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The influence of the Tropics on Arctic and Antarctic sea ice extent

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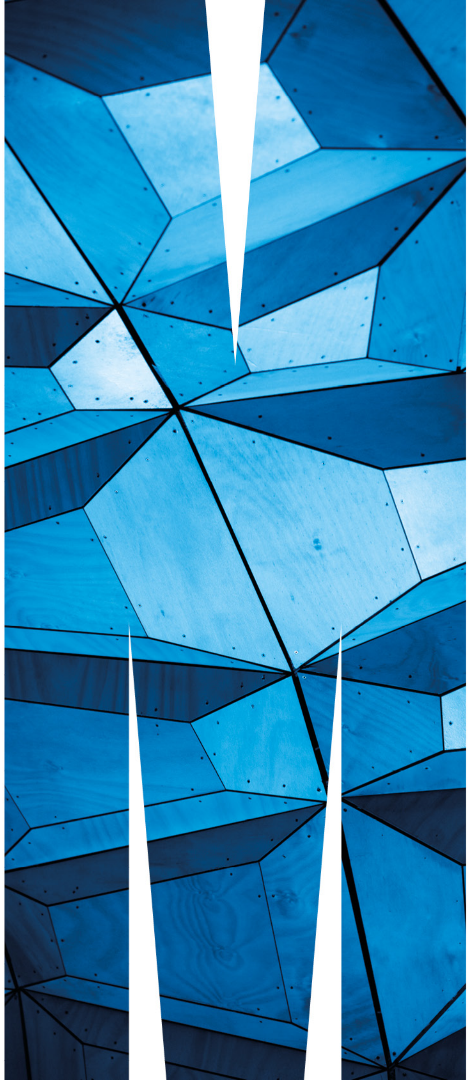
(*with thanks to many co-authors*)

NCAR

U.S. DEPARTMENT OF ENERGY
Office of Science

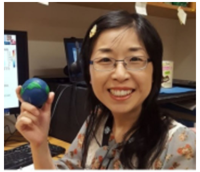


Thankyou

- Wang, G., H.H. Hendon, J.M. Arblaster, E.-P. Lim, S. Abhik, P. van Rensch, 2019, Compounding tropical and stratospheric forcing of the record low Antarctic sea-ice in 2016, Nature Comm, https://doi.org/10.1038/s41467-018-07689-7
- Meehl, G.A., J.M. Arblaster, C.T.Y. Chung, M.M. Holland, A. DuVivier, L. Thompson, D. Yang and C.M. Bitz, 2019, Sudden Antarctic sea ice retreat in late 2016 caused by connections to the tropics and sustained ocean changes around Antarctica, Nature Comm, https://doi.org/10.1038/s41467-018-07865-9
- Meehl, G., Chung, C., Arblaster, J., Holland, M., & Bitz, C. (2018). Tropical decadal variability and the rate of Arctic sea ice decrease. *Geophysical Research Letters*, **45**, 11,326– 11,333. https://doi.org/10.1029/2018GL079989
- WMO/UNEP Ozone Assessment, 2018, 'Stratospheric Ozone Changes and Climate'
- https://theconversation.com/why-antarcticas-sea-ice-cover-is-so-low-and-no-its-not-just-about-climate-change-109572








Motivation

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- Ozone Assessment 2018: "**Antarctic ozone depletion** was the **dominant driver** of the changes in Southern Hemisphere tropospheric circulation in austral summer during the **late 20th century**"

- However, tropical SSTs are also known to influence the SH mid- to high-latitudes across many timescales

What contribution have the tropics made to **recent** interannual and decadal changes in the SH extratropical climate? (SH westerlies and Antarctic sea ice)

Poleward shift in DJF SH atmospheric circulation over recent decades

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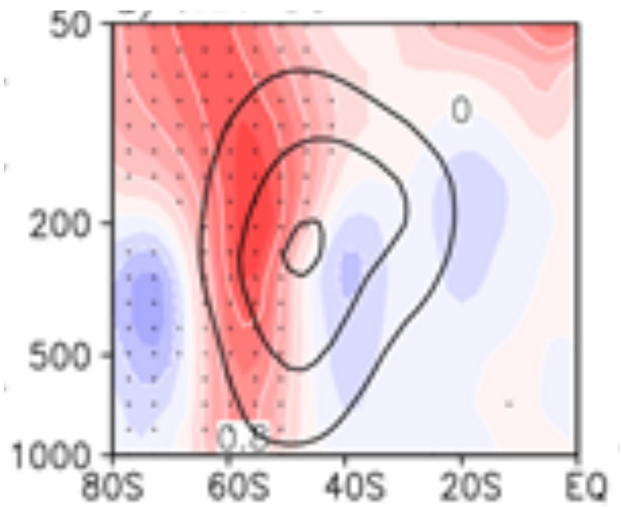
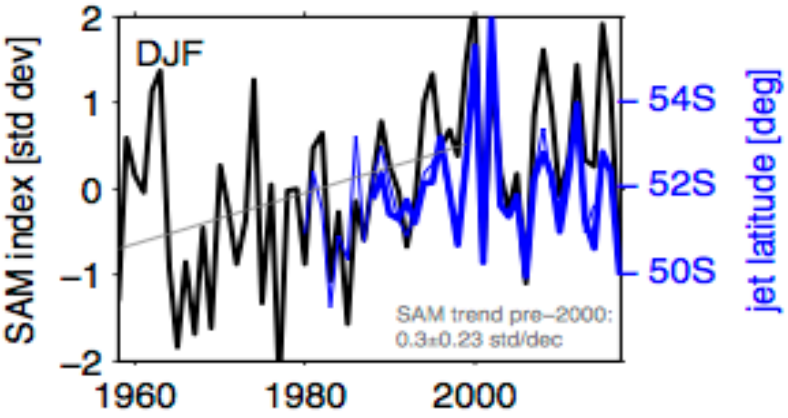
JRA-55 reanalysis

1960-2000 DJF Zonal U trends



DJF SAM (SLP) and jet latitude (CCMP)



- Climate models can reproduce trends in zonal wind when driven by anthropogenic forcings
- Coupling with chemistry (CCMI) or an ocean component makes little difference to the trend

Son et al ERL 2018; WMO/UNEP Ozone Assessment 2018

SAM influence on surface temperature trends

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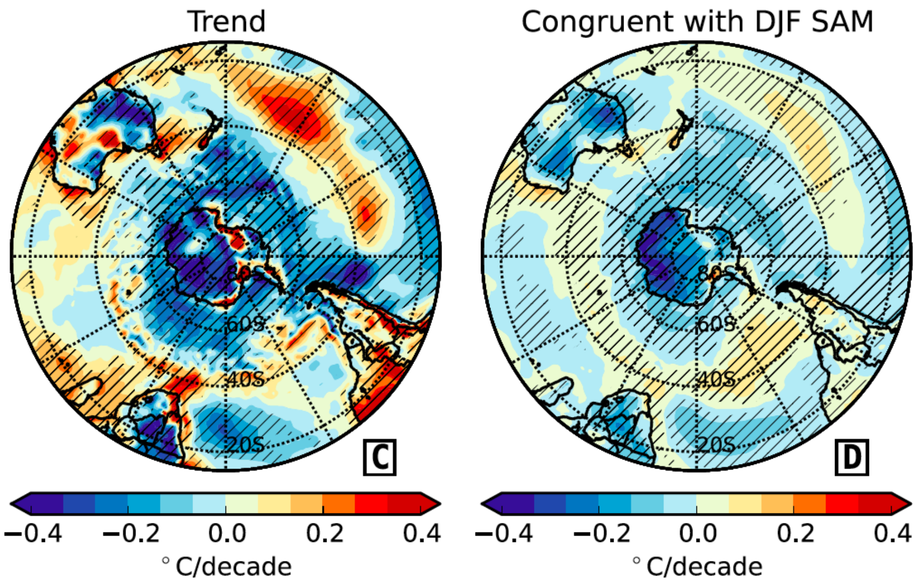
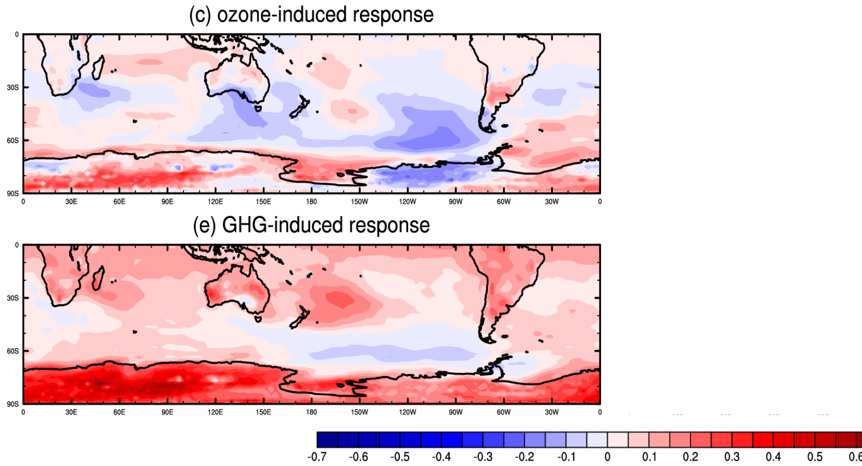
ERAI DJF surface temperature trends 1979-2012



