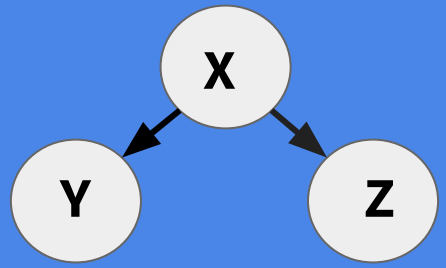
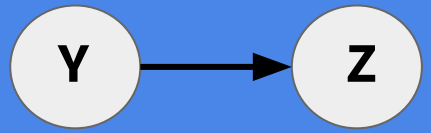
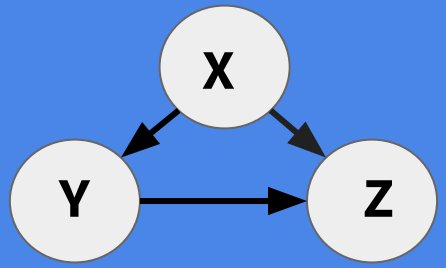
Precipitation changes in the Subtropical convergence zones and the stratospheric polar vortex: Common driver or causal link?

Julia Mindlin[1,2,3], Theodore G. Shepherd[4], Carolina Vera[1,2,3], Marisol Osman[1,2,3]





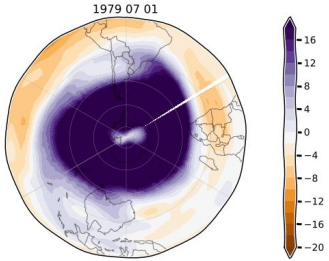


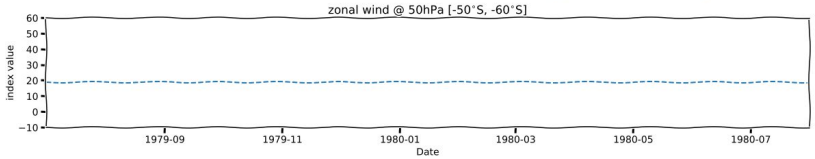
1. Departamento de Ciencias de la Atmósfera y los Océanos, FCEN, UBA; 2. Centro de Investigaciones del Mar y la Atmósfera, CONICET; 3. Instituto Franco Argentino Sobre Estudios del Clima y sus Impactos, CNRS; 4. Department of Meteorology, UoR

Motivation - Stratospheric polar vortex seasonal cycle

ERA5 reanalysis (May 1979-May 1980)

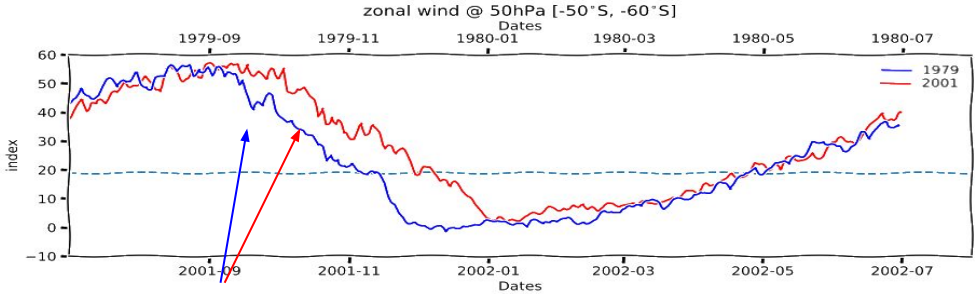
Vortex Breakdown **date**:
u @50hPa < 19 m/s





The seasonal cycle of the stratospheric polar vortex is conditions the Southern Hemisphere tropospheric circulation.

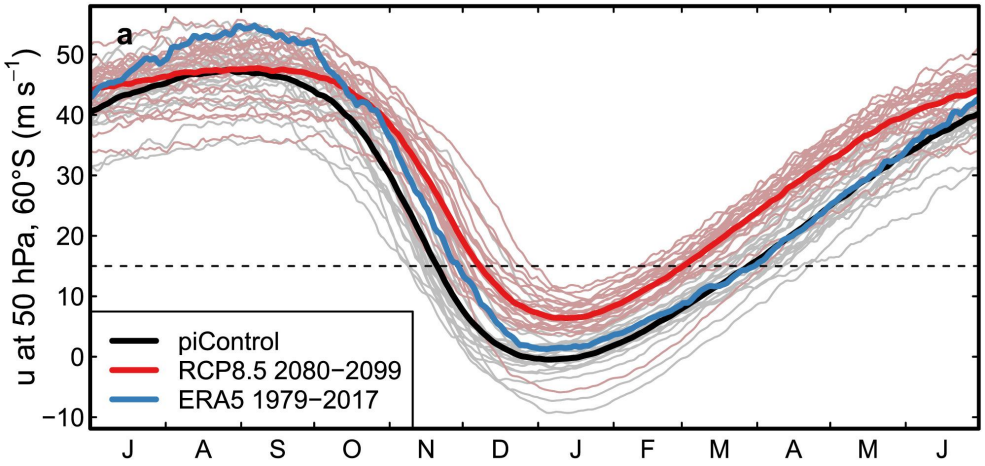
The trends in the vortex breakdown date observed in 1980-2000 have been attributed to ozone depletion.



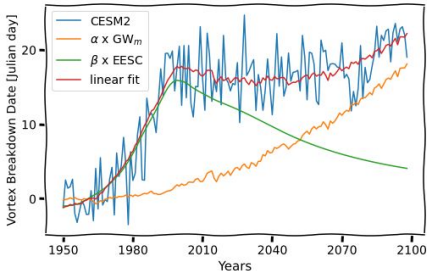
Vortex Breakdown **date**: u @50hPa < 19 m/s

