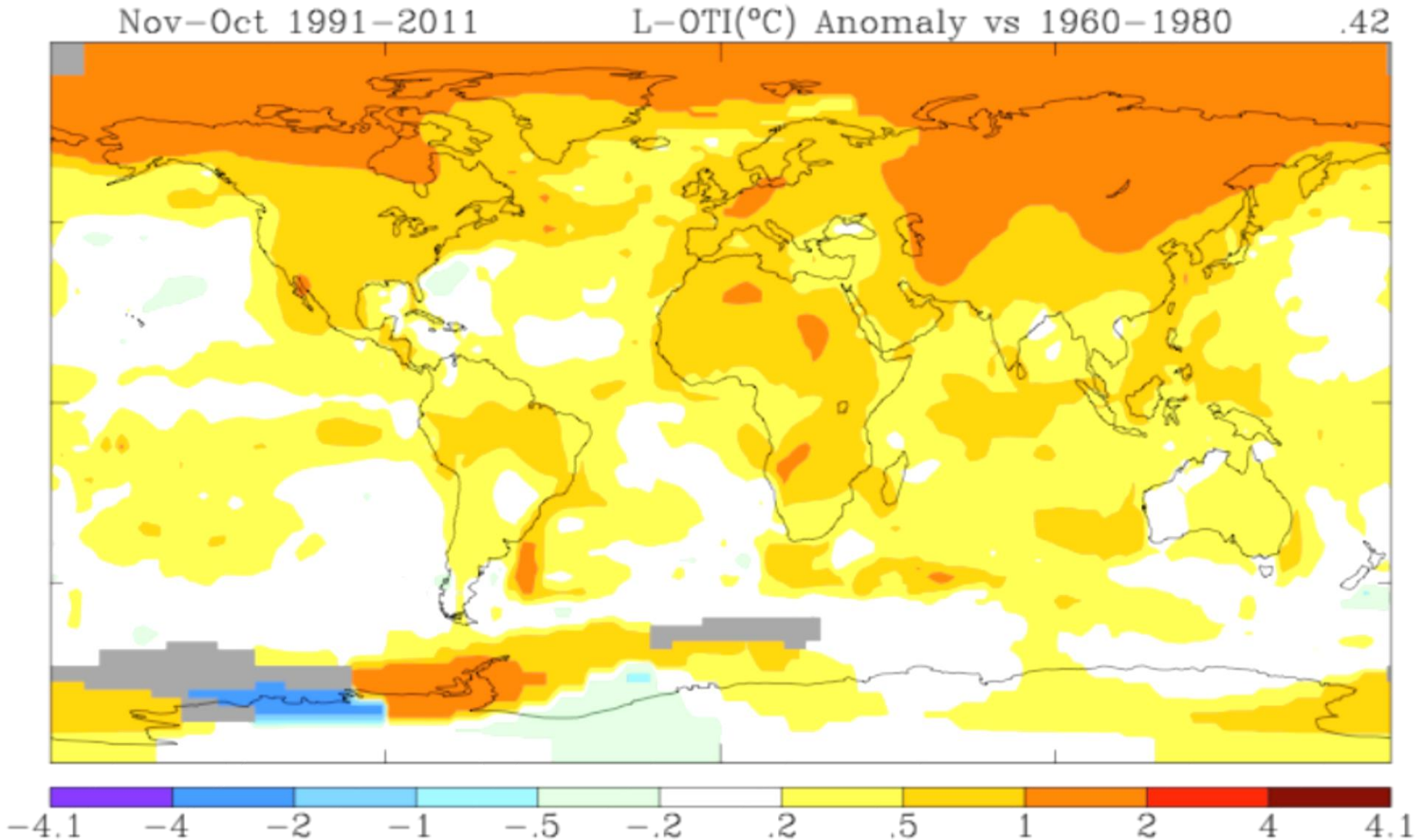
C.H. Lagoon, 16 Jul 2006

# Polar Climate Predictability

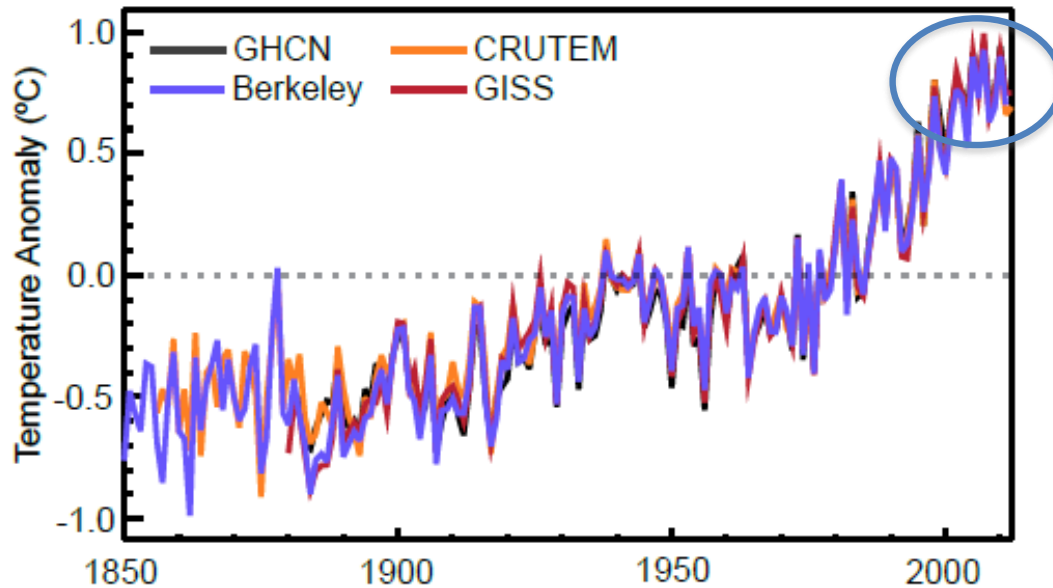
Ted Shepherd  
Department of Meteorology  
University of Reading

Photos: The desiccation of high Arctic shallow ponds: Smol & Douglas (2007 PNAS)

- **The Arctic is warming faster than any region on Earth**
  - Annual mean surface air temperature changes, last 30 years



- Importance for global climate

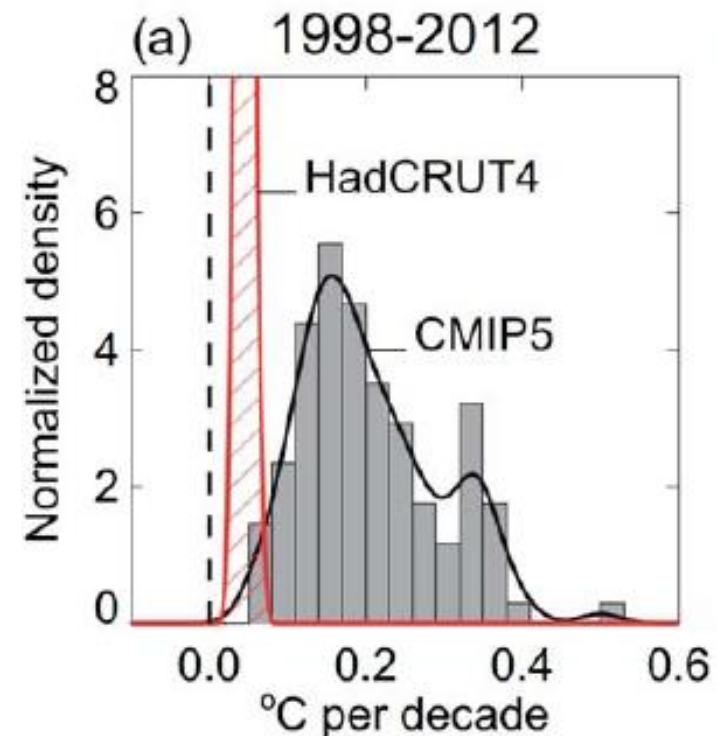


- Even the most heavily scrutinised of all the climate data records seems to have not accounted for systematic biases associated with Arctic warming

Dataset	Trend $\pm \sigma$
NCEP/NCAR	$0.178 \pm 0.107$
GISTEMP	$0.080 \pm 0.067$
NOAA	$0.043 \pm 0.062$
HadCRUT4	$0.046 \pm 0.063$
Null reconstruction	$0.064 \pm 0.078$
Kriging	$0.108 \pm 0.073$
Hybrid $s = 1.0$	$0.119 \pm 0.076$

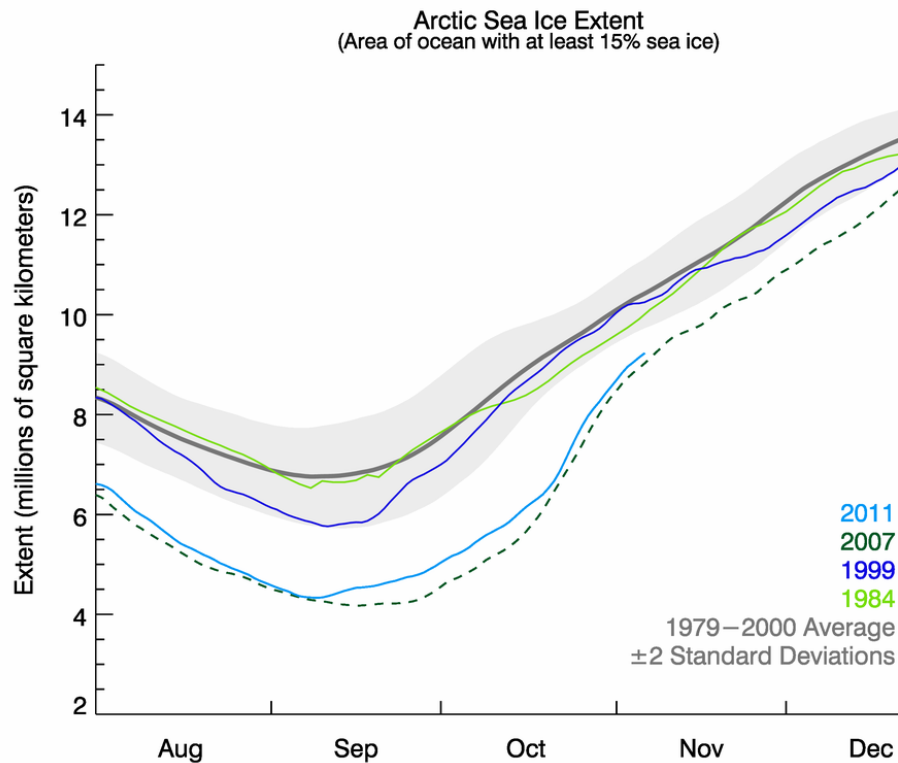
Hiatus

No hiatus



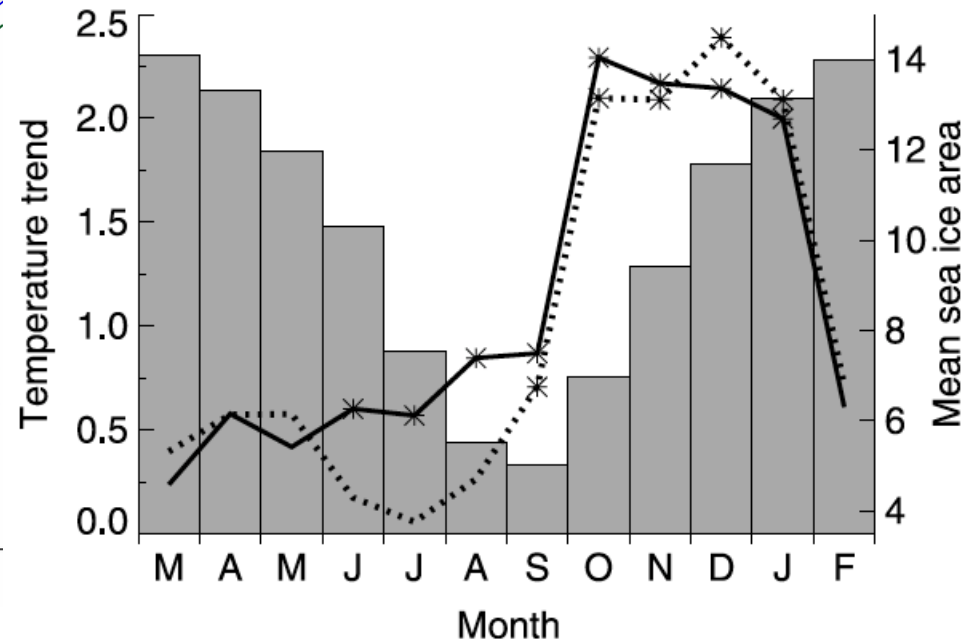
IPCC AR5, Cowtan & Way (2013 QJRMS)