Bandoro et al J Climate 2014

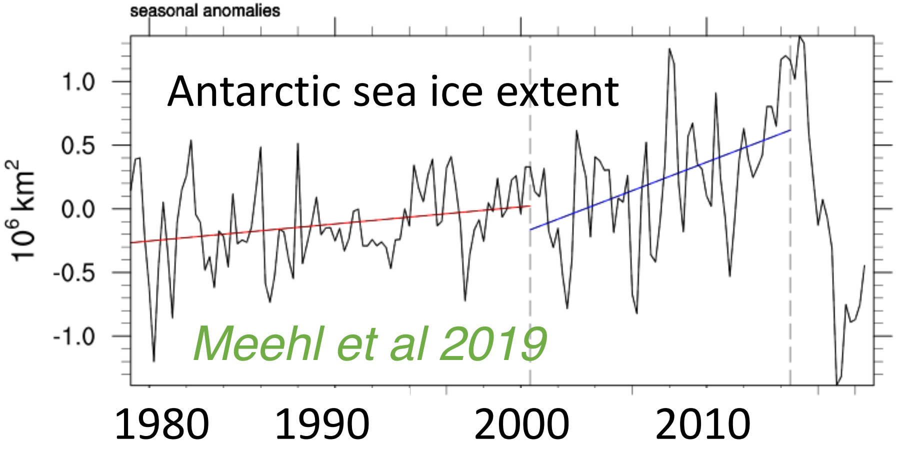
WACCM coupled model: 1960-2004 trends

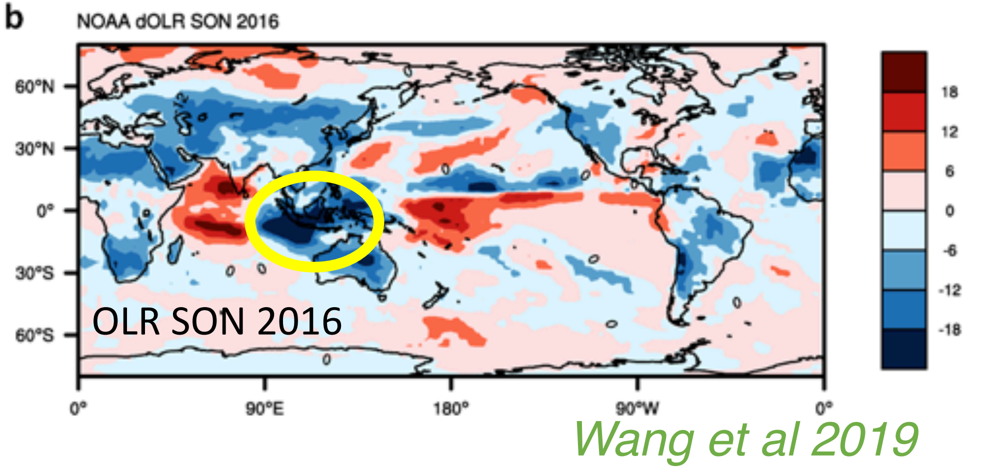


Gillett et al, J Clim 2019 (and Honours thesis)

Influence of the Tropics on interannual timescales

Two recent papers have suggested the rapid Antarctic sea ice decline in the spring of 2016 was due to surface wind forcing, triggered by record convective heating over the eastern Indian Ocean





September-October circulation dominated by wave train

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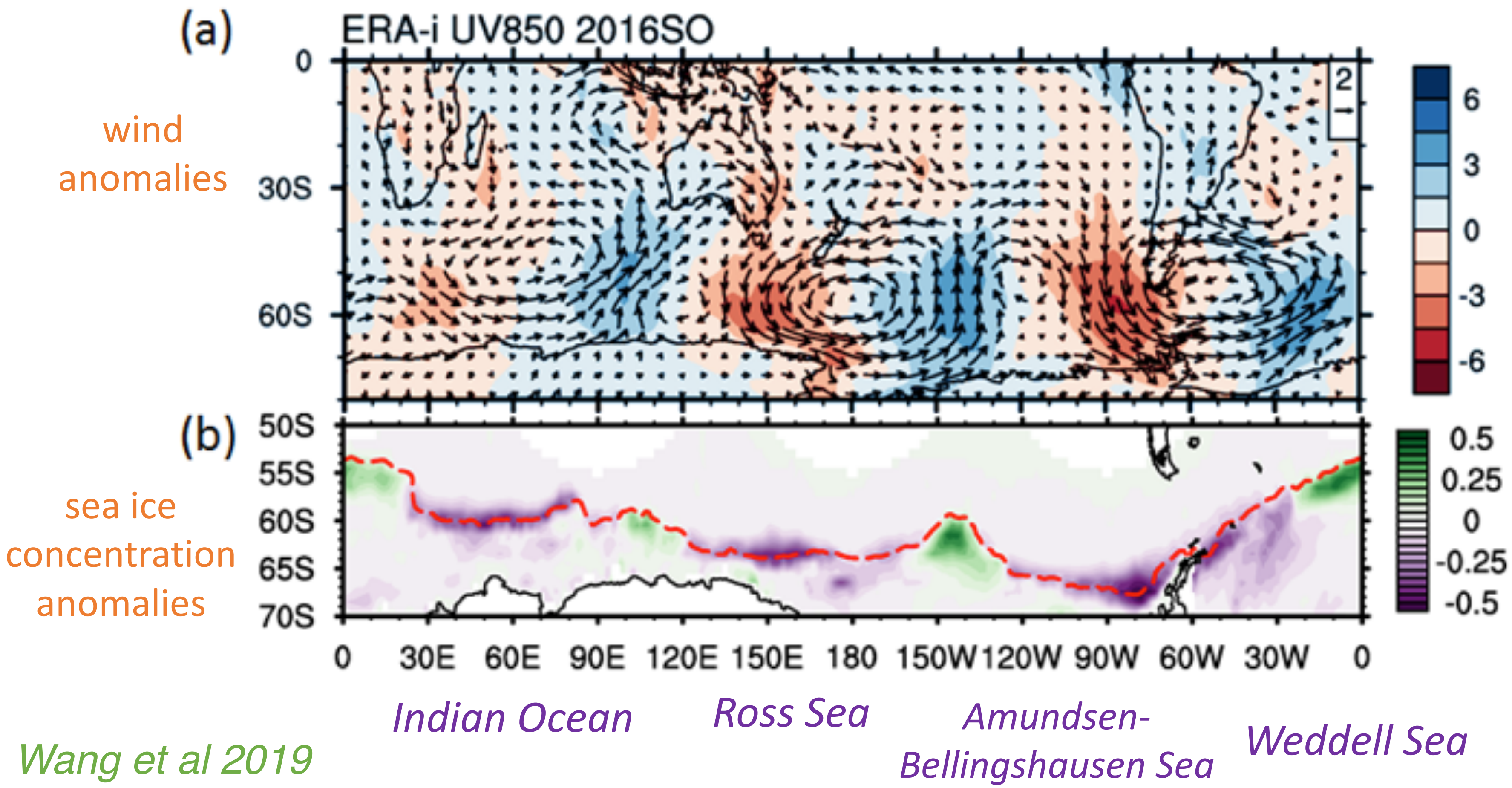
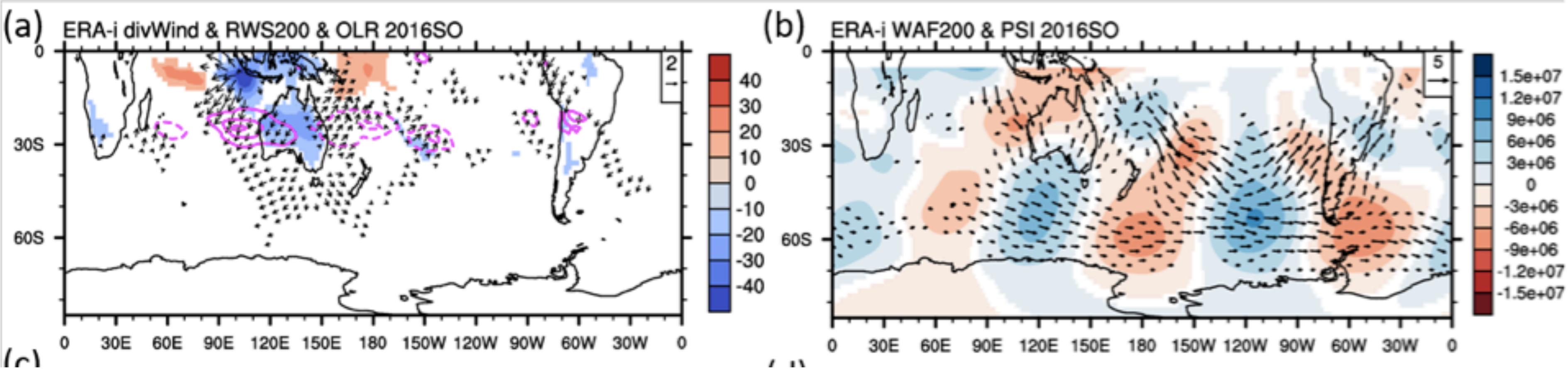