Motivation - Stratospheric polar vortex breakdown delay

CESM2 historical simulation

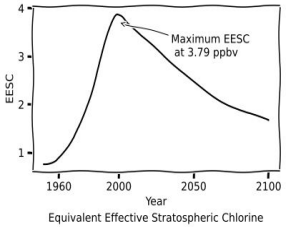


Ceppi & Shepherd (2019) https://doi.org/10.1029/2019GL082883

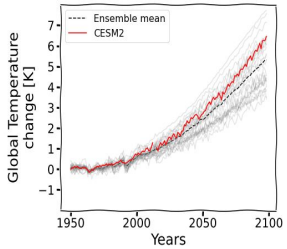


$$VB_{delay}(t) = \alpha\ EESC(t) + \beta\ \Delta T_m(t) + \epsilon$$

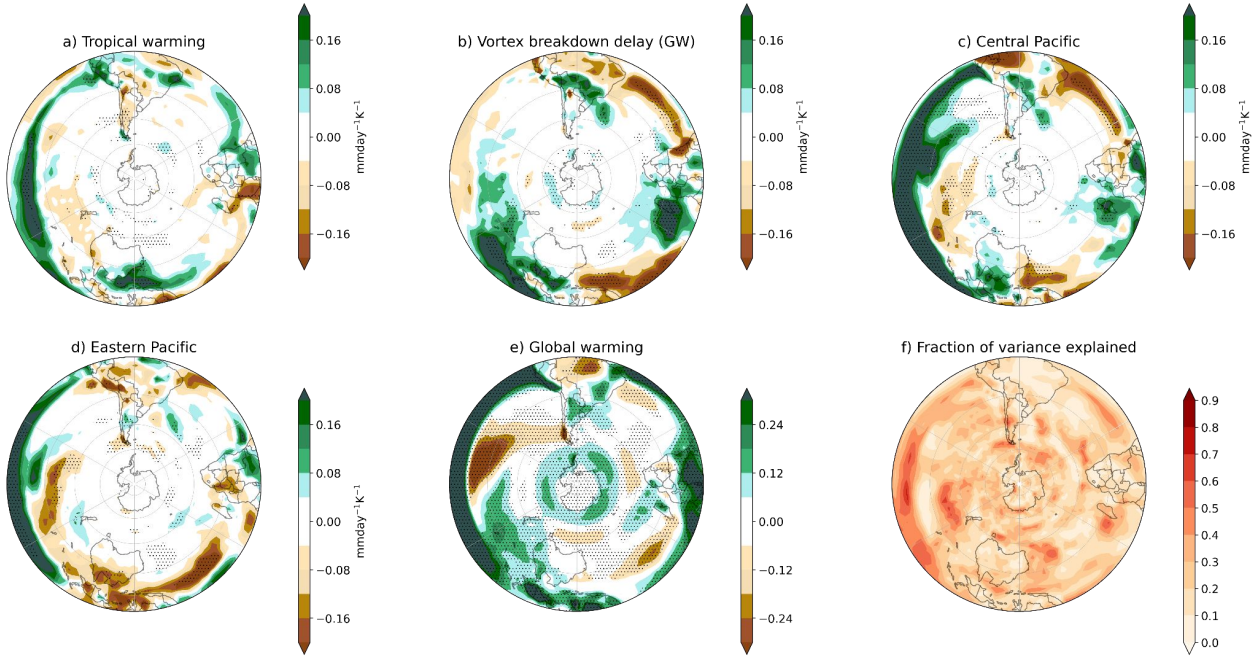
VB response to

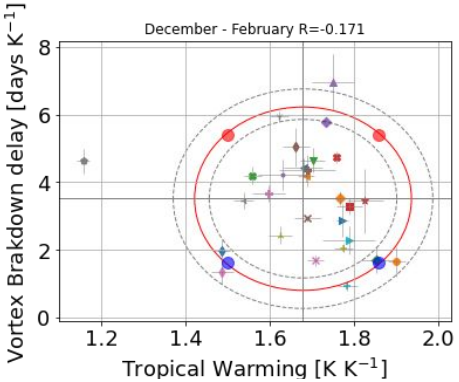


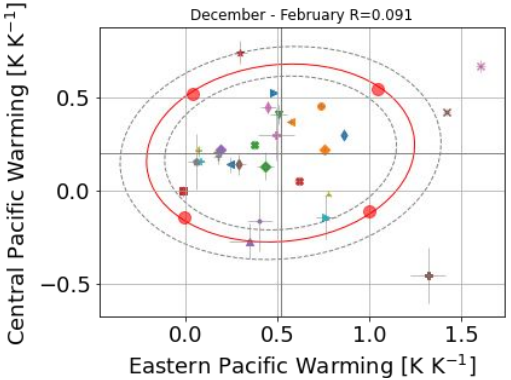
VB response to



Long term changes in Vortex Breakdown delay and other remote drivers of SUMMER (DJF) circulation