- **Temperatures have warmed most in late-fall/early-winter**
  - Results from strong seasonality of Arctic sea ice; heat is released from ocean to atmosphere during this season



From NSIDC web site

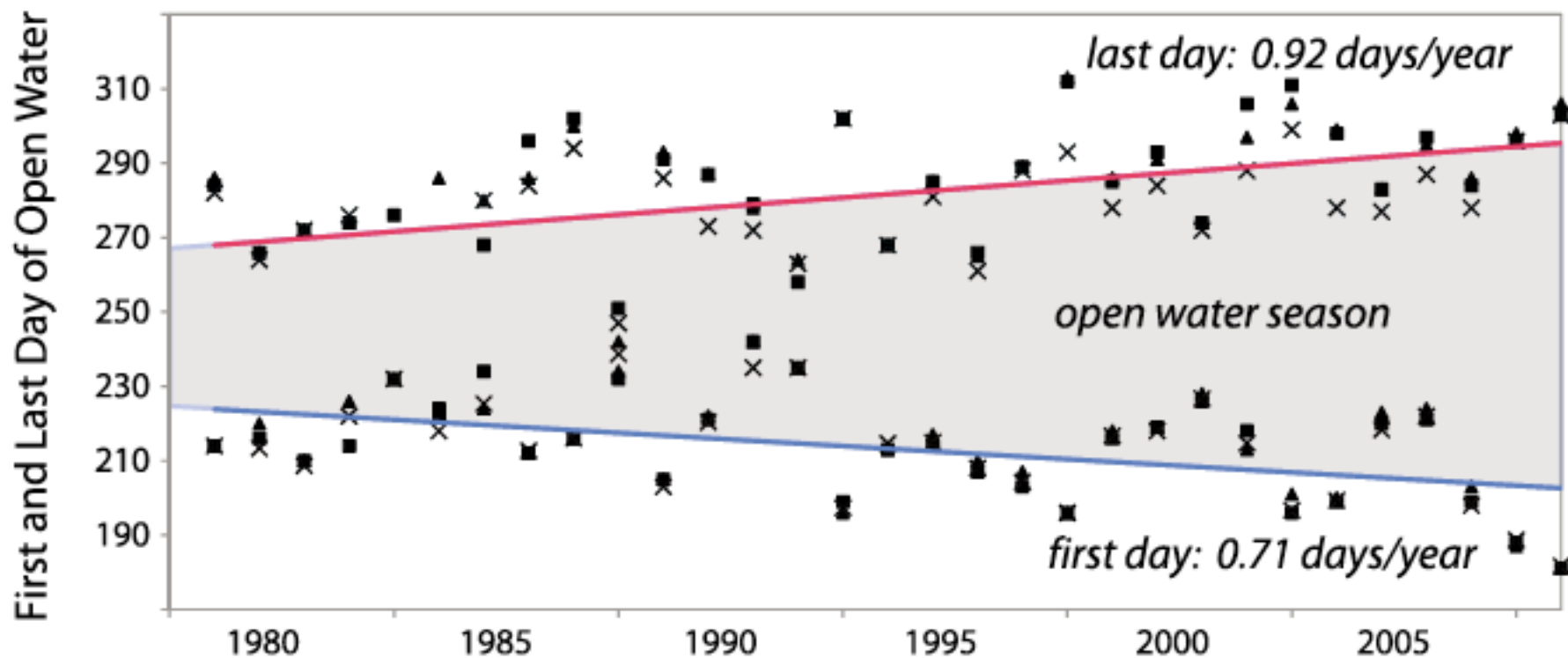
**Surface air temperature trends over 1989-2009 (K/decade), from ERA-Interim (dotted) and station data (solid) poleward of 70° N**



Screen & Simmonds (2010 GRL)

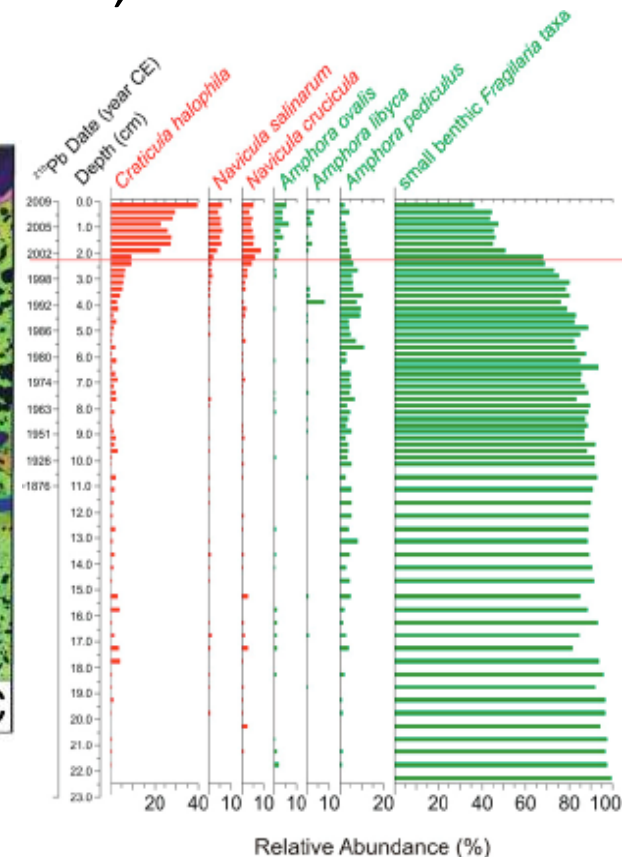
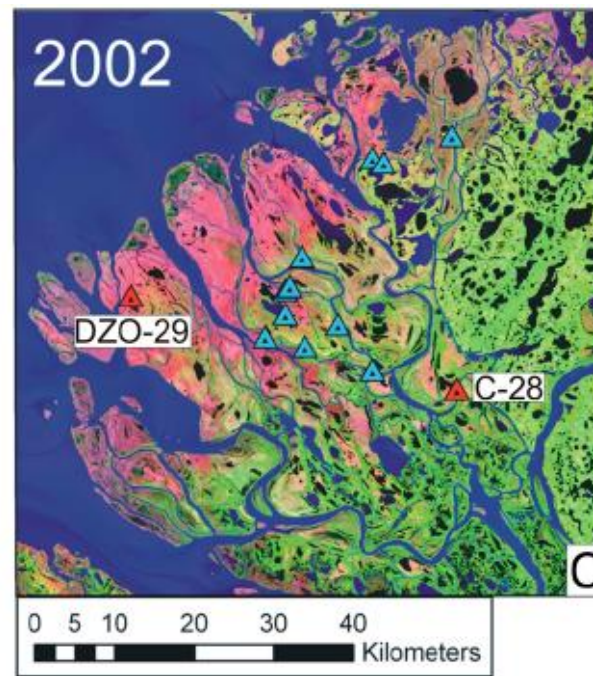
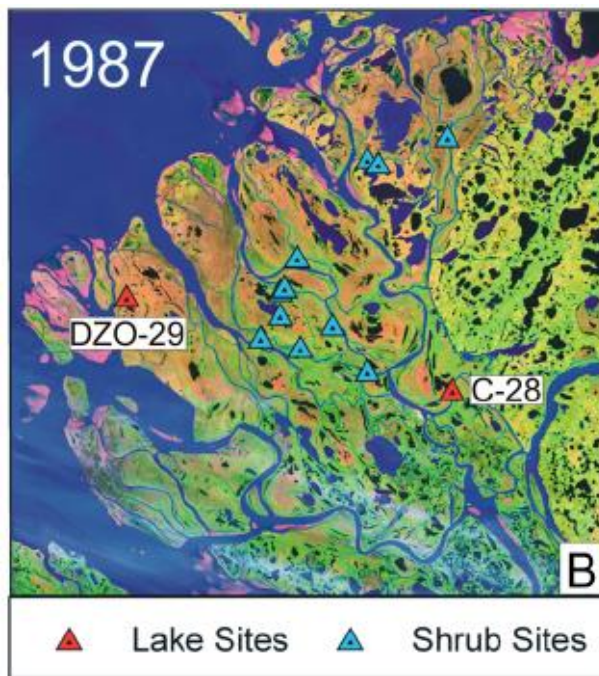


- **Coastal zones are experiencing longer periods of open water,** leading to increased storm surges and erosion of permafrost coasts
  - Open water season along Beaufort Coast in north Alaska



Overeem et al. (2011 GRL)

- **Increasing intrusion of sea water from storm surges is changing coastal ecosystems**
  - A large storm surge in the Mackenzie Delta in 1999 led to widespread changes from freshwater (green) to brackish (red) species, unmatched in over 1000 years, which have persisted to the present day

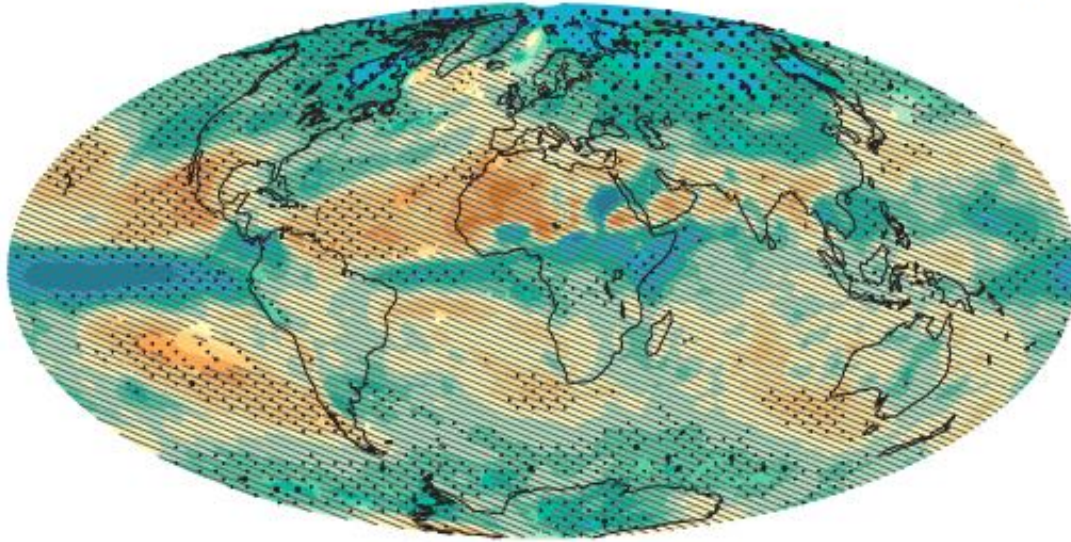


Pisaric et al. (2011 PNAS)