Wang et al 2019

Eastern Indian Ocean and western Pacific wave sources



Shading = OLR
Vectors = divergent wind at 200 hPa
Pink contours = Rossby Wave Source

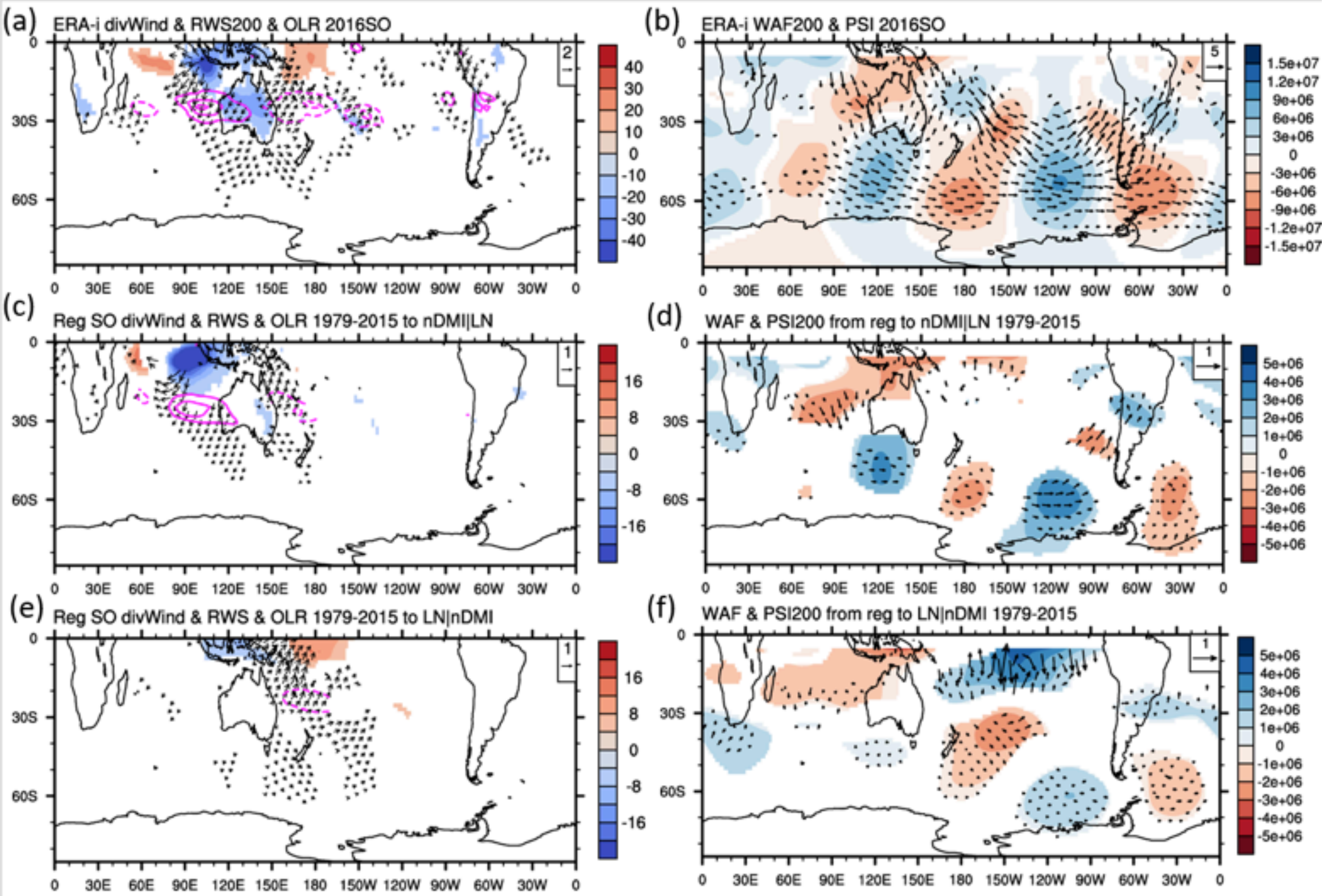
Shading = streamfunction
Vectors = wave activity flux

Wang et al 2019

Eastern Indian Ocean and western Pacific wave sources

with ENSO influence removed

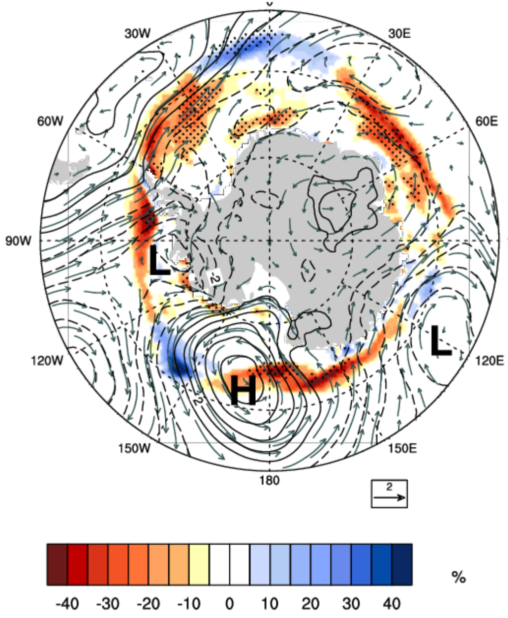
with DMI influence removed



September-October circulation dominated by wave train

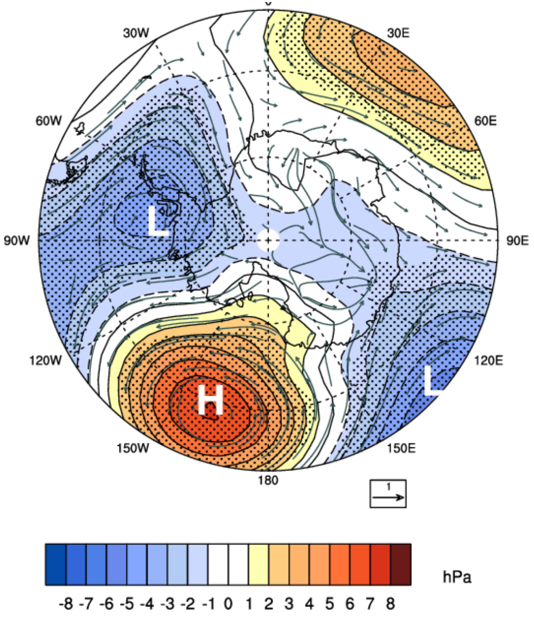
CAM3 model experiment supports the conclusion from Wang et al. (2019) that atmospheric heating over the eastern Indian Ocean drove the initial sea ice decline