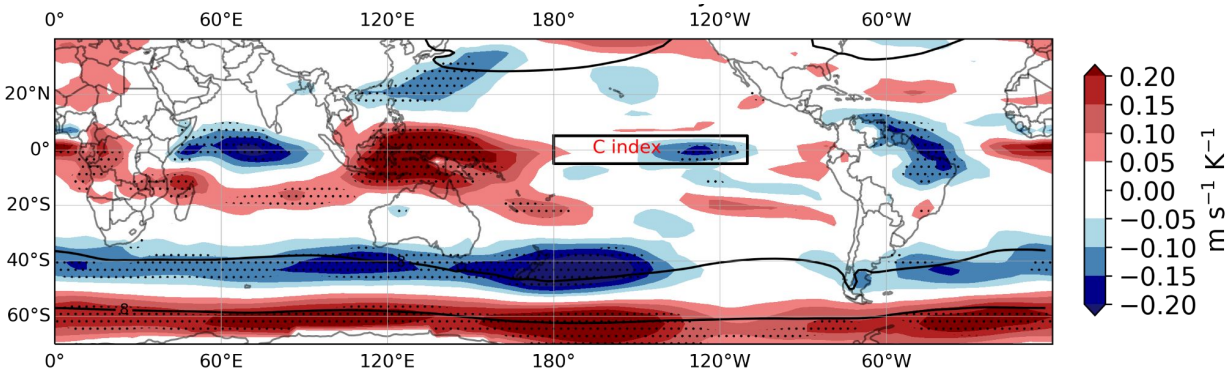




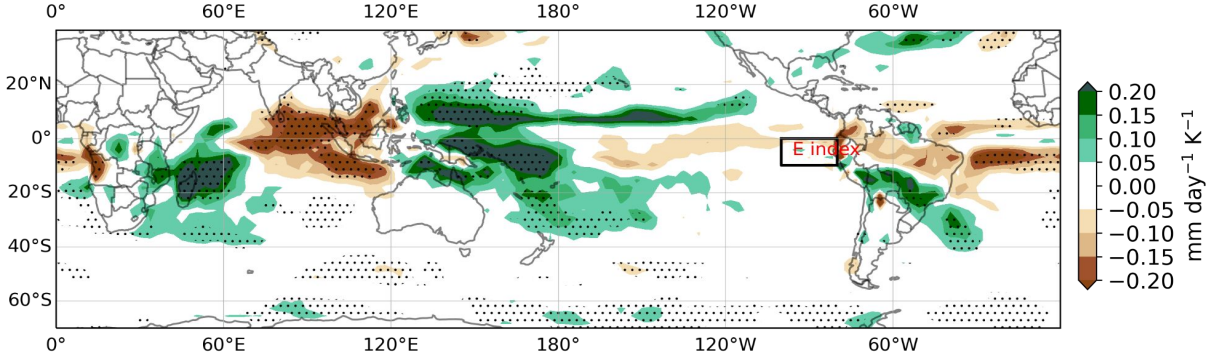


Tropospheric response to Vortex breakdown delay

Long term changes - CMIP6 models - SSP 8.5 scenario

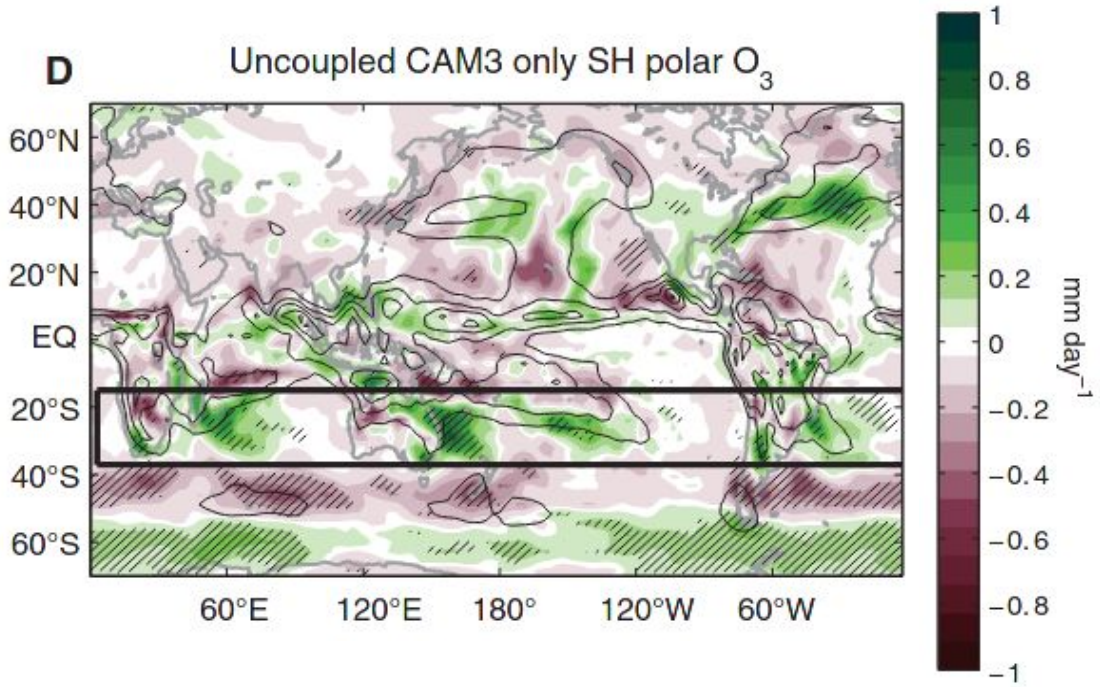


Zonal wind (u 850hPa)

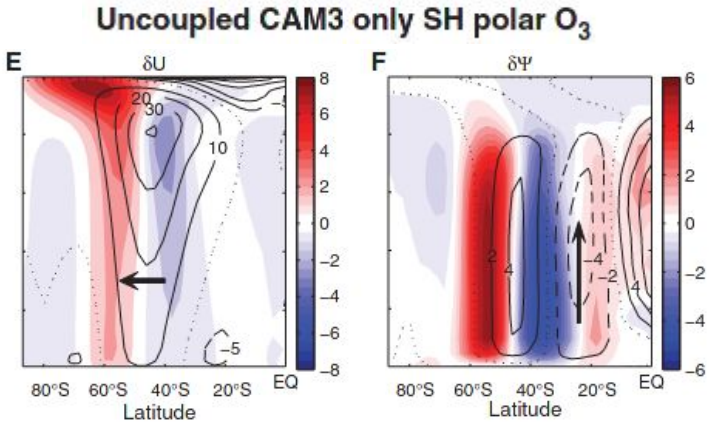


Precipitation change

Precipitation change (DJF) - ozone depletion



Precipitation patterns congruent with poleward shift of the westerly jet show moistening the subtropics. However, this does not explain longitudinal asymmetries

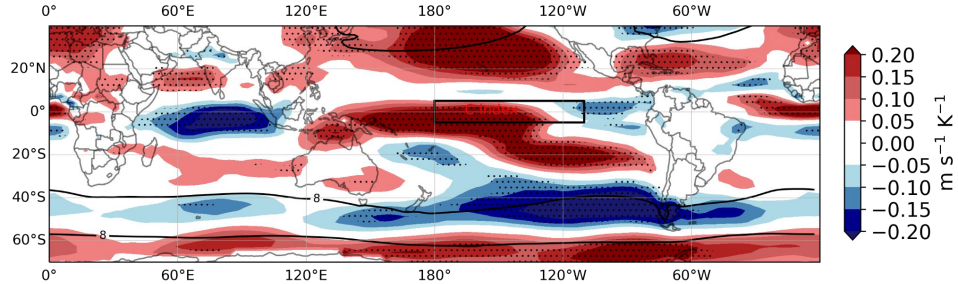


Kang et al. (2011) doi:10.1126/science.1202131

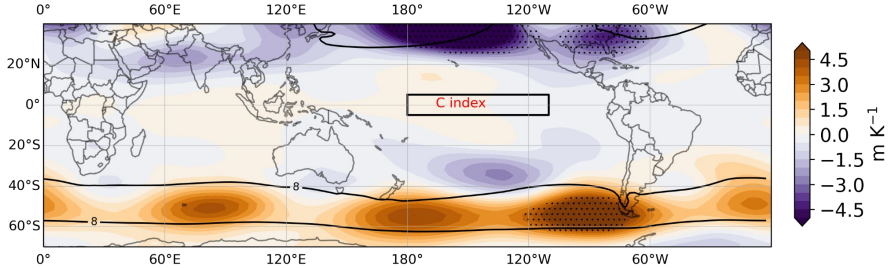
Tropospheric response to Central pacific warming

Long term changes - CMIP6 models - SSP 8.5 scenario

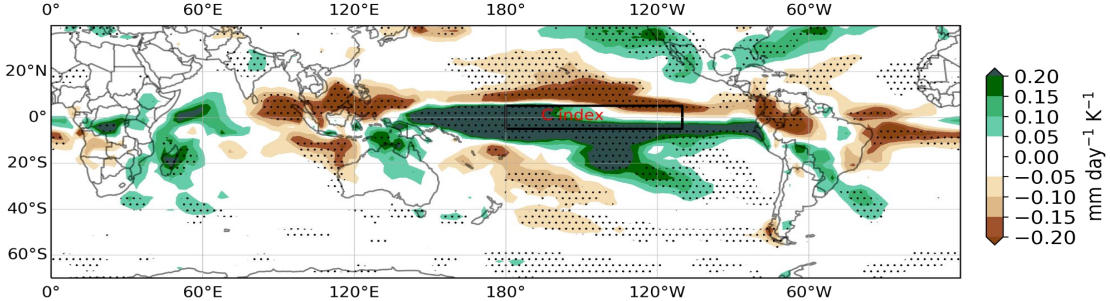
Zonal wind (u 850hPa)



