Response of the Southern Hemisphere atmospheric and oceanic circulation to single forcings - SH WG community paper

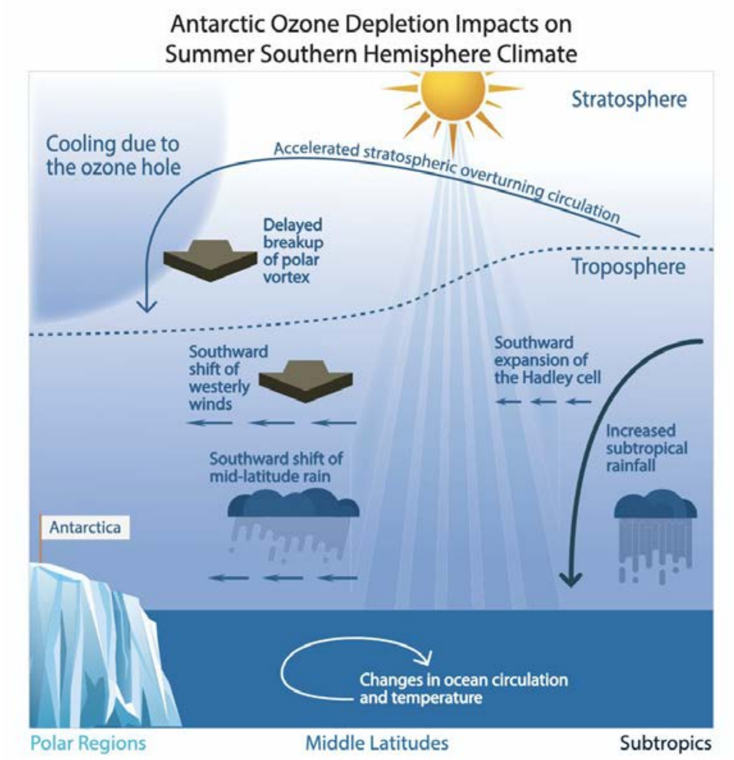
Leandro B. Díaz (CIMA-University of Buenos Aires)
Amy H. Butler (NOAA-Chemical Sciences Laboratory)
on behalf of the Southern Hemisphere EPESC/LEADER working group

.UBA Universidad de Buenos Aires
CONICET
CIMA
IFAECI

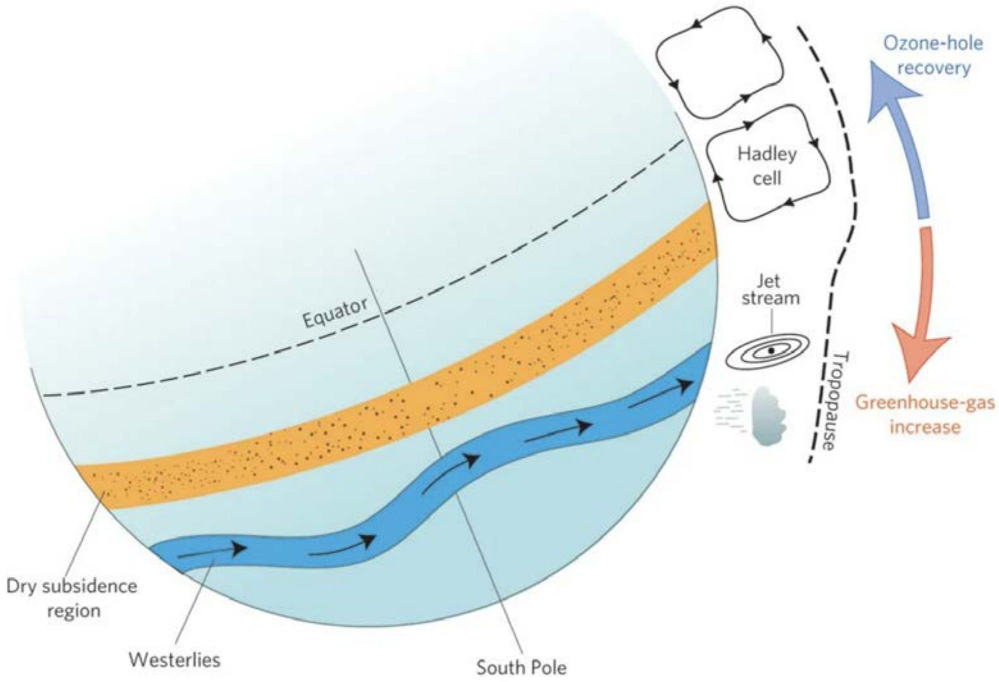
Southern Hemisphere EPESC/LEADER working group