Obs Sea-Ice, winds and SLP



SON 2016 anomalies

CAM3 SLP and winds

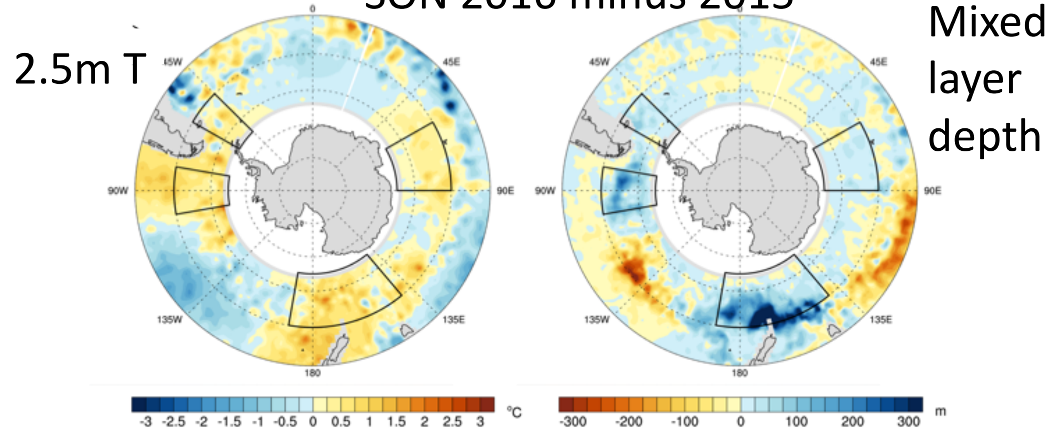


Positive convective heating anomaly experiment
@ 120E, Equator

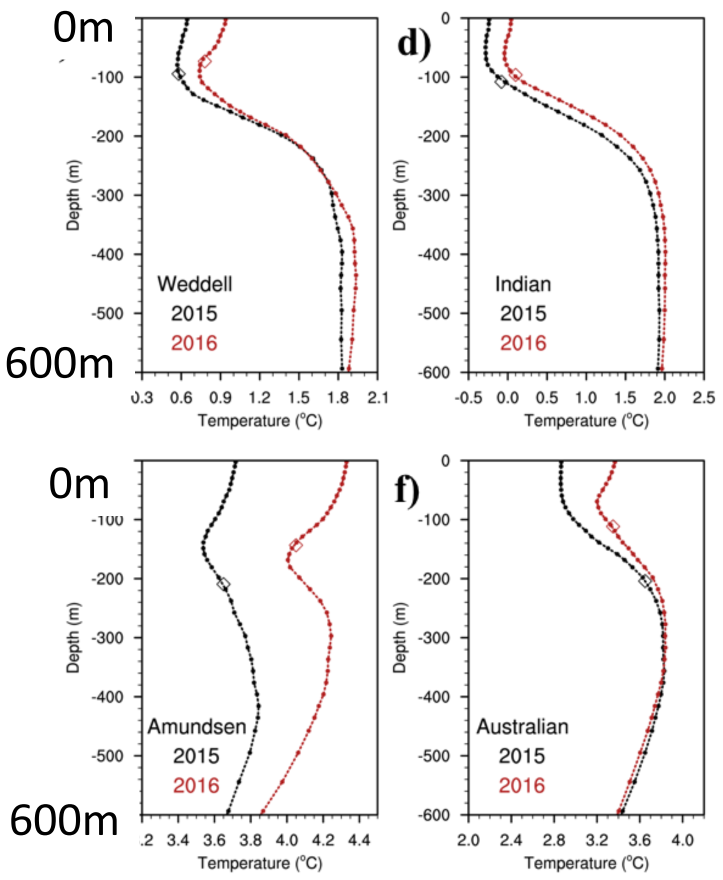
Meehl et al 2019

Rapid warming of the Southern Ocean in SON 2016

SON 2016 minus 2015



Argo float profiles



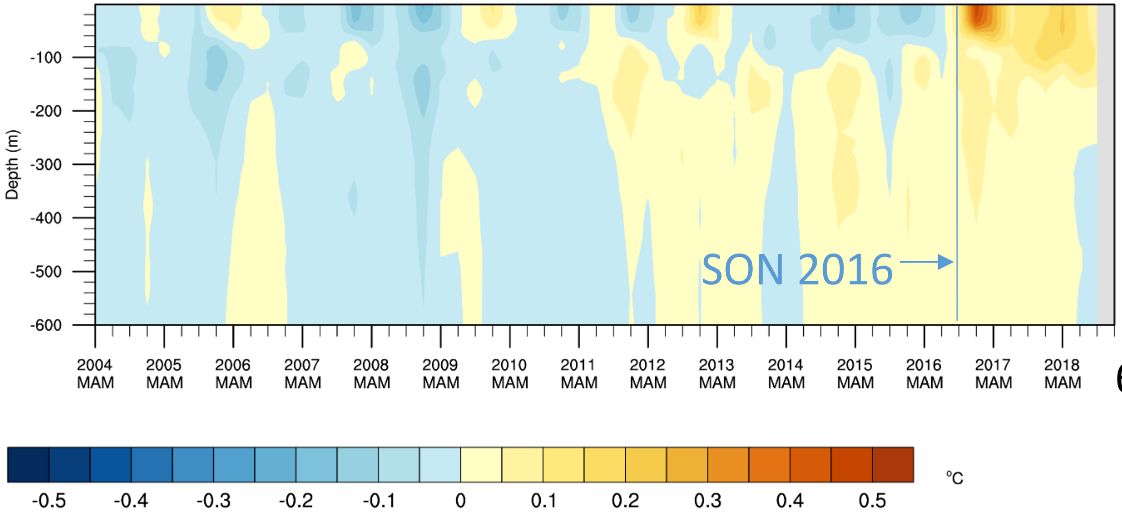
SSTs warmed and mixed layer depth rapidly shallowed in same regions as sea ice decline

Depth of warming suggests longer term processes could be at play

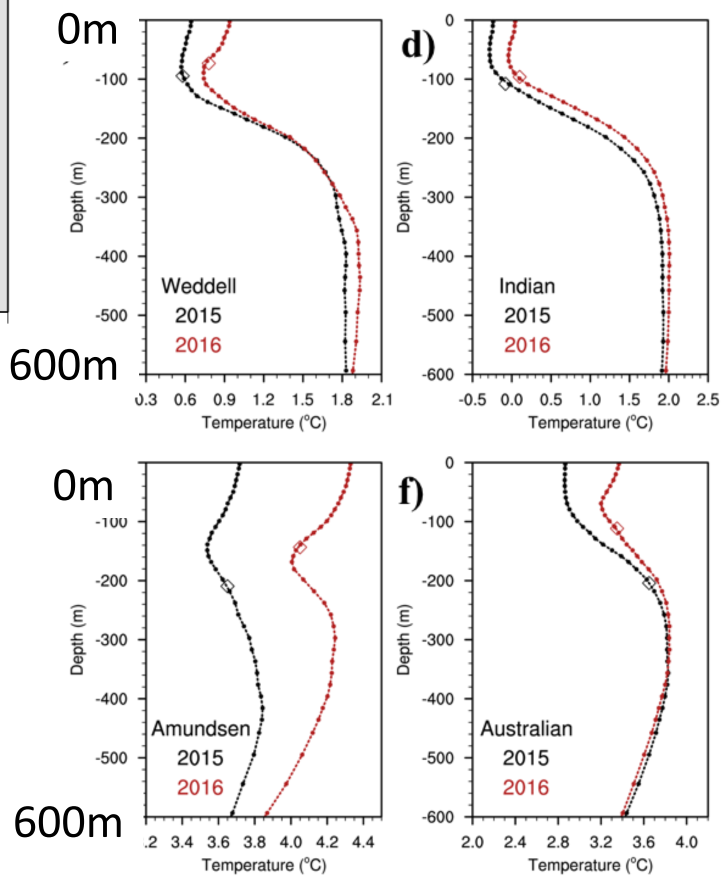
Meehl et al 2019

Rapid warming of the Southern Ocean in SON 2016

Argo float data: zonal mean temperature 50-65S



Argo float profiles



Episodic movement of warm subsurface water upward in the water column til SON 2016 when entire column in upper 600m had positive temperature anomalies