Geopotential height (z 500hPa)



Precipitation change

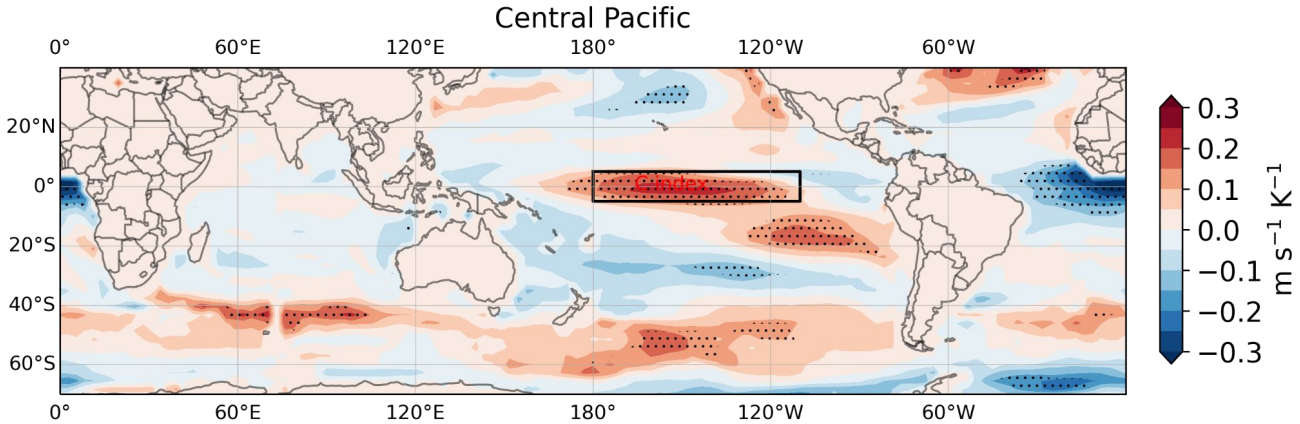


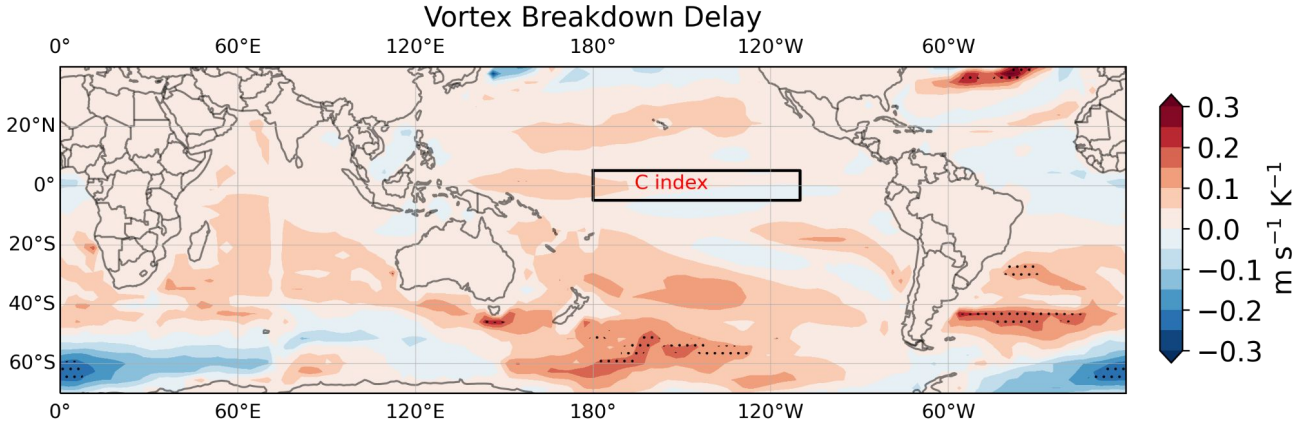
Common driver or causal link?

* How can changes in vortex breakdown date affect precipitation patterns in the subtropics?
* What change in the climate system could cause both a delay in the vortex breakdown date and precipitation in the subtropics?

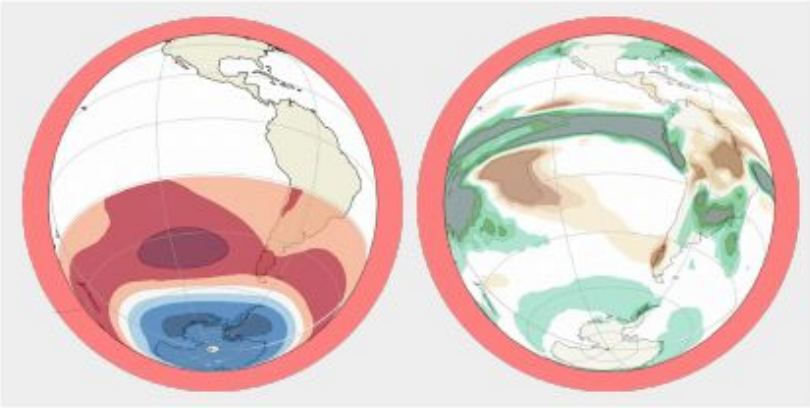
Backup slides

SST response to central pacific index





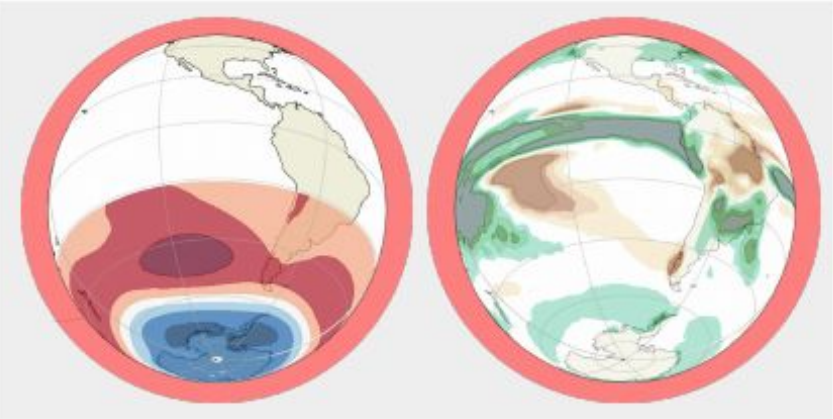
Statistical methods for storyline evaluation
1. across-model regressions