Amy Butler (co-leads)	Chaim Garfinkel	Scott Osprey
Leandro Diaz (co-leads)	Doug Smith	Lin Wang
Kevin Grise	Amanda Maycock	Gabriel Chiodo
Jonathon Wright	Marisol Osman	Elio Campitelli
Sabine Bischof	Julia Mindlin	David Thompson
Hemant Khatri	Panos Athanasiadis	Marlene Kretschmer
David Avisar	Julie Arblaster	Gang Chen
Ghyslaine Boschat	Tom Bracegirdle	Peidong Wang
William Dow	Eun-Pa Lim	Melody (Kezhou) Lu
Bianca Mezzina	Tiffany Shaw	Kewei Lyu
Chloe Boehm	James Renwick	Qiang Fu
Yuanrui Chen	Michael Sigmond	

Known drivers of SH circulation changes



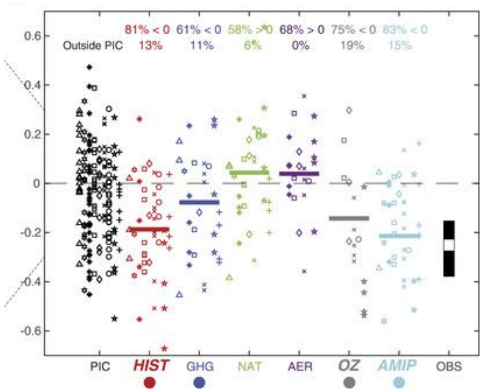
Ozone depletion
WMO (2018)



Ozone recovery + greenhouse gas increases
Perlwitz (2011)

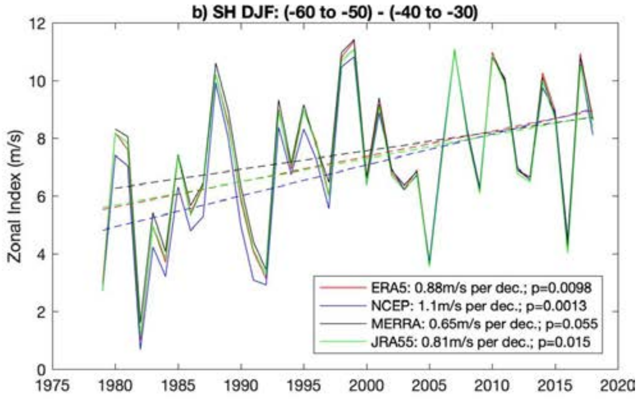
Some examples of emerging signals in the SH circulation

SH Hadley cell poleward shift



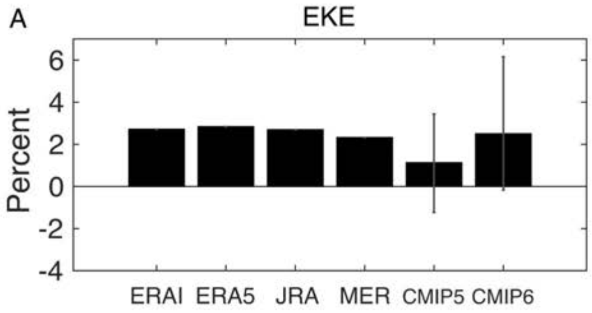
[Grise et al (2019)]

SH upper-troposphere jet poleward shift



[Woolings et al (2023)]

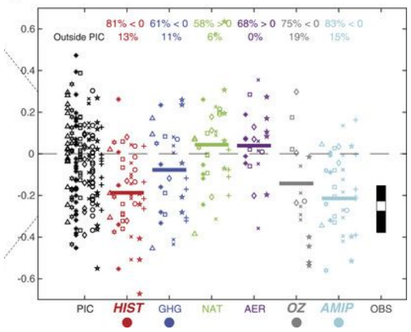
SH Storm track strengthening (eddy kinetic energy)



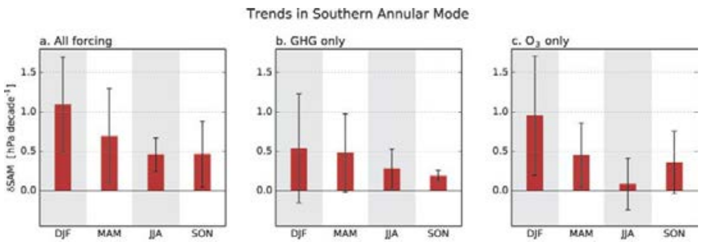
[Shaw et al (2022)]

Review on [Shaw et al (2024)]

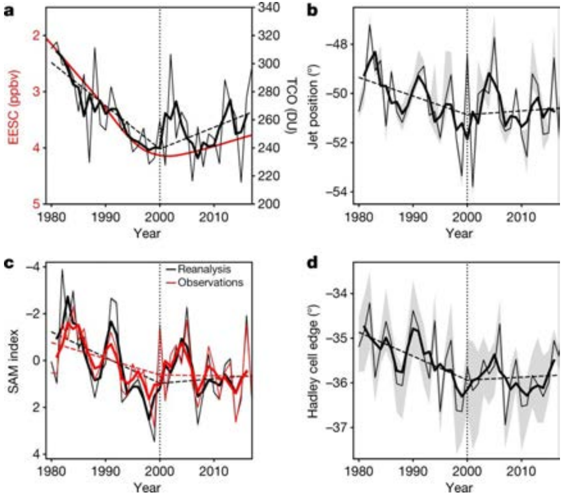
Attribution of emerging signals in the SH circulation



Grise et al (2019)



Boisier et al (2018)



Banerjee et al (2020)

Long-term trends in atmospheric circulation (e.g. Hadley cell shift, SAM) have been attributed to human activities (increase in greenhouse gases and ozone depletion).