Meehl et al 2019

Rapid warming of the Southern Ocean in SON 2016

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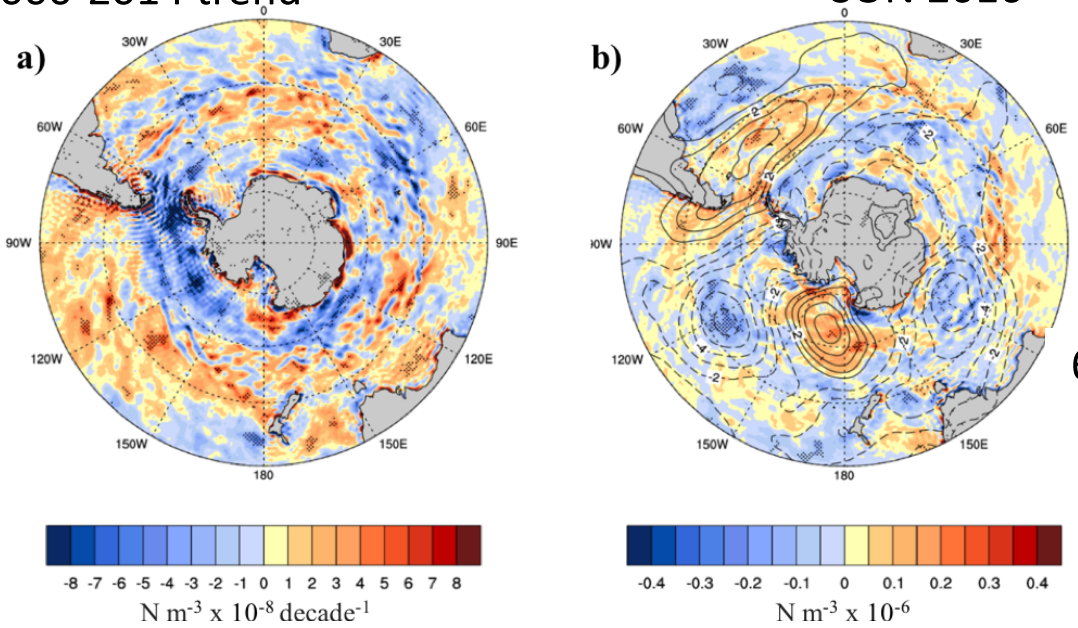
wind stress curl

2000-2014 trend

SON 2016



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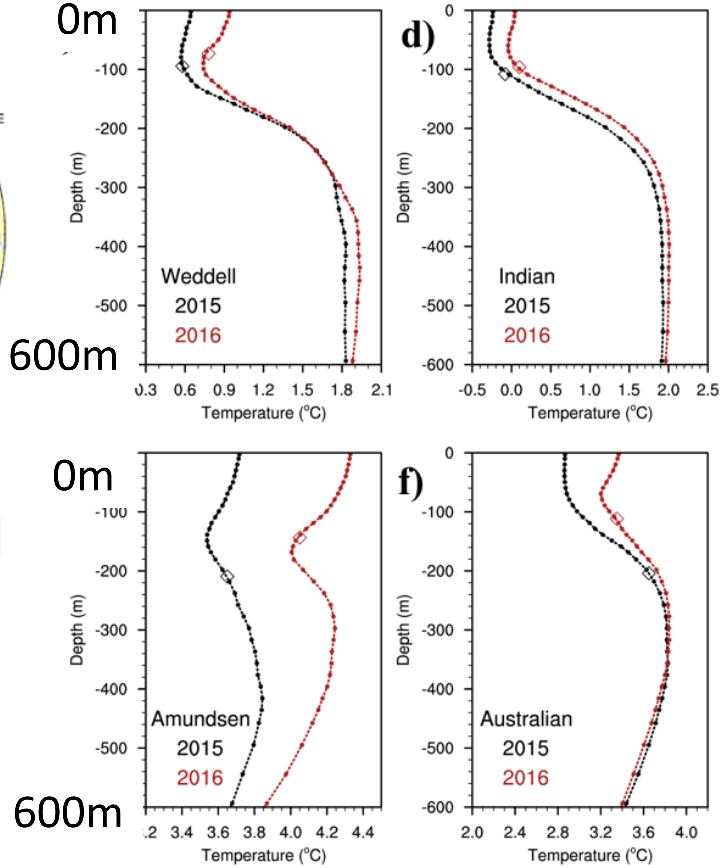
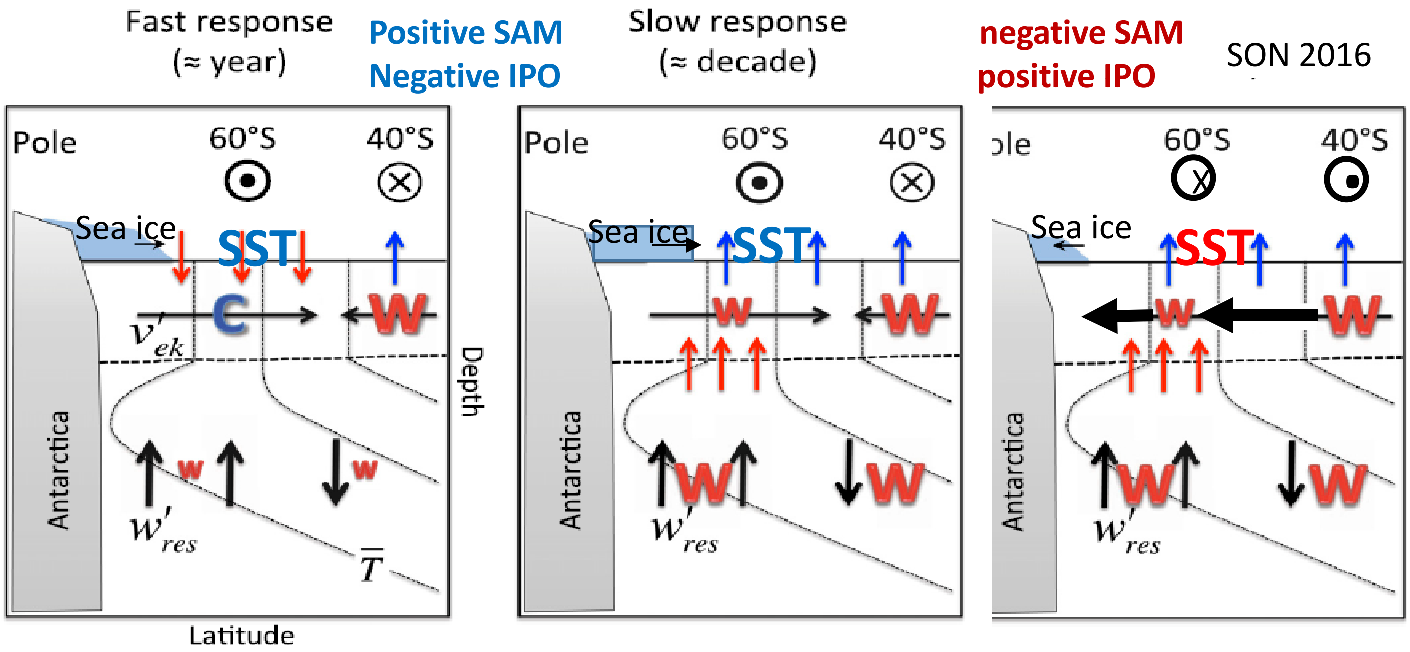