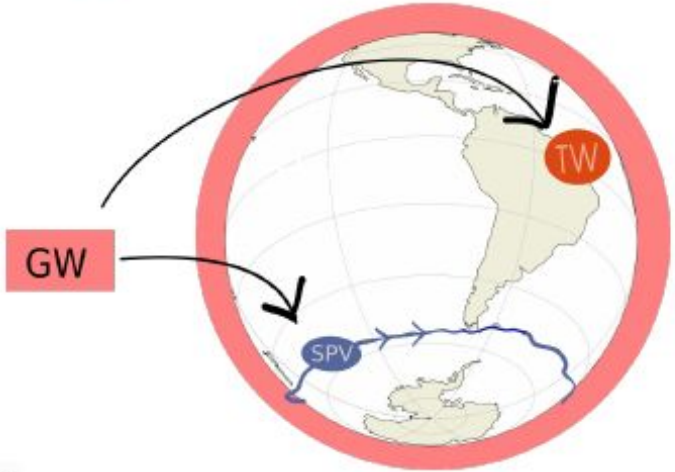


Change in a field factorized with pattern scaling
where m indicates a model and x a grid point

$$\Delta C_{xm} = \Delta T_m P_{xm}$$

Statistical methods for storyline evaluation
1. across-model regressions





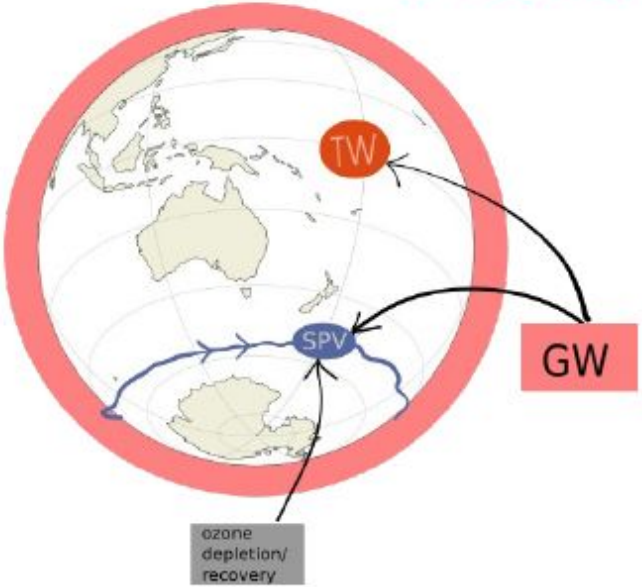
Change in a field factorized with pattern scaling where m indicates a model and x a grid point

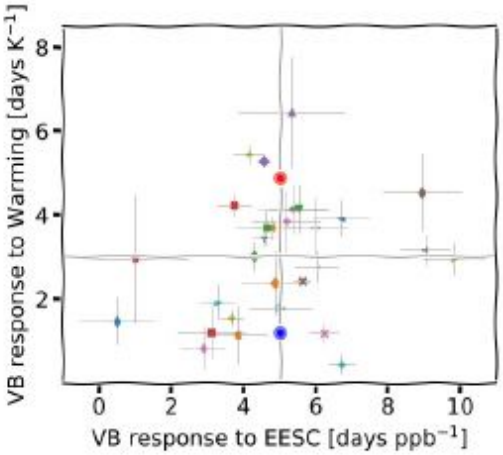
$$\Delta C_{xm} = \Delta T_m P_{xm}$$

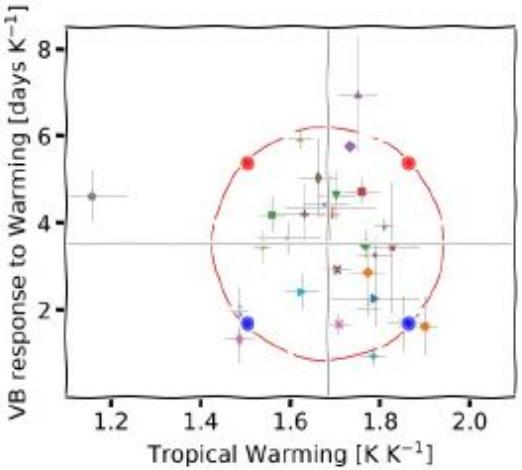
$\left(\frac{\Delta T_{trop}}{\Delta T}\right)'_m$ Temperature change in the Tropical Upper Troposphere (T at 250hPa; [15°S,15°N])

$\left(\frac{VB_{delay}}{\Delta T}\right)'_m$ Vortex Breakdown date change (Julian days of delay)

Statistical methods for storyline evaluation
1. across-model regressions







Spread in the remote drivers of summer (DJF) circulation in the Southern Hemisphere
Red and blue dots indicate different stoyrlines of the remote drivers' response

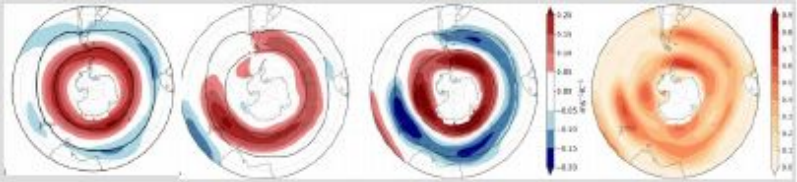
Statistical methods for storyline evaluation
1. across-model regressions

From Zappa & Shepherd (2017)

Step 1: Evaluate sensitivity patterns - linear regressions

$$\Delta C_{xm} = \Delta T_m P_{xm}$$

$$P_{xm} = a_x + b_x \left(\frac{\Delta T_{trop}}{\Delta T} \right)'_m + c_x \left(\frac{VB_{delay}}{\Delta T} \right)'_m + e_{xm}.$$



Step 2: Storyline evaluation - linear combinations

$$\left[\left(\frac{\Delta T_{trop}}{\Delta T} \right)' \right]^2 + \left[\left(\frac{VB_{delay}}{\Delta T} \right)' \right]^2 = \chi^2(0.8, 2),$$

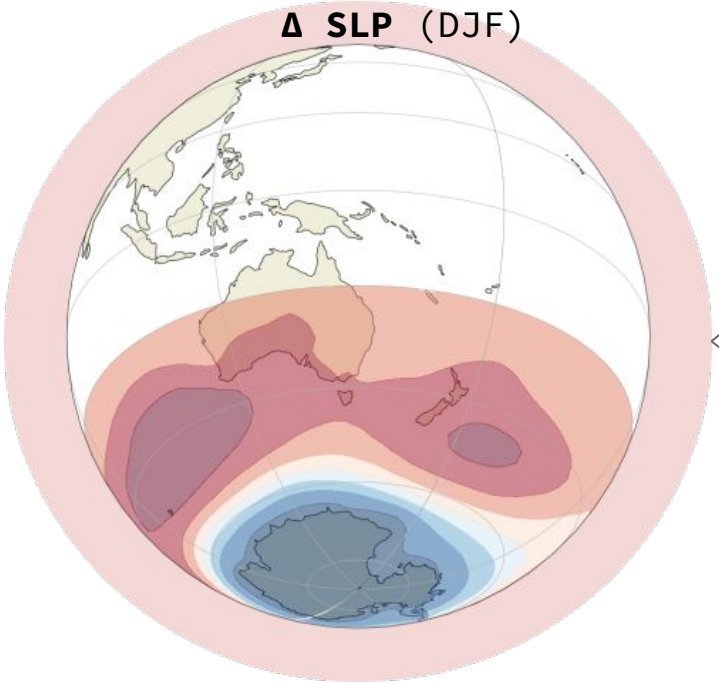
$$t_s = \sqrt{\chi^2(0.8, 2)/2} \approx 1.26.$$