Recent studies have suggested a pause in the SH circulation trends observed in the last decade due to ozone recovery.

Attribution of emerging signals in the SH circulation

Previous studies are mostly based on **single models or models with few members** (not able to properly represent the internal variability range). There is also a **lack of systematisation** in assessing the changes using a common approach.

What are the competing roles of stratospheric ozone, GHGs, aerosols, and internal variability in driving multidecadal trends in Southern Hemisphere atmospheric and oceanic circulation?

What is the impact of ozone recovery during the early 21st century on Southern Hemisphere circulation trends?

What is the role of aerosol forcing in driving certain Southern Hemisphere circulation features that may have been underemphasized in previous studies?

What are the changes in Southern Hemisphere circulation during fall and winter?

LESFMIP Data

Model	Experiments			
	Historical	hist-GHG	hist-aer	hist-totalO3
ACCESS-ESM1-5	40	10	10	
CanESM5	65	50	30	10
CMCC-CM2-SR5	10	10	10	
CNRM-CM6-1	30	10	10	
GISS-E2-1-G	40	40	40	40
HadGEM3GC31-LL	55	55	55	50
IPSL-CM6A-LR	33	10	10	
MIROC6	50	50	10	10
MPI-ESM1-2-LR	50	30	30	30
NorESM2-LM	43	23	23	20

- 10 models with historical, hist-GHG and hist-aer experiments.
- Only 6 models have the hist-totalO3 experiment.
- For all experiments we have at least 10 members per model.

Smith et al. (2022)

Assessment approach

Forcing responses: Difference between 1980-2014 (present) and 1850-1884 (pre-industrial).

Multi-model mean: equal weight for each model.

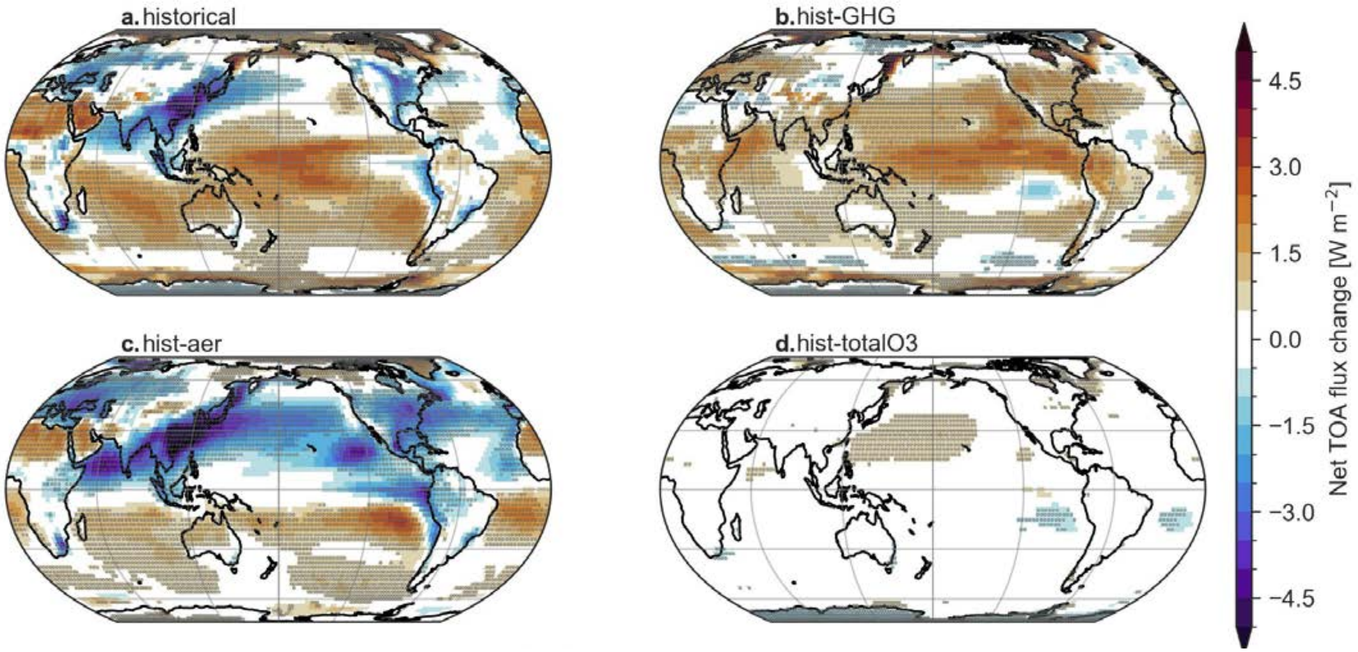
Model Agreement: stippling when >80% models match.