Windstress curl anomalies near Antarctica also switched sign in 2016

Meehl et al 2019

Two-timescale response of the Southern Ocean



A modified "two timescale response" to wind forcing over the Southern Ocean, leading to a sudden SST and sea ice transition

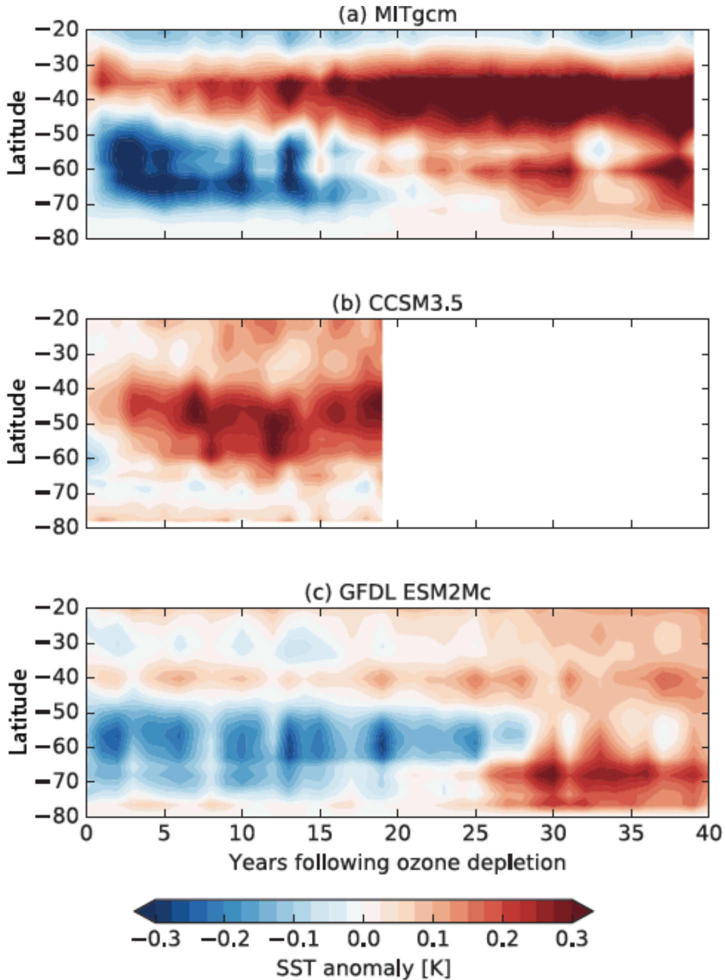
(modified from Ferreira et al., 2015, J. Clim.)

Two-timescale response

Zonal mean annual mean SST response to a abrupt ozone depletion in various coupled models. All show a two-timescale response, consisting of a cooling followed by a warming from ~ 50-70S but the magnitude and timescales vary greatly

Figure 5-19, WMO/UNEP Ozone Assessment 2018

Zonal mean annual SST



What produces winds on decadal timescales?

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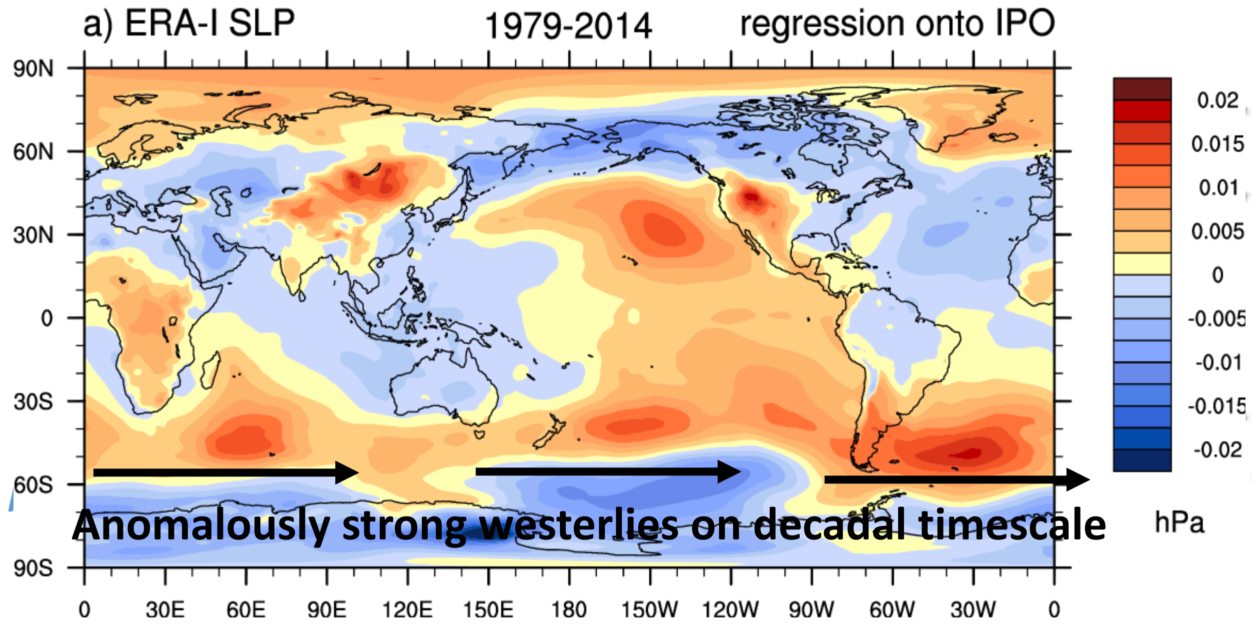
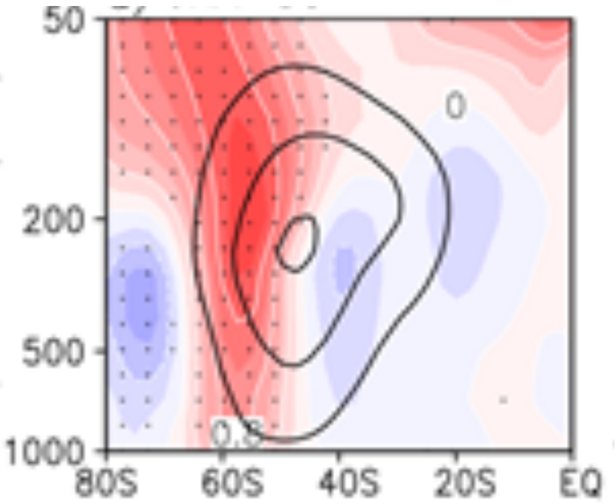
Negative IPO

and/or external forcing



JRA-55 reanalysis

1960-2000 DJF Zonal U trends



Meehl et al 2019

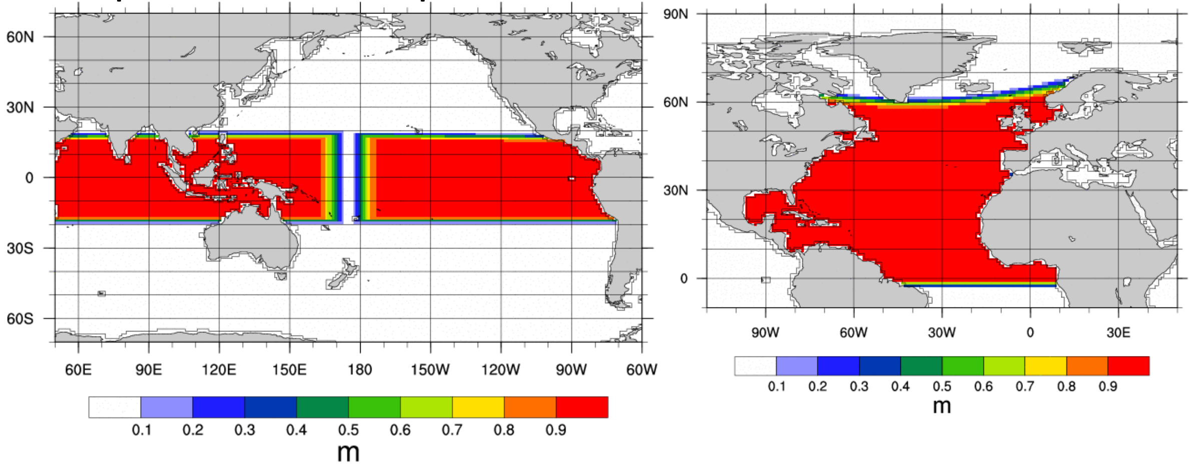
Son et al ERL 2018

Role of the Tropics in decadal wind changes

Pacemaker experiments with the CESM1 for the tropical Pacific, tropical Indian and tropical+North Atlantic regions