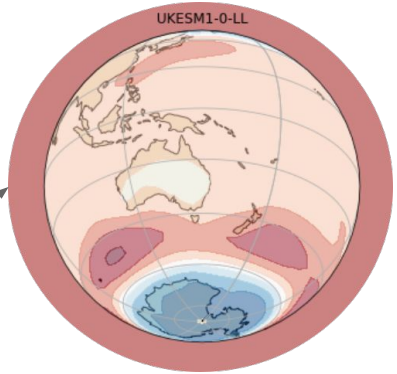
$$\frac{\Delta C_x}{\Delta T} = \hat{a}_x \pm \hat{b}_x t_s \pm \hat{c}_x t_s$$

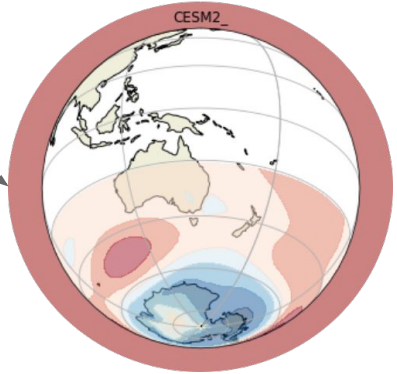
UNCERTAINTY IN THE SOUTHERN ANNULAR MODE FUTURE CHANGES

Multi-model ensemble mean

Δ SLP (DJF)

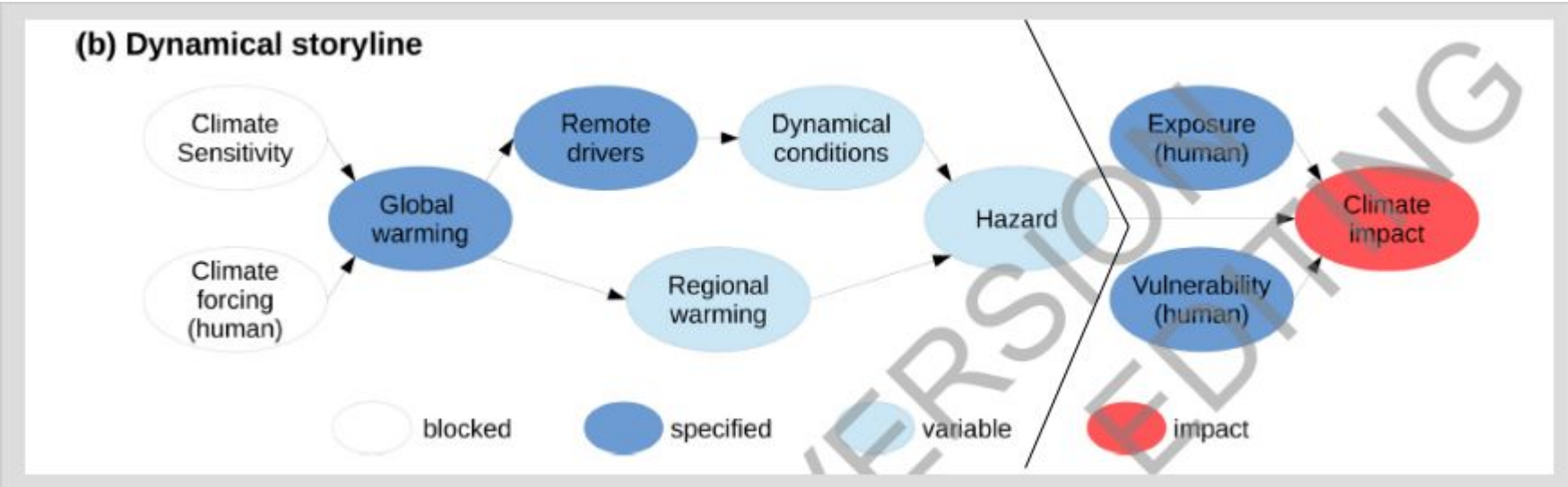






SSP5 8.5 (2070-2099) minus historical (1950-1979)

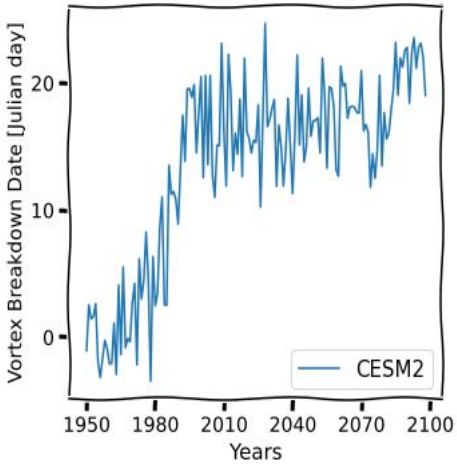
Storyline approach



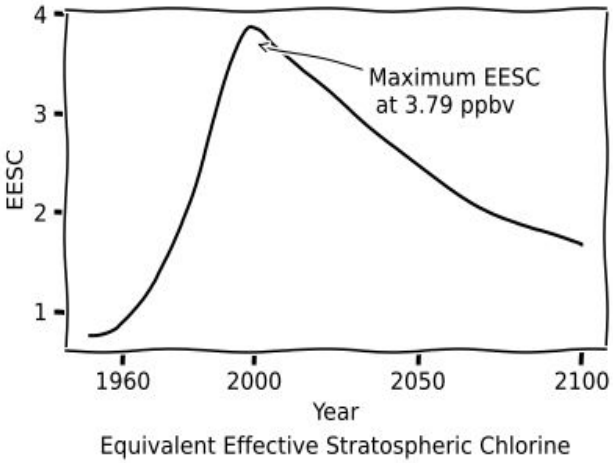
Storyline: physically plausible pathway for global climate change.