Timeseries: 1850 to 2014/2020.
1980-2014 trends compared with reanalysis (ERA5, MERRA2,JRA55)/observations
1980-1999 vs 2000-2014 trends

Net downward TOA flux	Hadley Cell edge latitude	Southern Ocean temperature/heat fluxes
Zonal wind (lat-p)	SH eddy-driven jet latitude	Sea ice concentration (Bianca's talk)
SLP	SAM (Ghyslaine's talk)	Surface temperature (Leandro's poster)
	Final stratospheric warming (Sabine's talk)	Precipitation (Leandro's poster)

Top of the atmosphere (TOA) flux

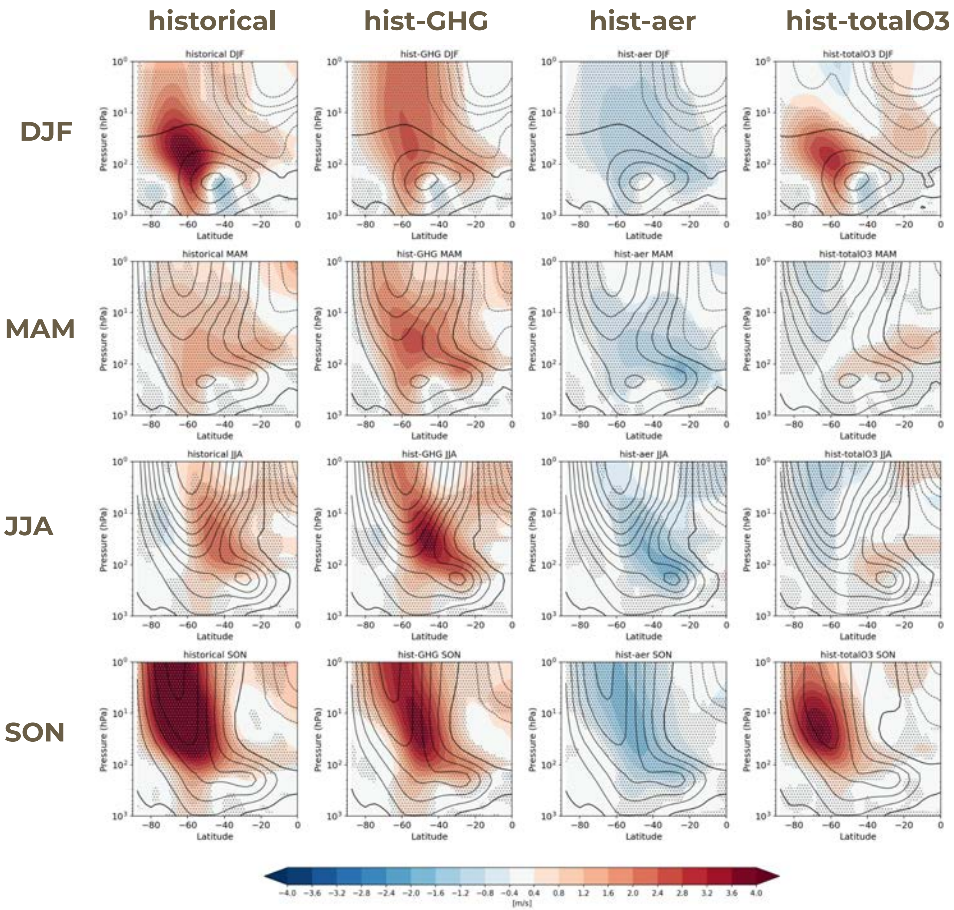
(1980-2014) - (1850-1884)



Courtesy of Jonathon Wright

Large-scale atmospheric circulation response: zonal wind (lat-press)

(1980-2014) - (1850-1884)