Separate the influence of external forcings and internally driven observed tropical SSTs in different regions

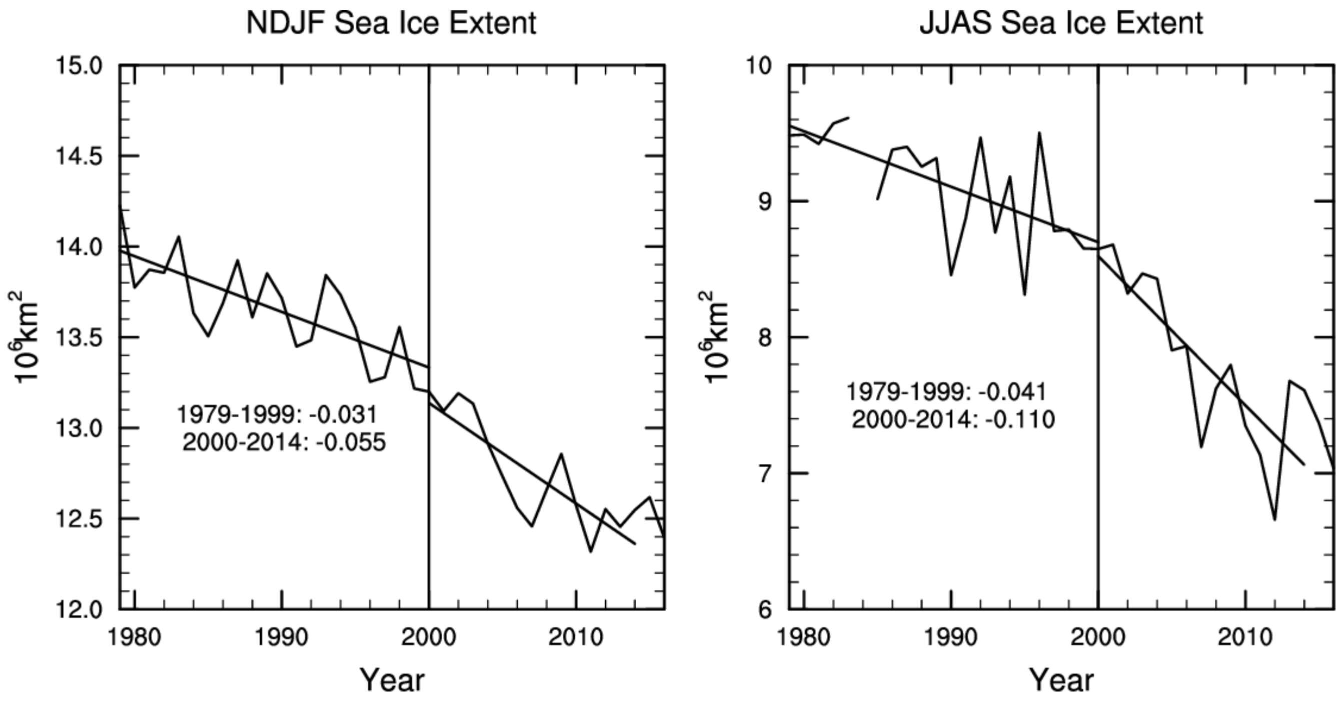
Tropical Indian, tropical Pacific and North Atlantic masks



Dongxia (Dawn) Yang et al, in preparation

Role of the Tropics in Arctic sea ice?

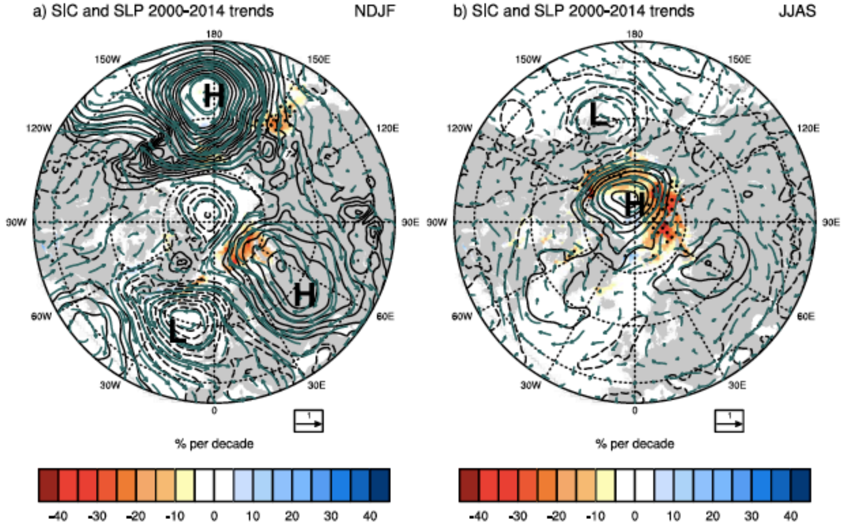
Arctic



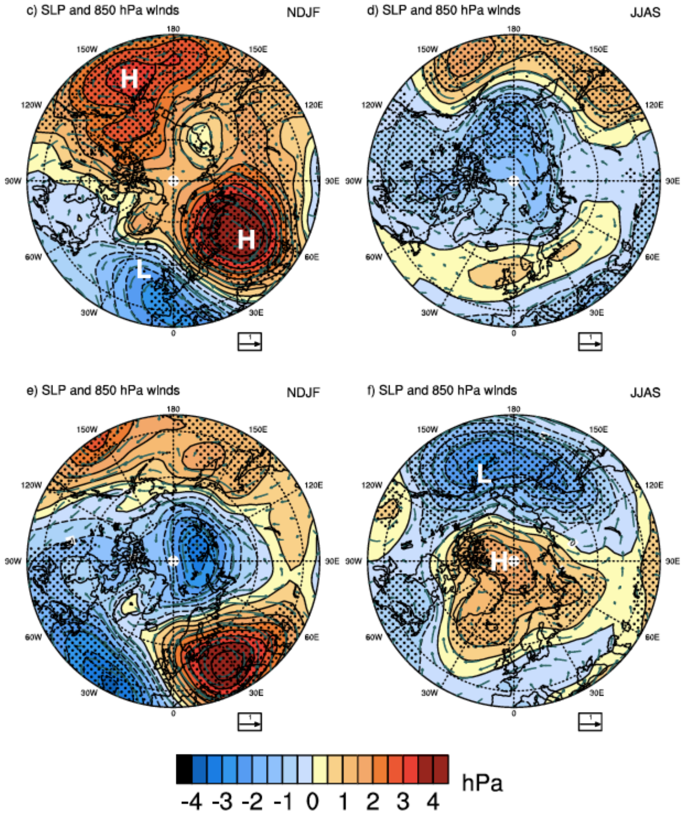
At the IPO transition around 2000, sea ice extent trends accelerate in both seasons (NDJF by nearly a factor of two, nearly a factor of three in JJAS)

Role of the Tropics in Arctic sea ice?