IPCC AR6 WGI Chapter 10, Box 10.2, Figure 1 (subject to editing); after Shepherd (2019 PRSA)

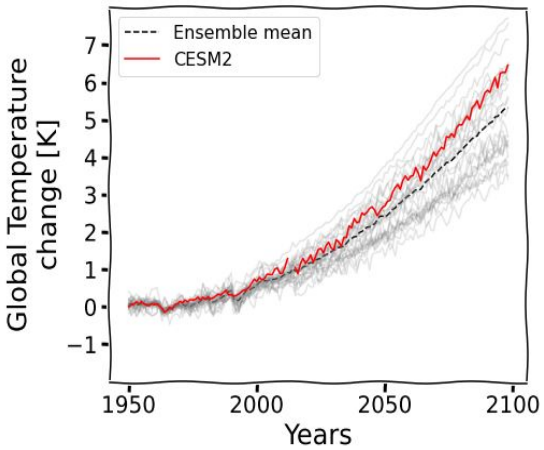
"Tug-of-war" - Time series analysis



Vortex breakdown delay with respect to pre-ozone hole date

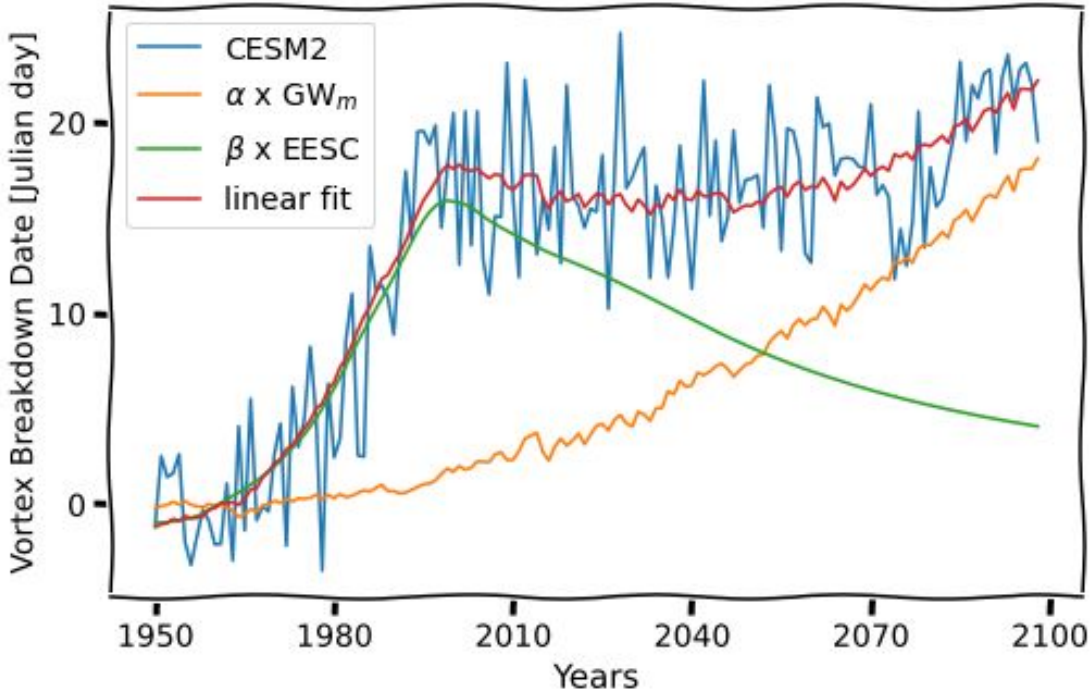


Ozone depleting substances



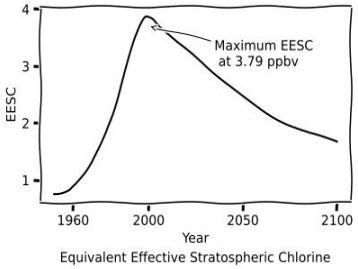
GHG increase proxy

"Tug-of-war" - Time series analysis