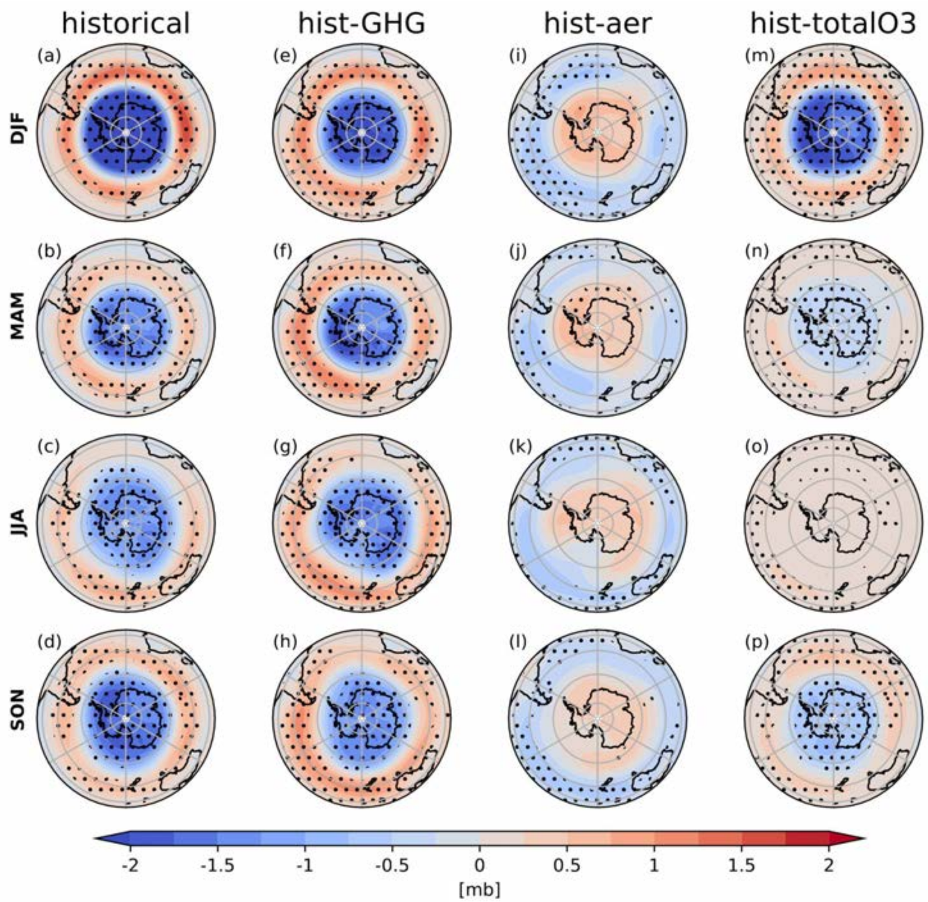


- Stronger positive changes ~60° S in SON and DJF associated with both GHG and ozone forcing.
- MAM and JJA smaller changes associated with GHG forcing.
- Aerosol forcing associated with weaker subtropical/extratropical stratospheric winds in all seasons.

Courtesy of Amy Butler

Large-scale atmospheric circulation response: sea level pressure

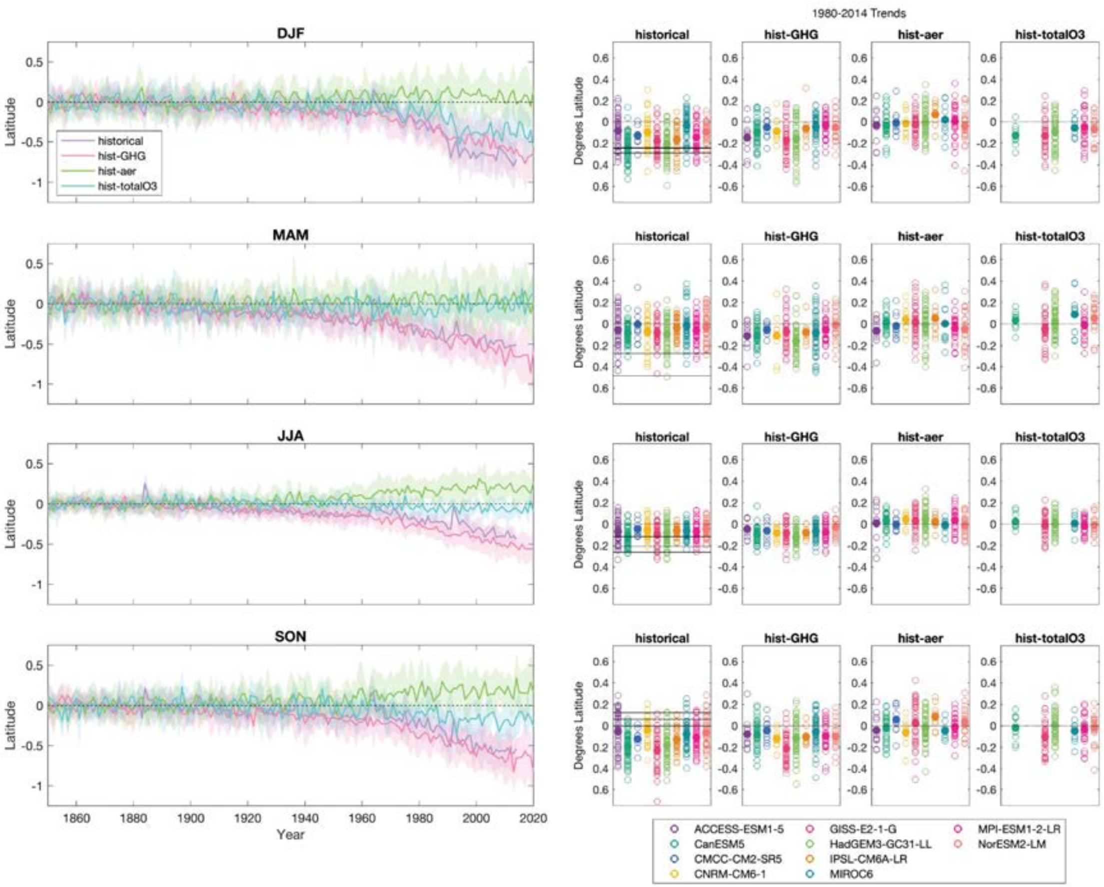
(1980-2014) - (1850-1884)



- Dipole response change (SAM-type response) mainly due to GHG (year-round) and ozone forcing (in DJF/SON).