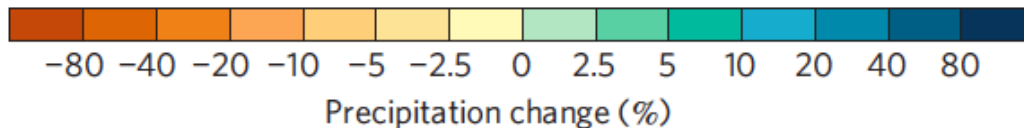
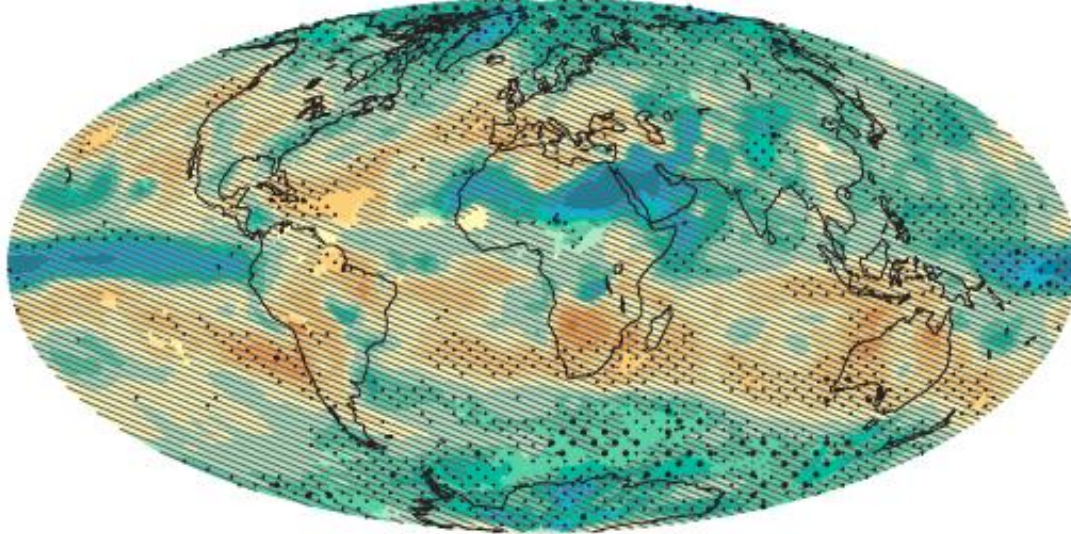
RCP85: 2016–2035

DJF



RCP85: 2016–2035

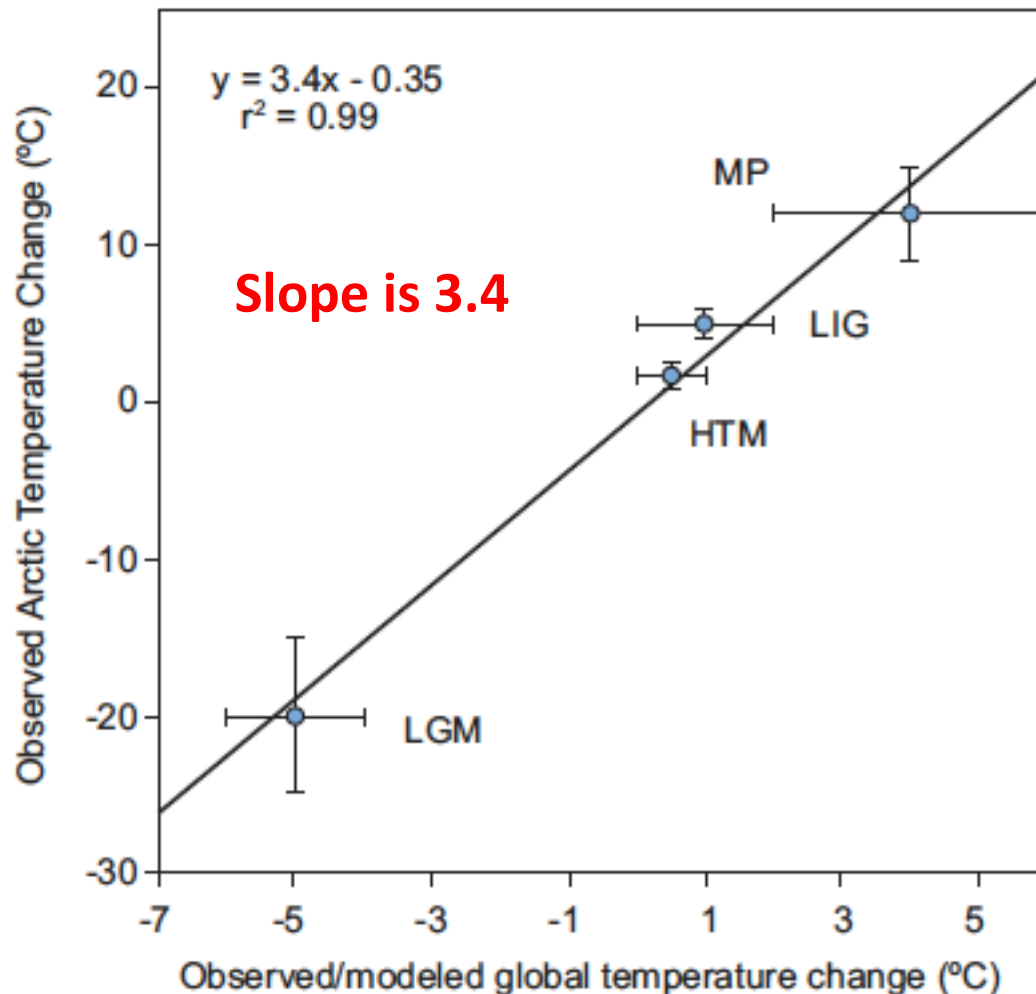
JJA



- CMIP5 projections of **mean precipitation changes** between 1986-2005 and 2016-2035; stippling indicates where the changes are robust
- **The most robust changes are found at high latitudes**
- Hatching means no significant change with respect to natural variability

Knutti & Sedlacek  
(2012 Nature CC)

- **“Arctic amplification” is inherent to the climate system:**  
reflected in paleoclimatic variations on various timescales



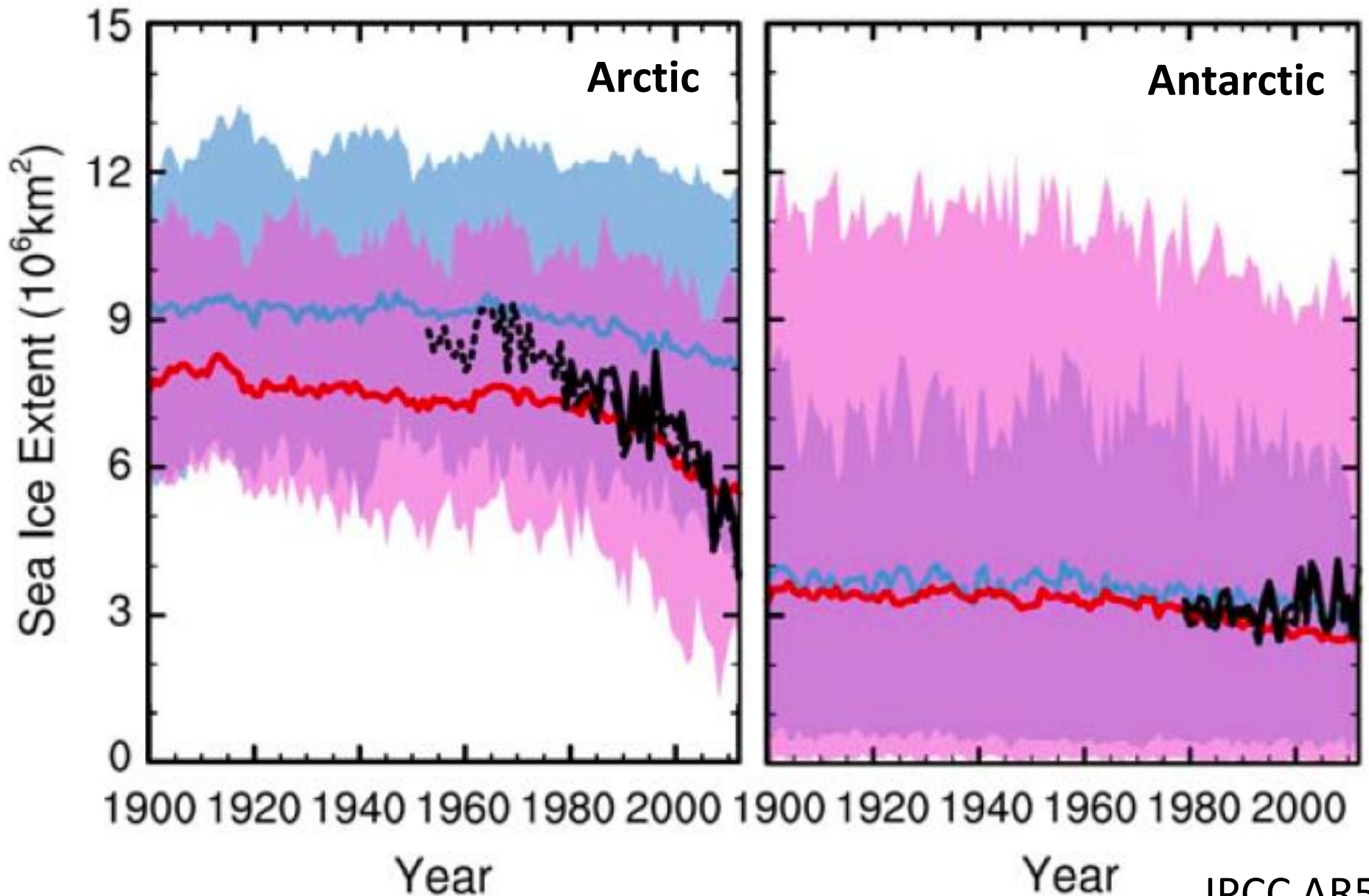
Miller et al. (2011 QSR)

Many mechanisms can contribute to Arctic amplification:

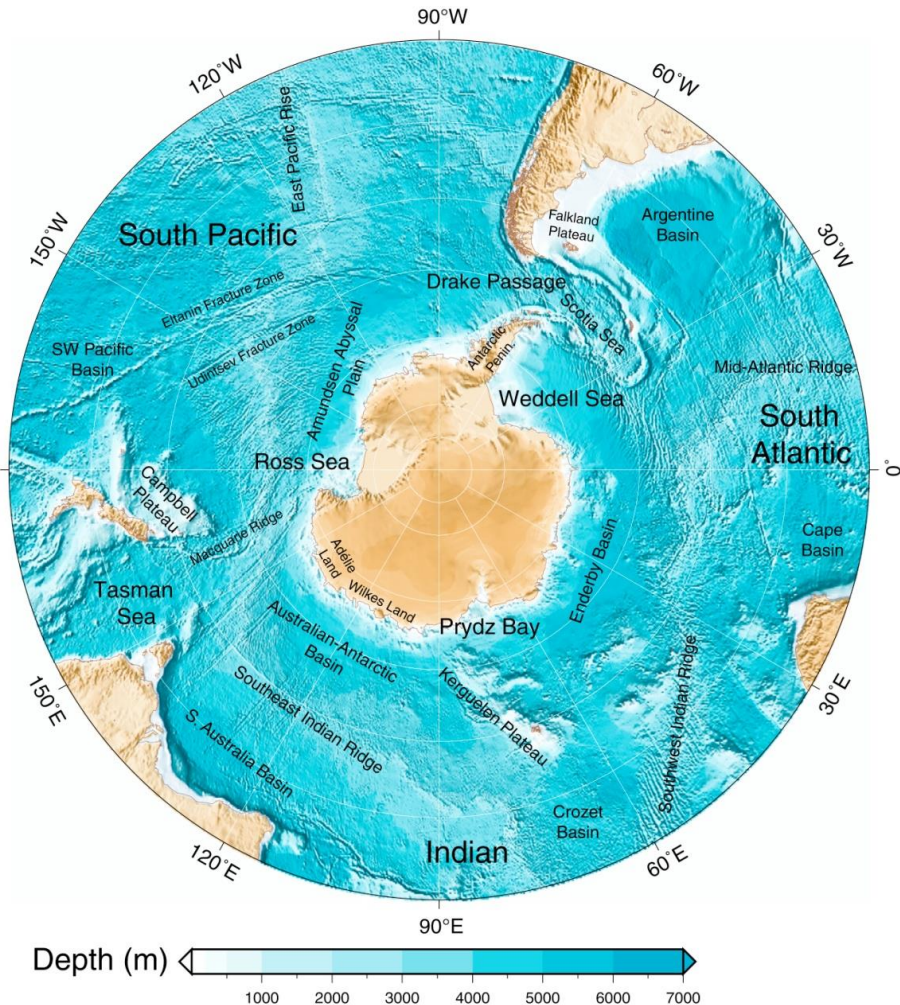
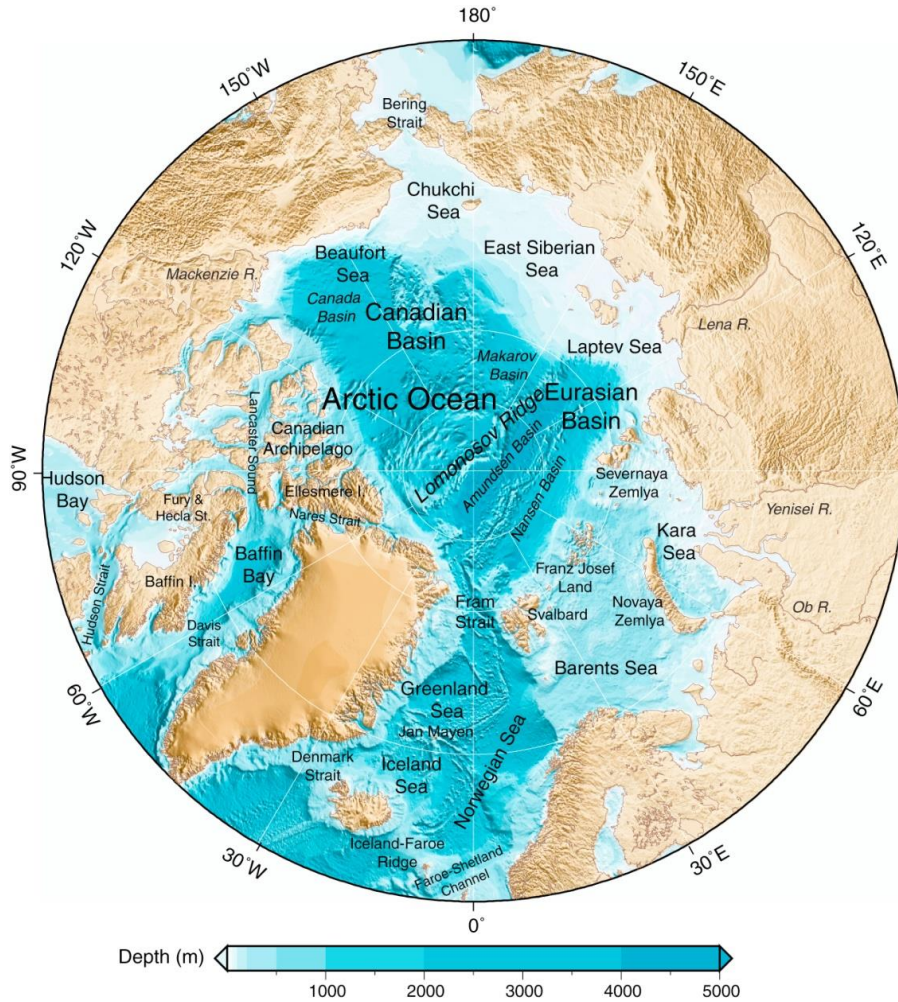
- Ice-albedo feedback
- Snow-albedo feedback
- Increased ocean-to-atmosphere heat flux
- Increased water vapour (GH warming)
- Increased low clouds
- Increased meridional energy fluxes in ocean and/or atmosphere
- Black carbon