NDJF Obs JJAS SLP



NDJF CAM3 JJAS



Eq East Pacific -ve conv heating

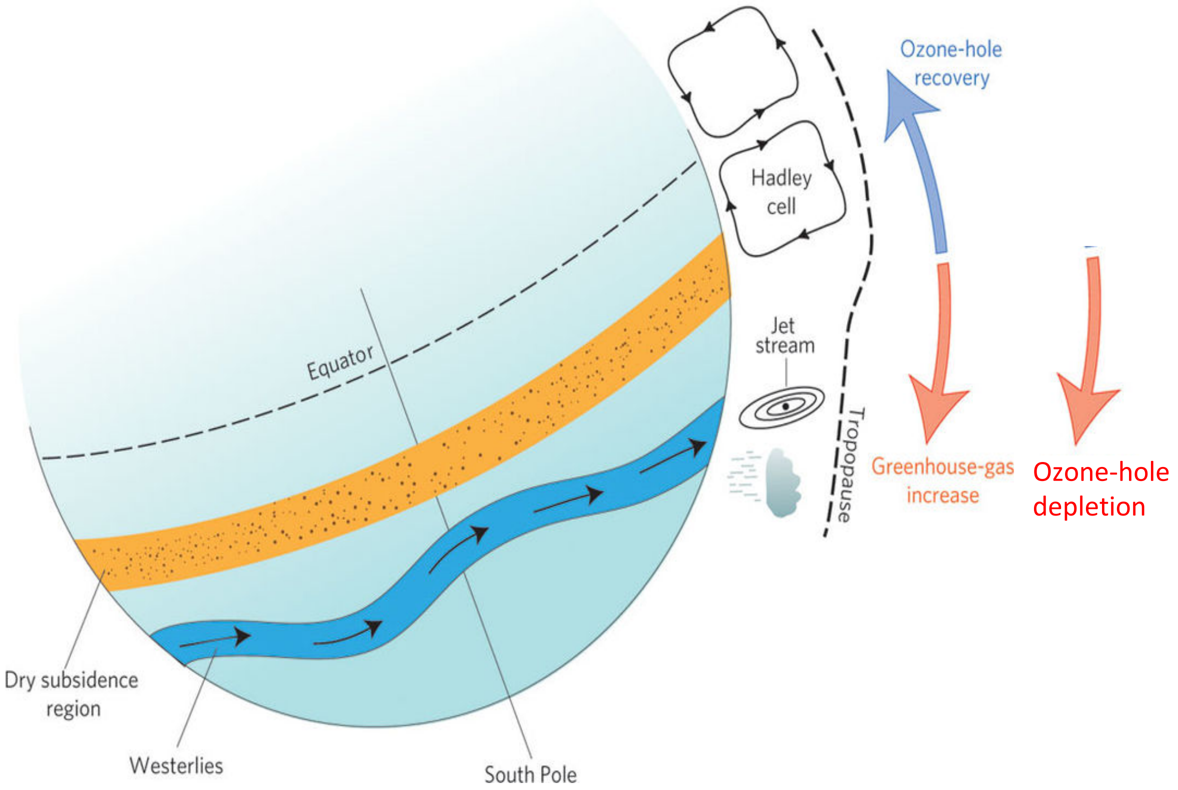
Eq Atl +ve conv heating

Equatorial Pacific convective heating exps match NDJF SLP patterns

Equatorial Atlantic match JJAS SLP patterns

Meehl et al GRL 2018

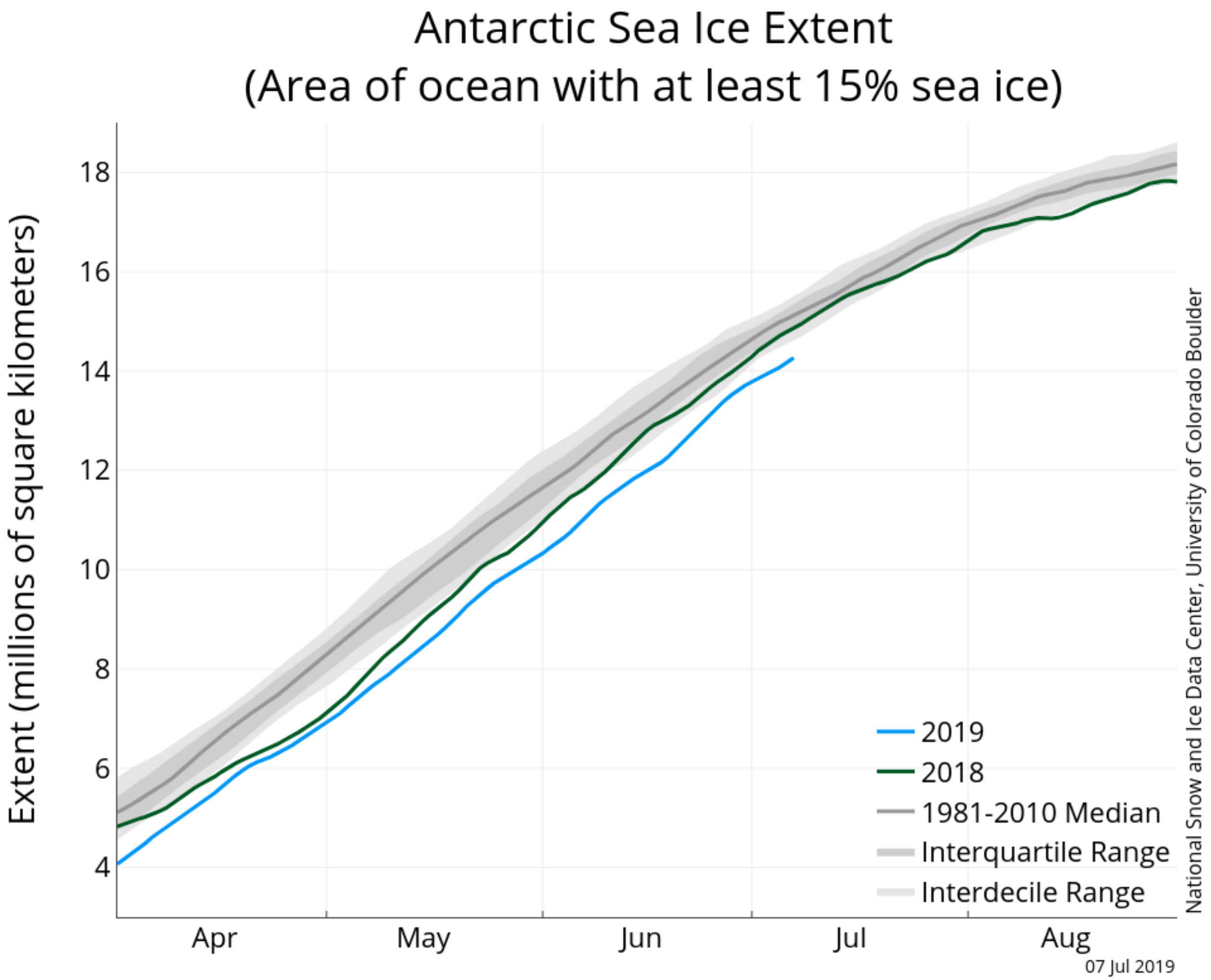
Future SH atmospheric circulation changes?



How will internally generated variability across timescales interact and combine with anthropogenic forcing in the future?

[recent papers by Zhang et al NCC 2019 and Purich & England, GRL, 2019]

Perlwitz, 2011



Antarctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Extent (millions of square kilometers)
18
16
14
12
10
8
6
4
Apr
May
Jun
Jul
Aug
2019
2018
1981-2010 Median
Interquartile Range
Interdecile Range
National Snow and Ice Data Center, University of Colorado Boulder
07 Jul 2019

Conclusions

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Strong role for internal variability in the tropics in driving recent changes in the Antarctic and Arctic sea ice extents

- The rapid and sustained decline in Antarctic sea ice that began in spring 2016 was triggered by a record negative IOD event, driving anomalous southward surface winds near Antarctica

- Propose that a warmer upper Southern Ocean due to the negative trend in wind stress curl over 2000-2014 was then brought to the surface, sustaining the anomalously low sea ice extent to present

- Pacemaker experiments suggest a dominant role of the tropical Pacific (IPO) in driving recent decadal changes in the SH mid-latitude winds

Thankyou

- Wang, G., H.H. Hendon, J.M. Arblaster, E.-P. Lim, S. Abhik, P. van Rensch, 2019, Compounding tropical and stratospheric forcing of the record low Antarctic sea-ice in 2016, Nature Comm, https://doi.org/10.1038/s41467-018-07689-7
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