Courtesy of David Avisar/Chaim Garfinkel

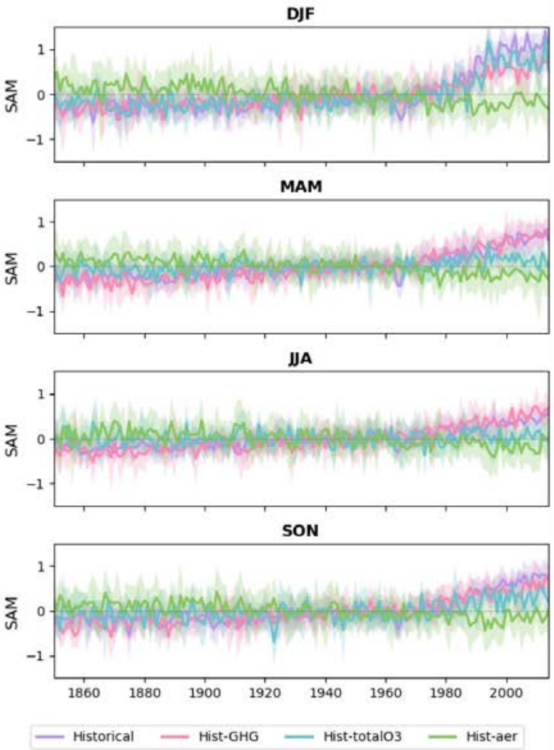
Large-scale circulation response: SH Hadley Cell edge



- SH Hadley cell poleward shift consistent signal in all seasons.
- Mostly attributable to GHG forcing and ozone forcing in DJF .

Courtesy of Kevin Grise

Large-scale circulation response: Southern Annular Mode (SAM)

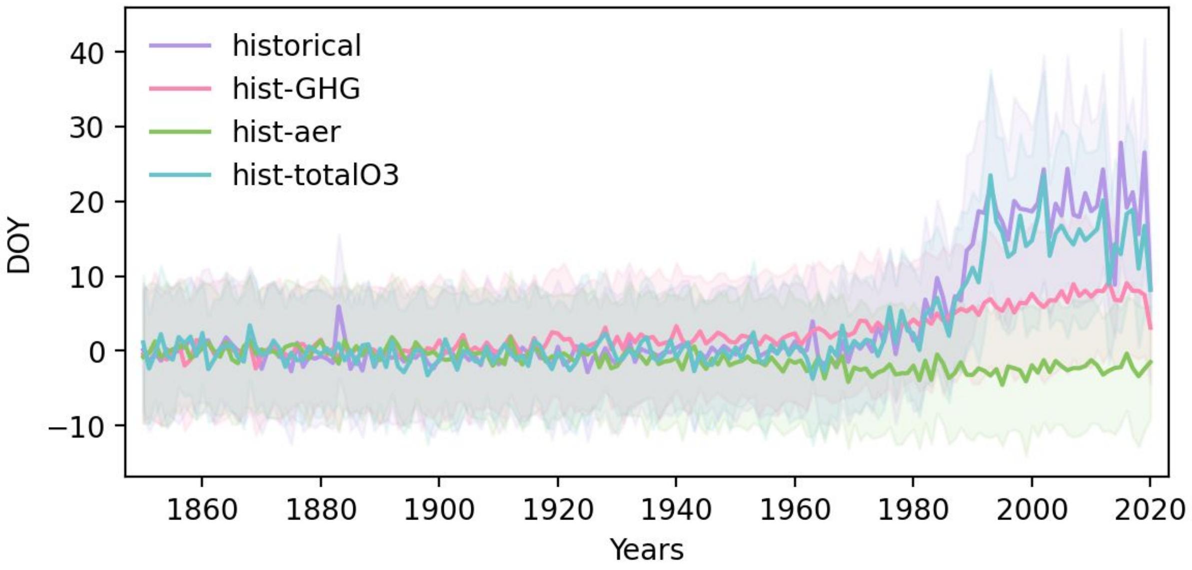


1980-2014 trends

- Aerosols show little influence on DJF SAM, which is mostly driven by GHGs and ozone.