## Late-summer sea-ice extent: a study in contrasts



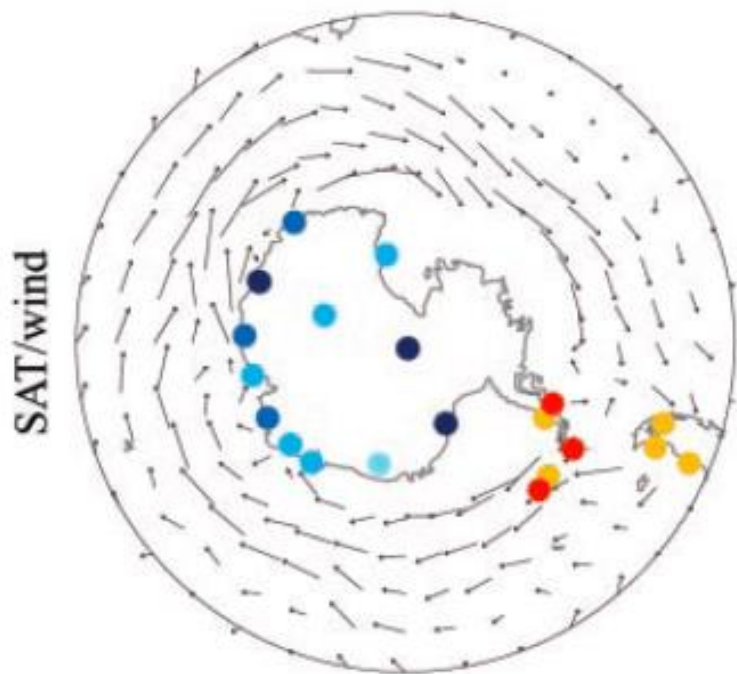
- **Arctic and Antarctic are almost mirror images of each other**
  - Also, the Antarctic has experienced the ozone hole





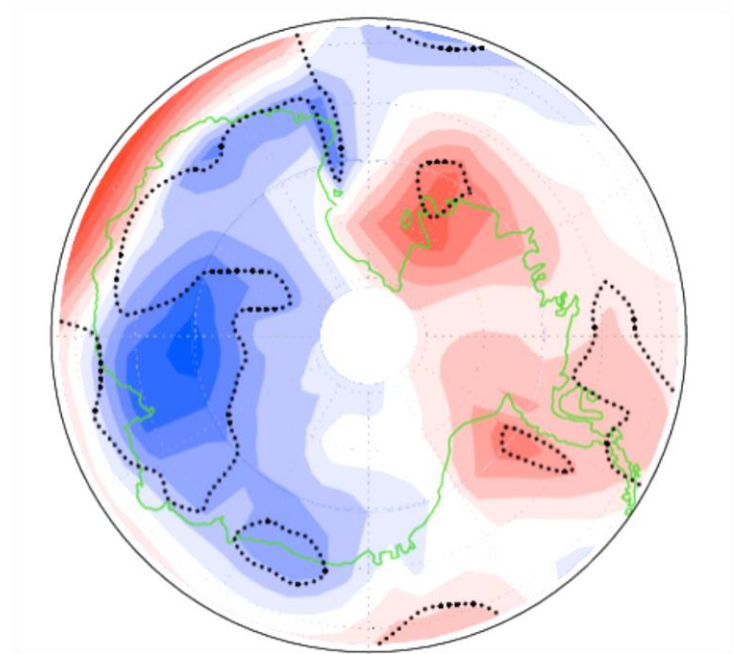
- The ozone hole has been the primary driver of past circulation-related summertime SH high-latitude changes
- **But how about Antarctic surface temperature?** This is not so clear, due to a lack of observations in West Antarctica

Observed summertime surface  
changes (to 2000)



Thompson & Solomon  
(2002 Science)

CMAM summertime surface  
temperature changes (to 2000)  
due to ODS changes alone

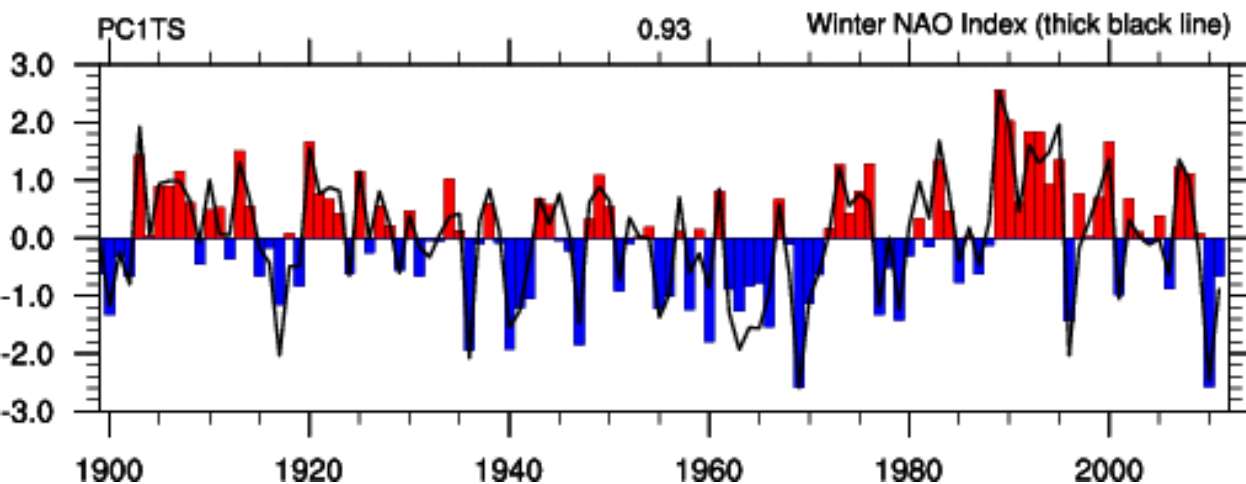
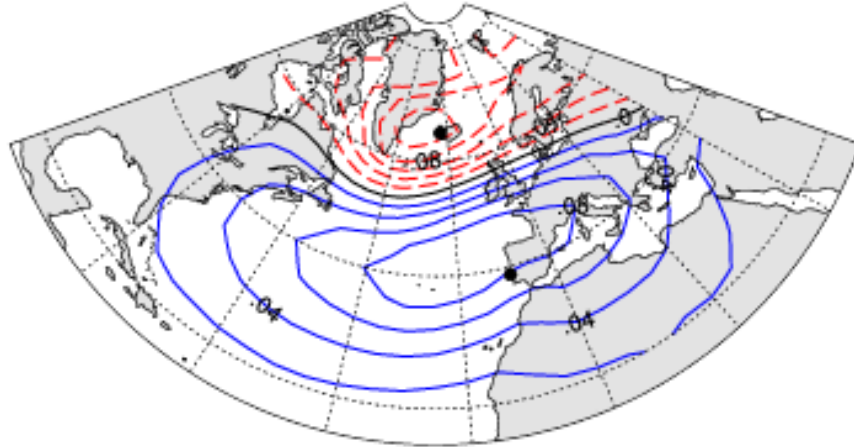


McLandress et al. (2011 J. Clim.)



- **There is strong polar climate variability on both year-to-year and decadal timescales**

Var. = 41.9      EOF1 SLP      DJFM 1899-2011



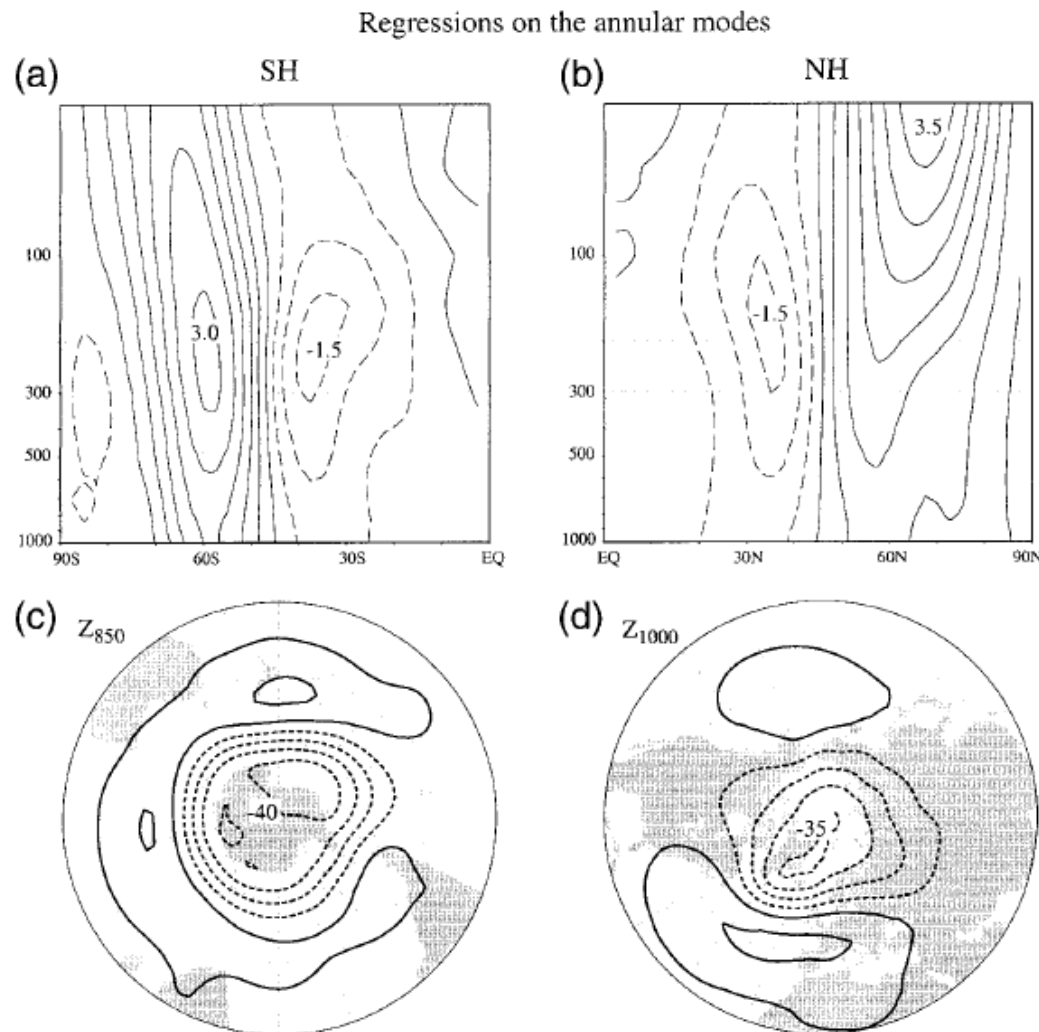
Manifested in large-scale spatial patterns, which modulate climate change

Their physical nature, causality, and timescales are unclear

GHG forcing projects onto modes of variability, so it is difficult to separate signal from noise

- Why is the climate at the two poles changing so differently (with the Arctic changing rapidly, and the Antarctic unevenly), and differently to global climate?
- Why are climate models generally unable to capture the observed behaviour in polar regions?
- What does high latitude climate change mean for lower latitudes?
- Do the ongoing amplified changes in the Arctic have an influence on extremes in the Arctic?
- How predictable is Arctic climate?
  - The stratosphere, sea-ice, land surface and ocean all represent boundary conditions for the troposphere with longer timescales (and inherent stability?), hence some memory
  - Stratosphere-troposphere coupling occurs most strongly in polar regions; stratosphere also provides external forcings
  - Forced component of predictability may dominate over initial condition component in as little as  $\sim 5$  yr

- In both hemispheres, **stratospheric polar vortex variability is connected to the troposphere** (where it affects the subtropical jet)

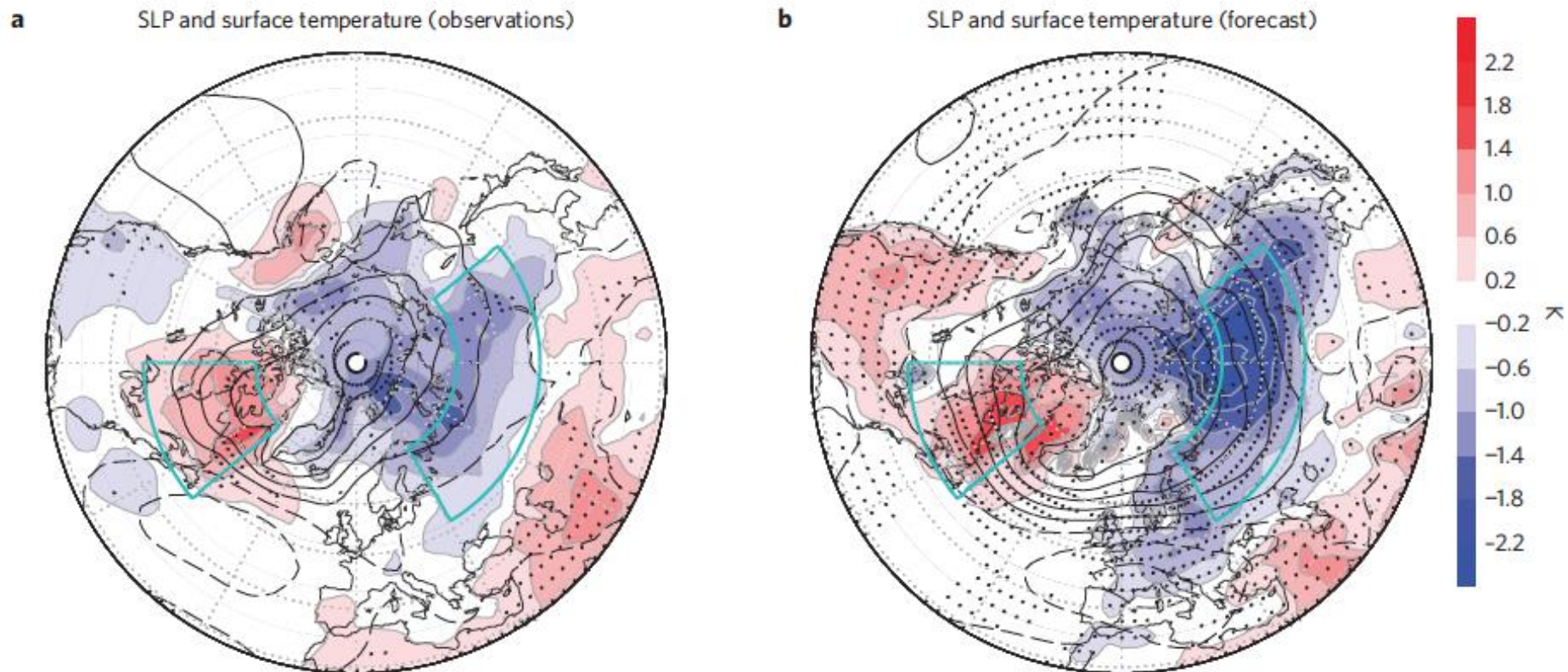


Southern and Northern Hemisphere “annular modes” (SAM and NAM), based on hemispheric EOFs

Thompson & Wallace (2000 J. Clim.)

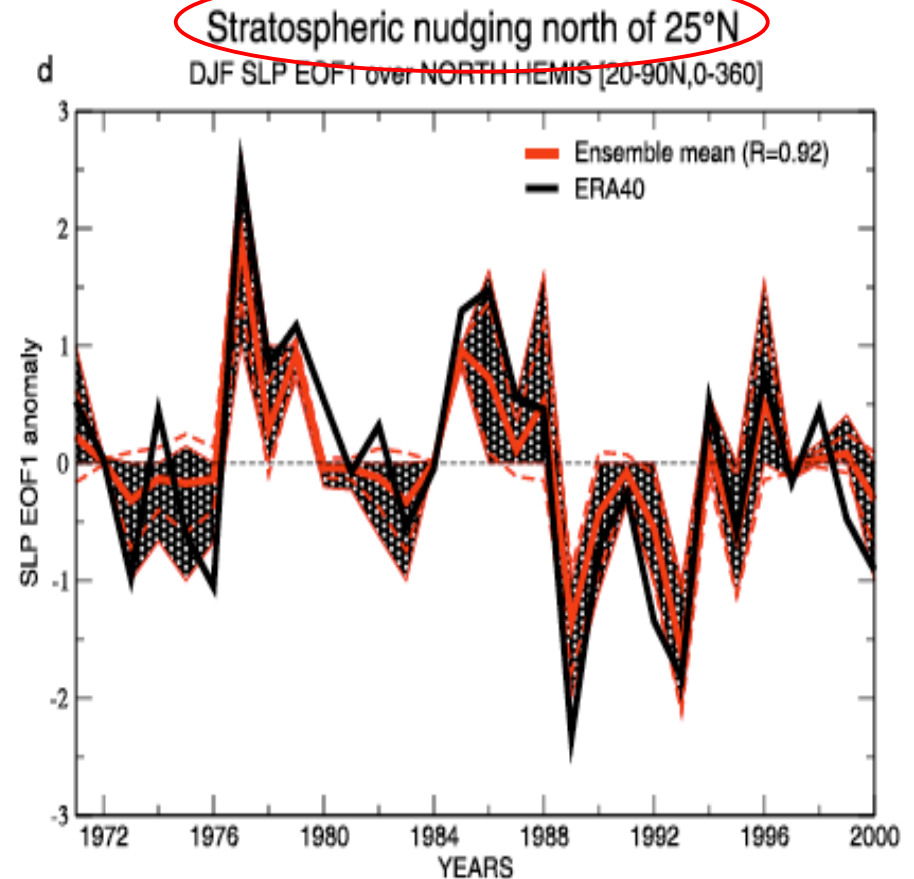
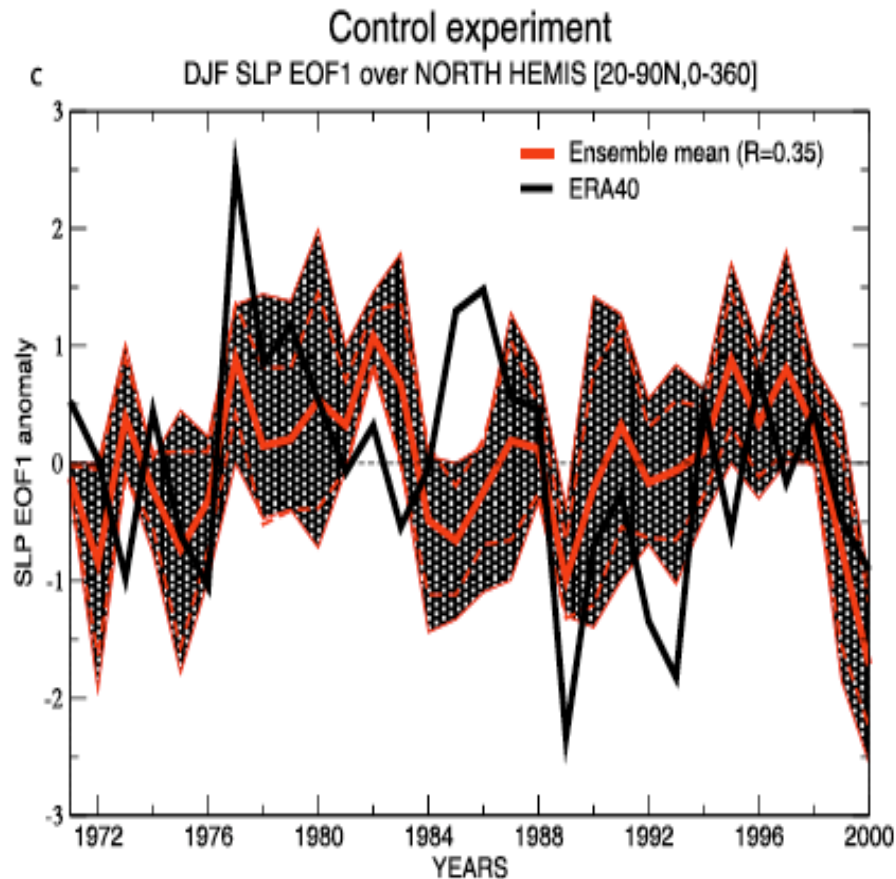


- **Stratosphere-resolving models can correctly predict the surface response to SSWs** when initialised at the time of the SSW
  - Figure shows response averaged over 16-60 days after the SSW, for 20 SSWs from 1970-2009 (model: ensemble of 10)



Sigmond, Scinocca, Kharin & Shepherd (2013 Nature Geosci.)