Courtesy of Ghyslaine Boschat

Large-scale circulation response: Final Stratospheric Warming

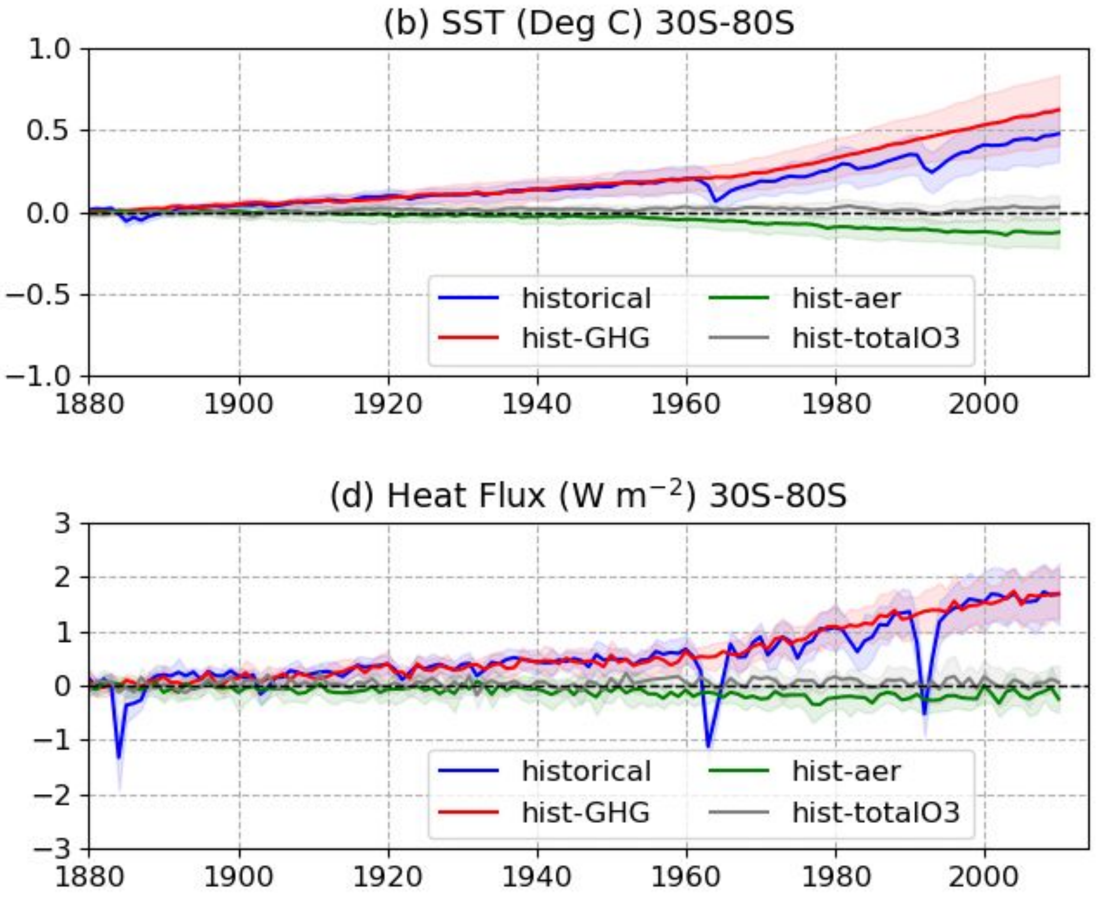


Final Stratospheric Warming: timing of the spring weakening of the vortex, marking the reversal of the climatological winter westerlies to summer easterlies in the stratosphere.

- There is a clear delay in Final Stratospheric Warming dates after the 70s peaking between 1990 and ~2010, which is dominated by the ozone forcing. GHG forcing are contributing, while aerosols are counteracting.