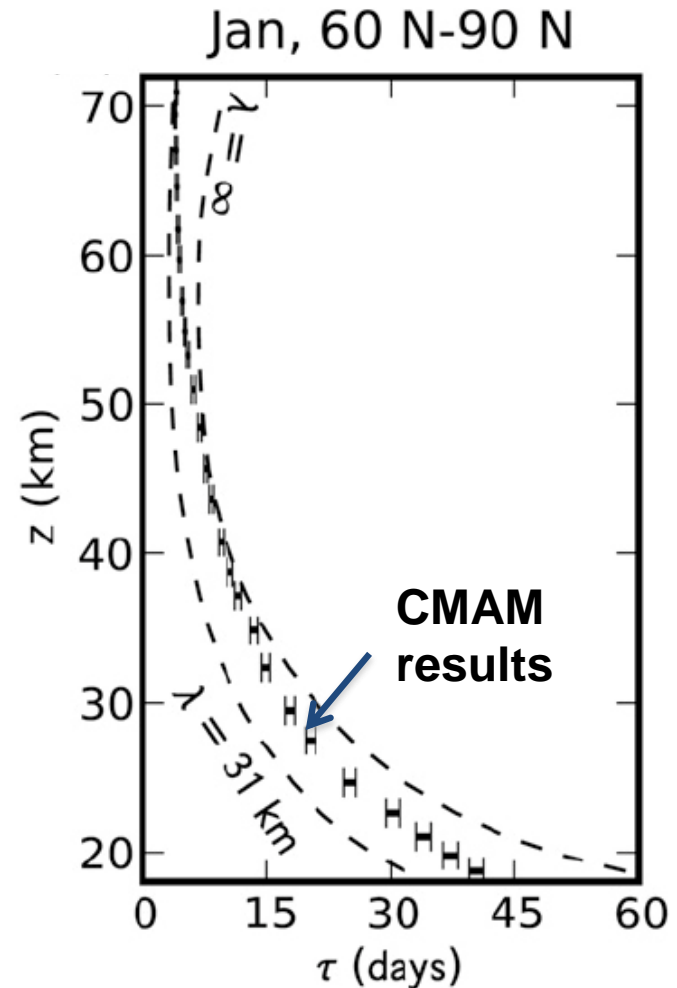
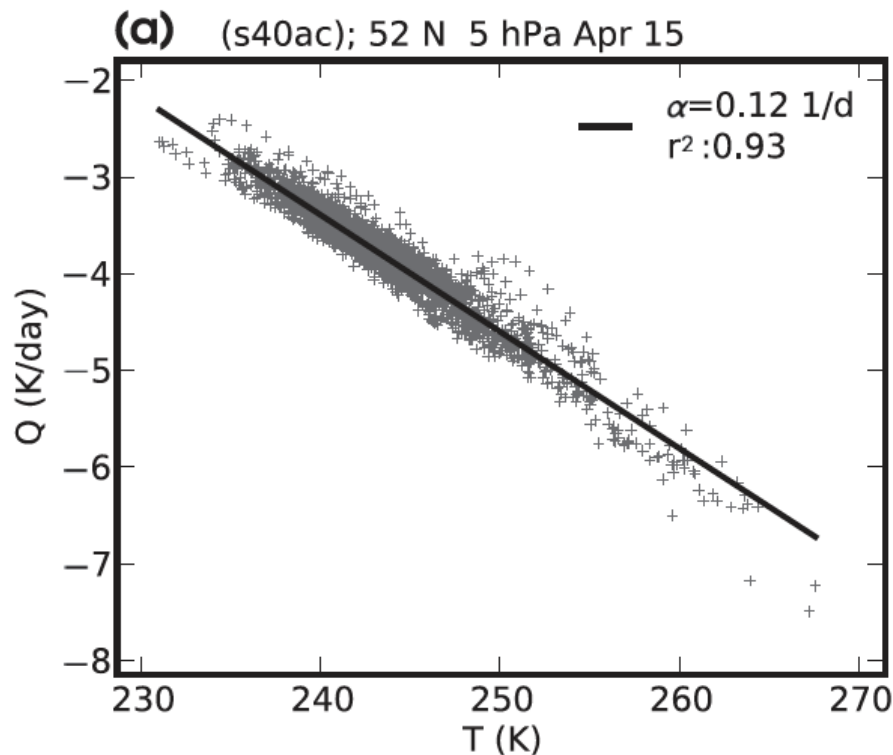
- The stratosphere appears to exert a significant control on interannual variability of the wintertime Arctic circulation
  - Wintertime surface NAM index in 30-year AMIP runs with Météo-France model: SSTs alone provide little control (left)



Douville (2009 GRL)

- **Radiative damping timescales are long in the polar lower stratosphere**, reaching over a month; provides mechanism for subseasonal memory

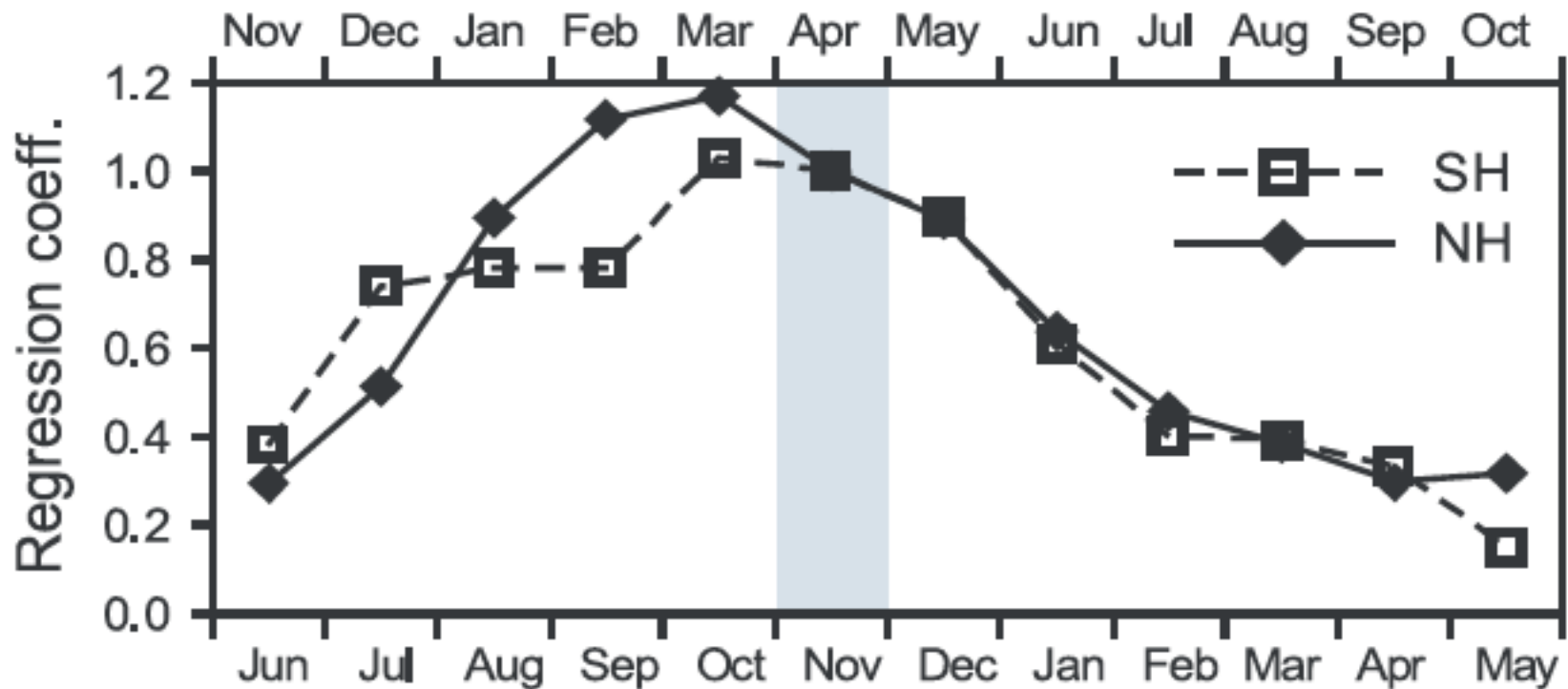
Estimated from variability in radiative cooling rates in a comprehensive chemistry-climate model (CMAM)



Hitchcock, Shepherd & Yoden (2010 JAS)



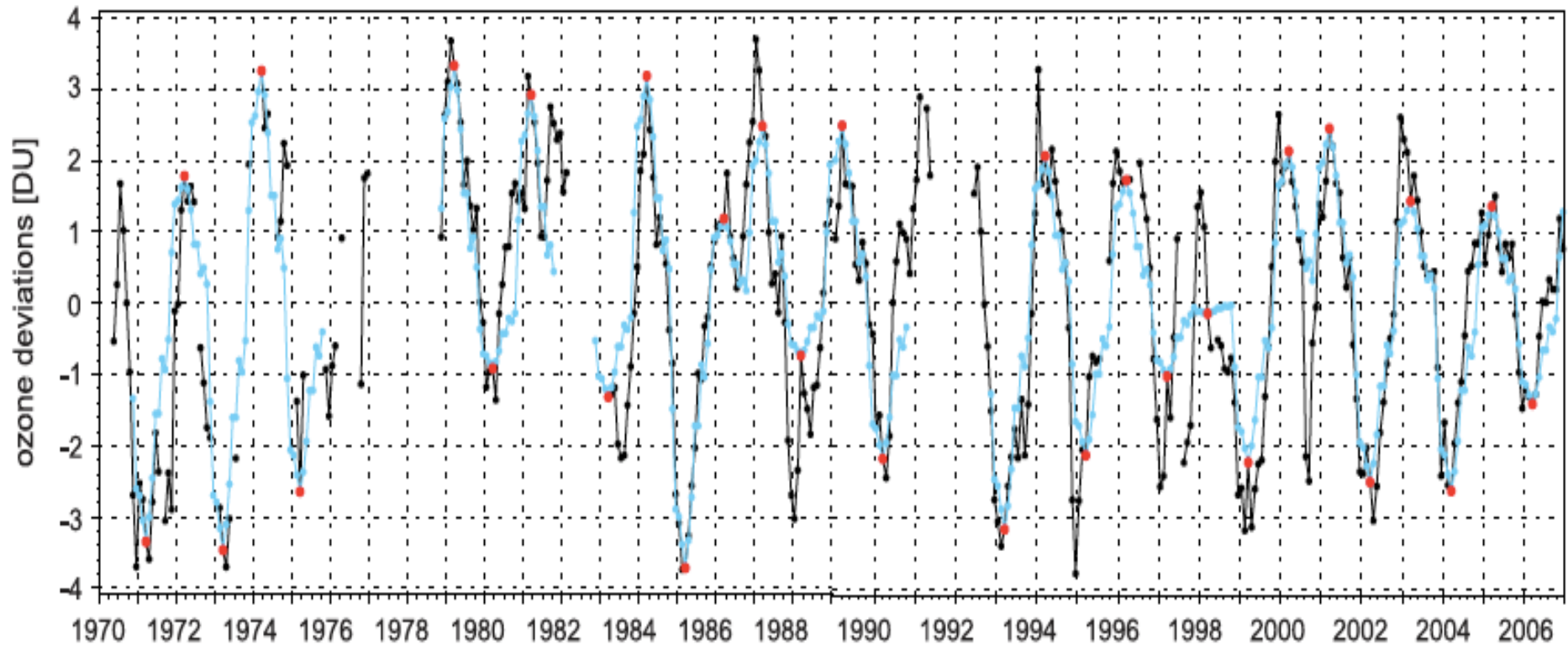
- The seasonal cycle of stratospheric variability implies a seasonal cycle in the Brewer-Dobson circulation
  - **Midlatitude column ozone anomalies build up through winter and spring, and decay photochemically during the quiescent summer (several-month timescale)**



TOMS total ozone, from Fioletov & Shepherd (2003 GRL)

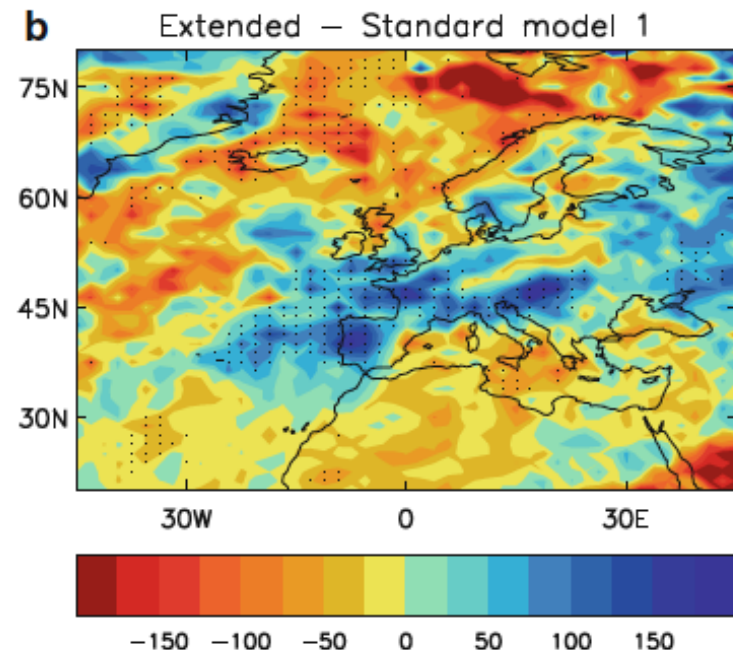
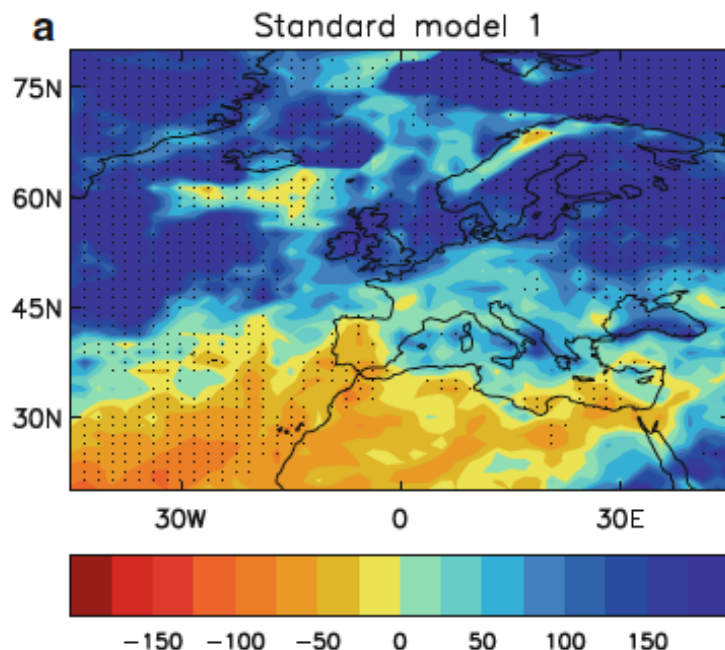
- This ozone “memory” is so strong that one can reconstruct (blue) the subtropical upper stratospheric SBUV(/2) ozone anomaly time series (black) **from March measurements alone** (red)

Reconstruction of ozone time series based on March ozone for 15N-45N, Layer 5-9 (16-1.6hPa)



Tegtmeier, Fioletov & Shepherd (2008 JGR)

- Effect of stratosphere is seen in the **response to climate change**
  - Inclusion of the stratosphere leads to less of a poleward shift in the wintertime North Atlantic storm track from climate change, due to weakening of the stratospheric polar vortex
  - Figure shows **percentage change in frequency of extreme wintertime rainfall** from 4xCO<sub>2</sub>: right is effect of stratosphere

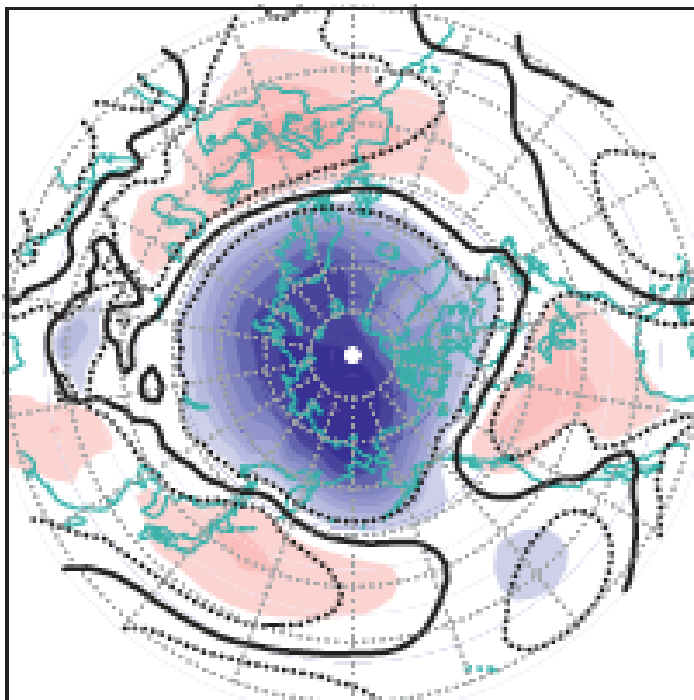


Scaife et al. (2012 Clim. Dyn.)

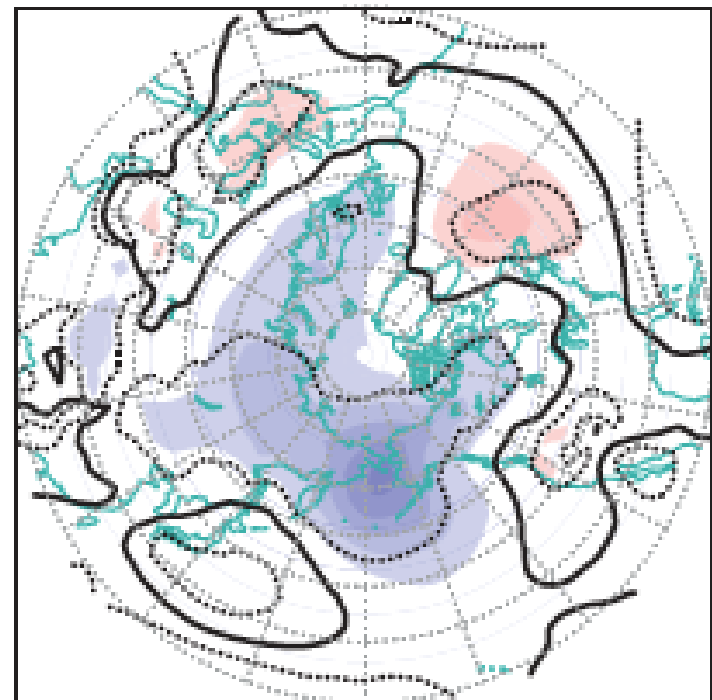


- **Same effect is seen in sensitivity of climate change response to orographic GWD settings**
  - Mean sea-level pressure response to doubled  $\text{CO}_2$  is sensitive to parameter settings in the orographic GWD scheme, through its control of lower stratospheric winds

(a) RESPONSE WEAK (DRAG)

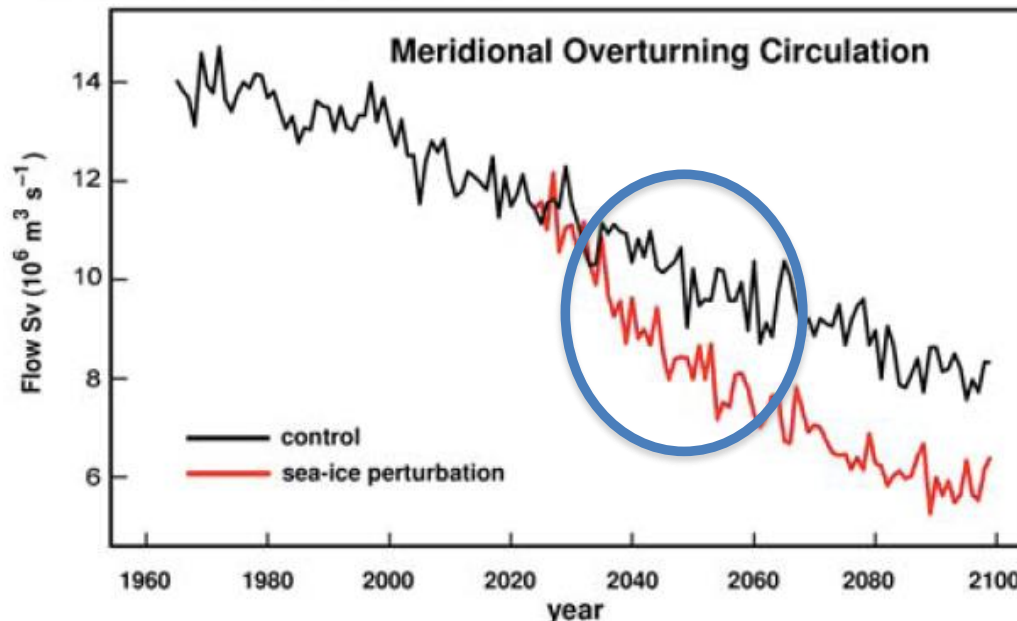
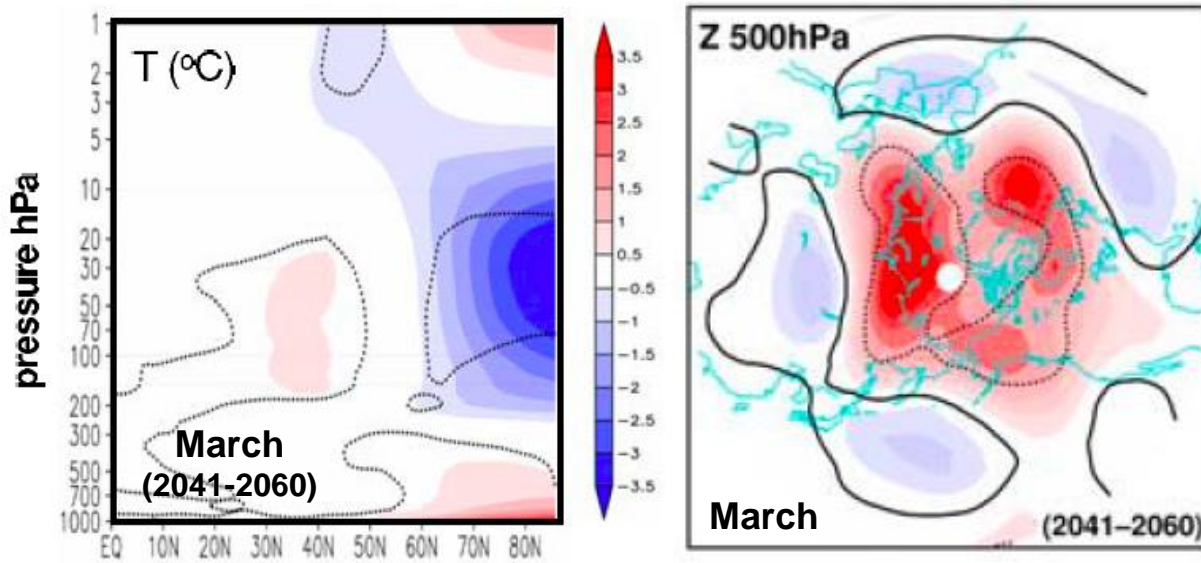


(b) RESPONSE STRONG (DRAG)



CMAM results from Sigmond & Scinocca (2010 J. Clim.)