Courtesy of Sabine Bischof

Southern Ocean response: Sea surface temperature and heat flux

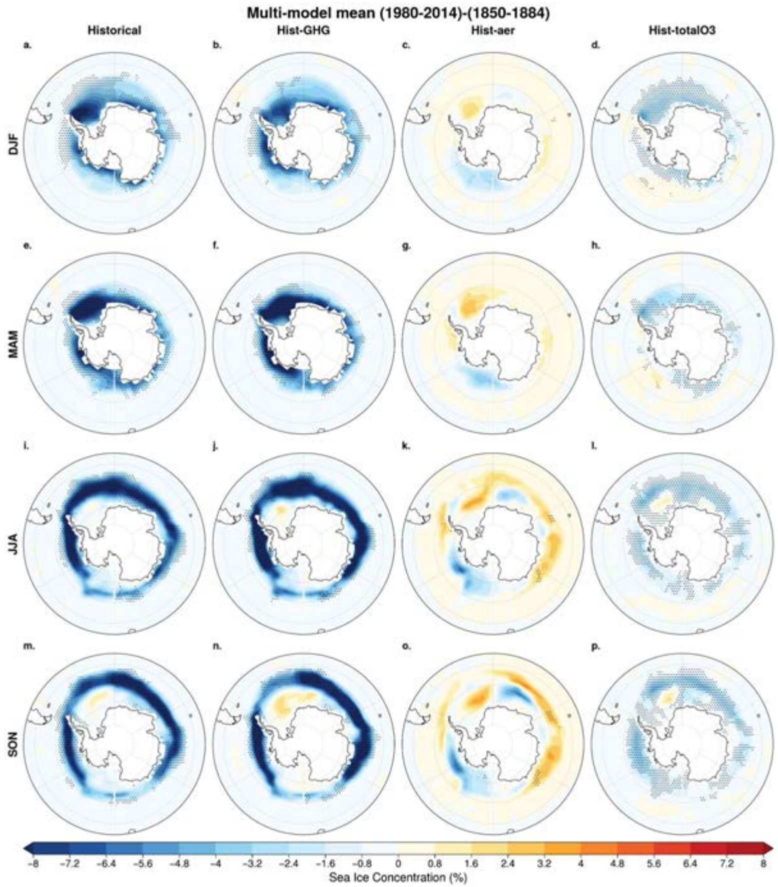


- Southern Ocean surface ocean warming driven by GHG forcing, but moderated by counter-effect of aerosol forcing.
- Ozone forcing has small to negligible effect, in part because it drives meridional dipole in SSTs (corresponding to +ve SAM), which cancels out in area average. Effect is also only apparent in DJF.
- Strong effect of volcanic forcing on heat flux

Courtesy of Hemant Khatri

Southern Ocean response: Sea ice concentration

(1980-2014) - (1850-1884)

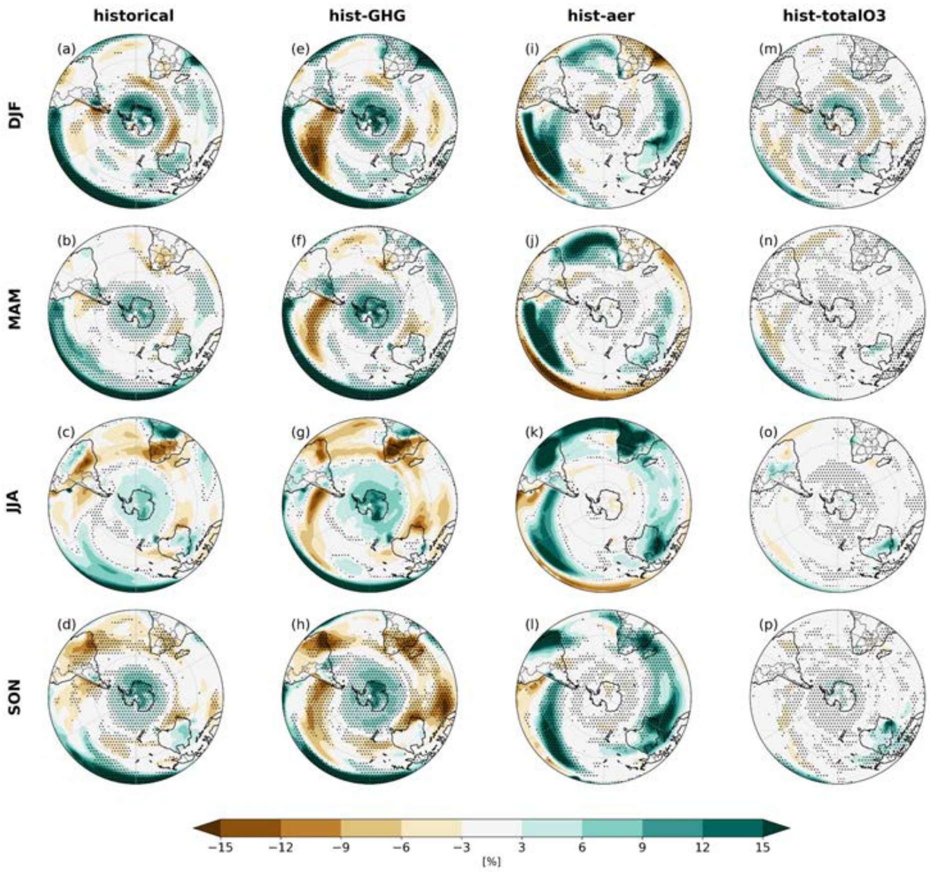


- Declining sea ice concentration in historical simulations is mostly attributed to GHG forcing.

Courtesy of Chloe Boehm and Bianca Mezzina

Surface response: Precipitation

(1980-2014) - (1850-1884)



- The precipitation response is zonally symmetric at high latitudes (driven by zonal wind changes) and asymmetric at low and mid latitudes.
- The response is mainly driven by GHG forcing, but is enhanced by ozone forcing at high latitudes and counteracted by aerosol forcing in tropical regions (e.g. South Pacific).

Courtesy of Leandro Díaz

Conclusions

- Large-scale circulation trends in the Southern Hemisphere and their effect on surface climate are largely explained by external forcing: mainly greenhouse gas forcing, but also ozone forcing relevant at mid to high latitudes in SON and DJF and aerosol forcing relevant at low latitudes.
- We have detected evidence of the impact of ozone recovery on large-scale circulation in the Southern Hemisphere and on the surface.
- Further research is needed to better understand across-model differences/biases and their relationship to the forced response.

Thank you very much for your attention!
Questions?

Leandro Díaz (on behalf of EPESC-LEADER SH WG)
ldiaz@cima.fcen.uba.ar