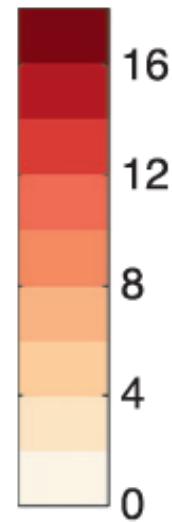
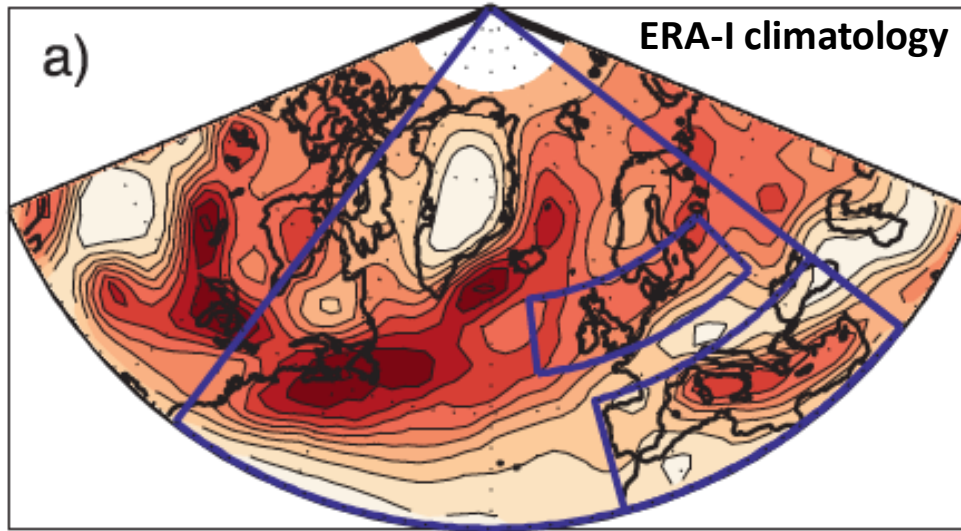
- Stratosphere may also play a role in **springtime Arctic response to loss of summertime sea ice**



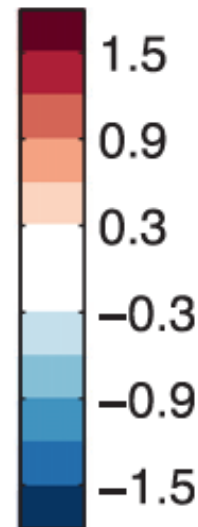
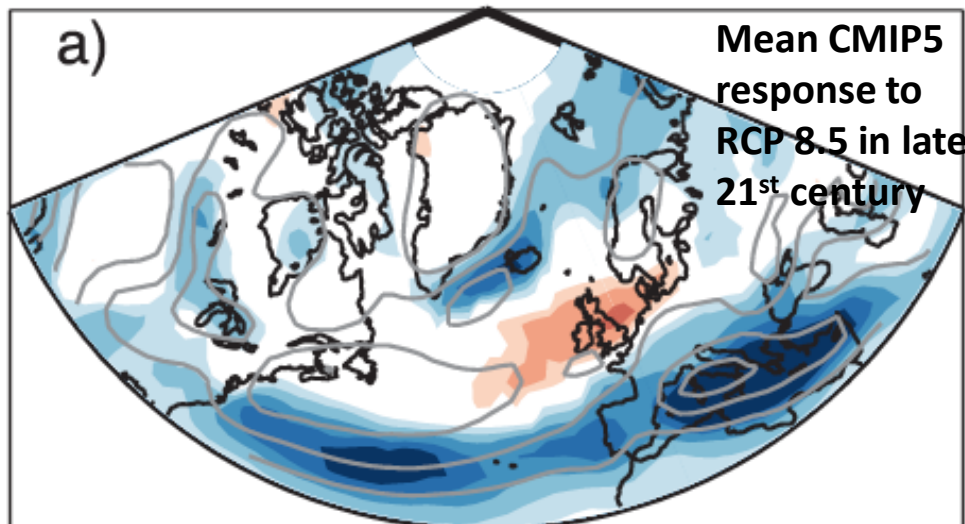
- Reduced forcing of planetary waves into the stratosphere leads to stronger vortex
- Associated with poleward shift of tropospheric circulation
- Appears to be mediated by response of Atlantic MOC

CMAM results from  
Scinocca et al. (2009 GRL)

Climate models suggest a **strengthening of the wintertime storm track density over the UK**, and a weakening on either side



Seems to result from a combination of tropical upper-tropospheric warming and Arctic lower-tropospheric warming

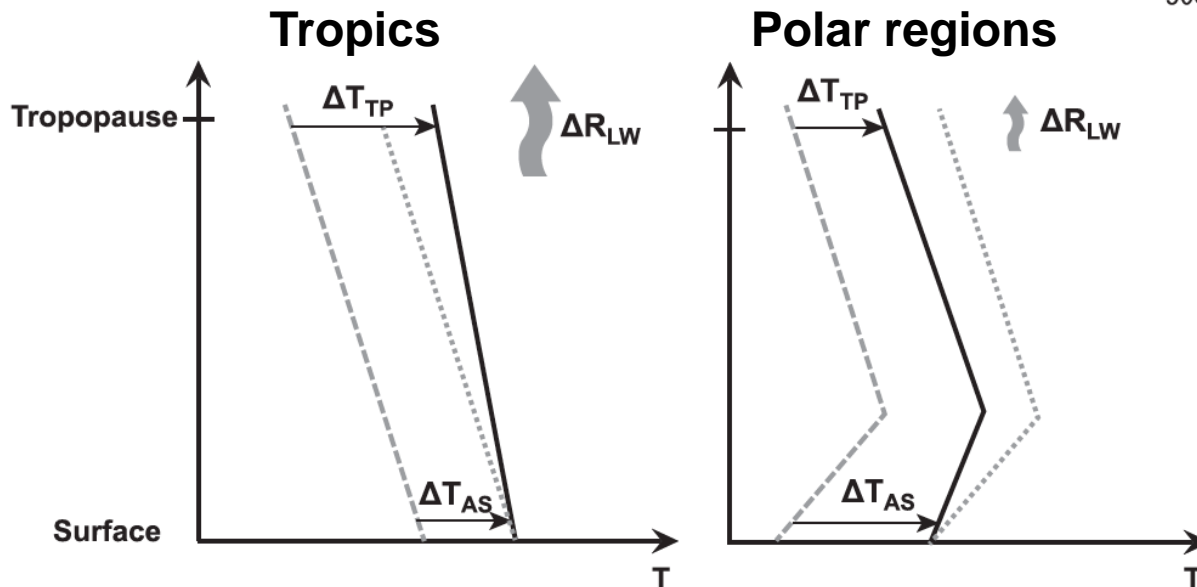
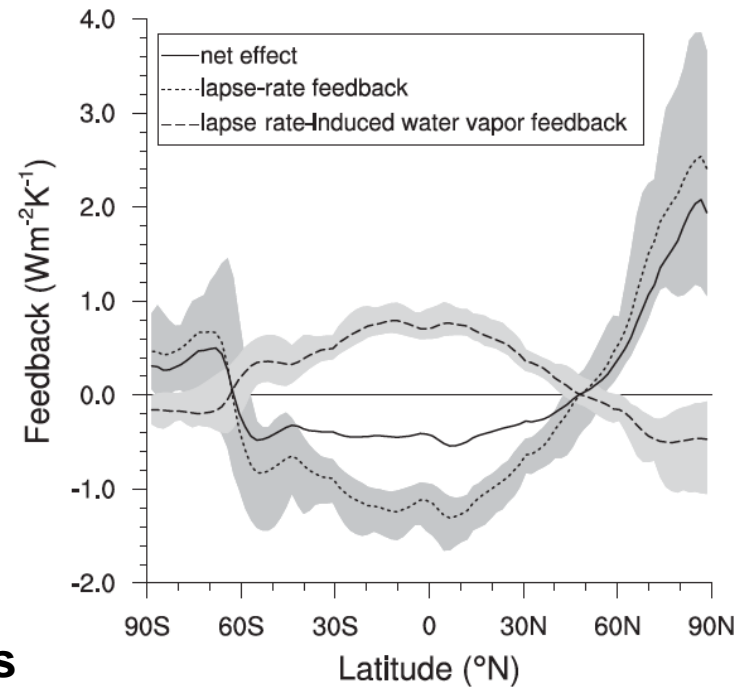


Model spread is largest on the poleward side

Zappa et al.  
(2013 J. Clim.)

- A basic mechanism for Arctic amplification results from the **stable boundary layer**: leads to a positive lapse-rate feedback, which strongly outweighs the negative lapse-rate induced water vapour feedback (Manabe & Wetherald 1975 JAS)

## CMIP5 response to 4xCO<sub>2</sub>

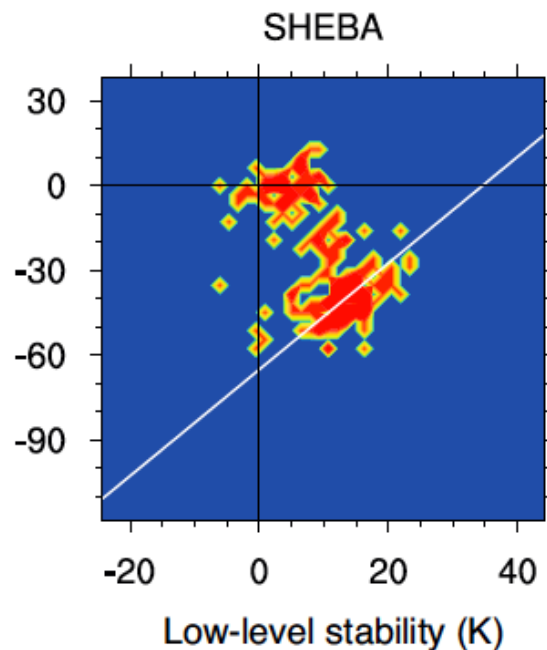
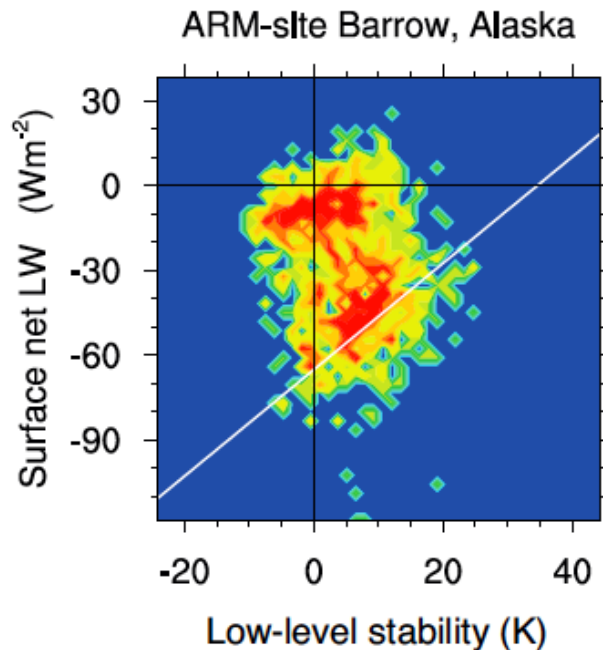


Points to fallacy in apparent emergent constraint of Boé et al. (2009 J. Clim.)

Pithan & Mauritsen (2012 J. Clim.)

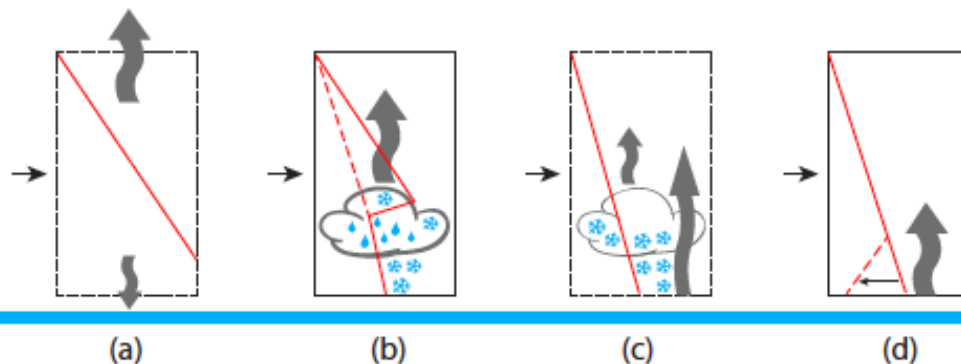


- Observations show **two states of the Arctic boundary layer**
  - Cloudy state with little radiative cooling, clear state with strong radiative cooling (stronger inversion => less cooling)



Result of Arctic air-mass formation (bottom figure)

Cloudy state (mixed phase clouds) not well represented in climate models



Pithan et al. (2013  
Clim. Dyn.)

## Summary

- The Arctic is warming faster than any place on Earth
  - Secular changes on decadal timescales are very apparent
  - Recent conditions are unprecedented in the last 1000 years
- The phenomenon of “Arctic amplification” is robust and well understood, although the details are still a matter of debate
  - Loss of summertime sea ice drives many of the changes
  - Evidence points to model biases in mixed-phase clouds and stable boundary layers (also important for weather prediction)
- There is significant interannual variability in Arctic climate, on decadal timescales, which modulates climate change
  - Wintertime variability involves two-way coupling with the stratosphere, which exerts a control on surface winds
- Stratosphere also appears to play a key role in long-term changes
- *The Antarctic is fundamentally different from the Arctic in many respects: see Cecilia Bitz’s invited talk*