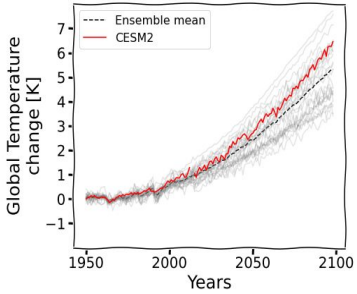


$$VB_{delay}(t) = \alpha\ EESC(t) + \beta\ \Delta T_m(t) + \epsilon$$

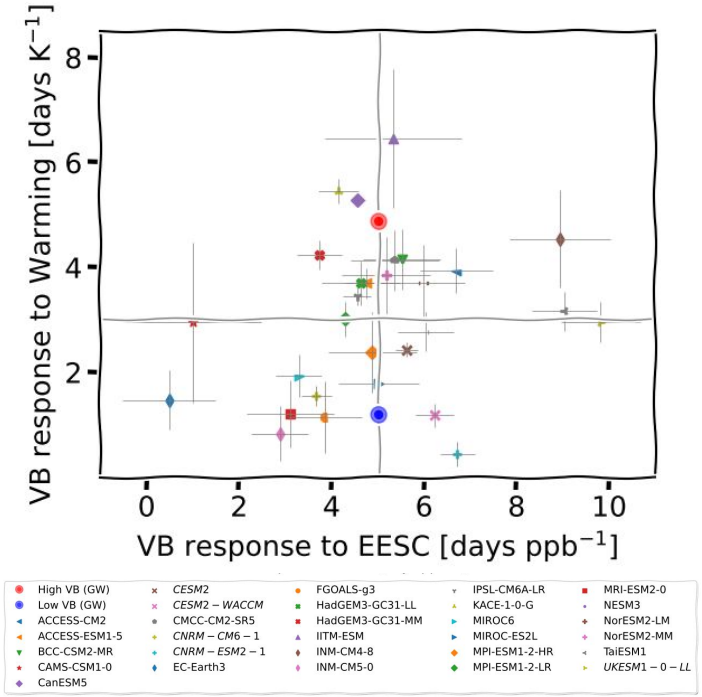
VB response to EESC

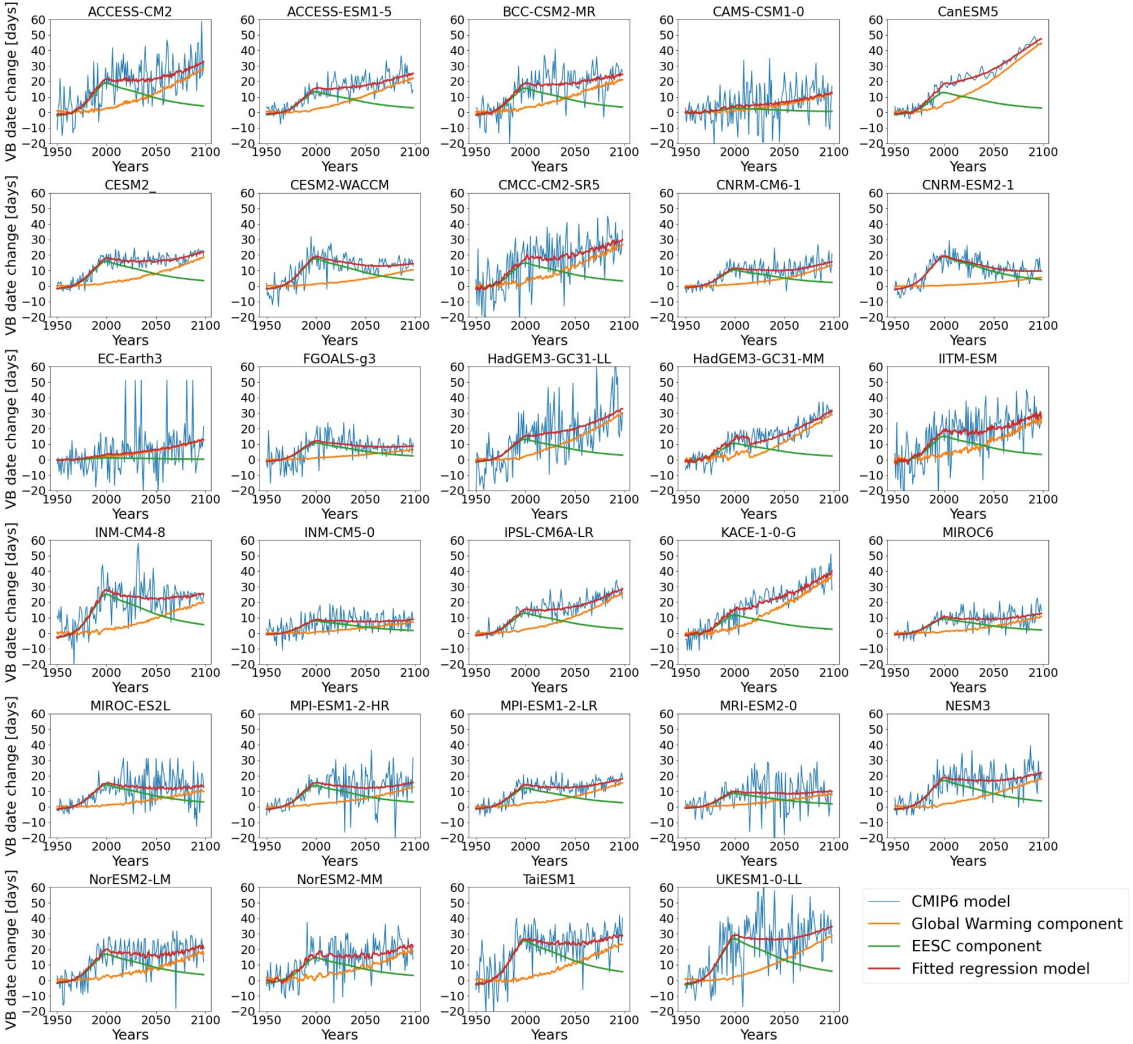


VB response to GW

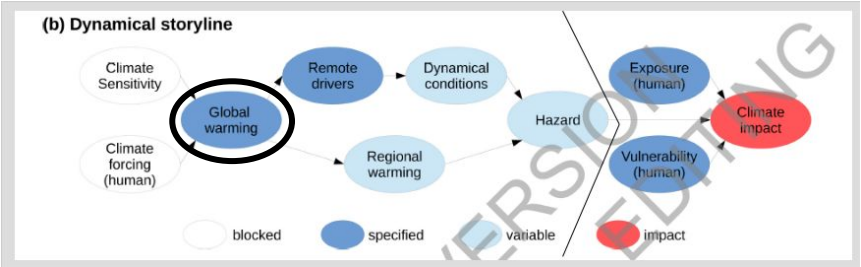


SIMPLE LINEAR MODEL CMIP 6 ENSEMBLE

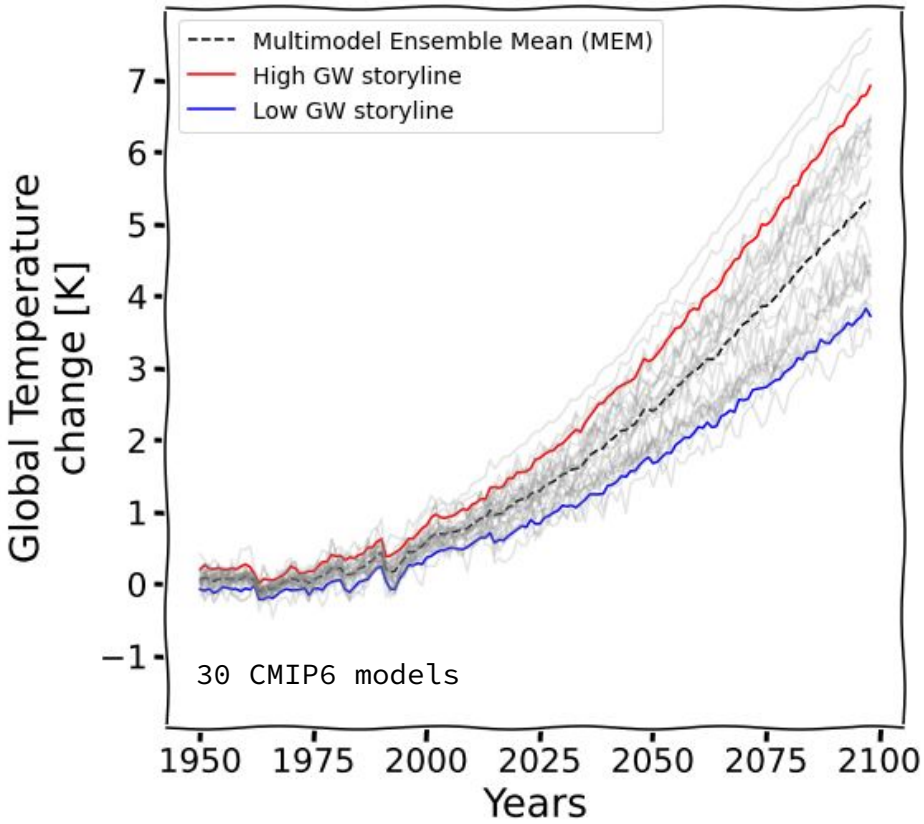




Storyline approach

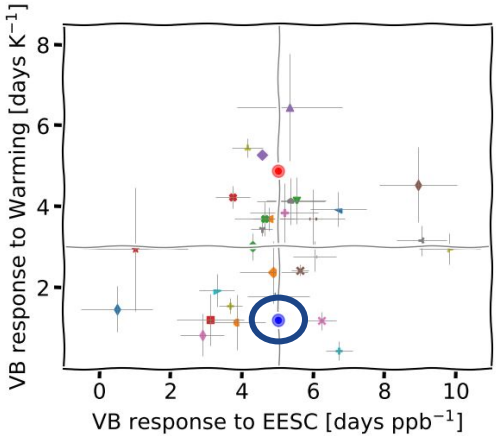


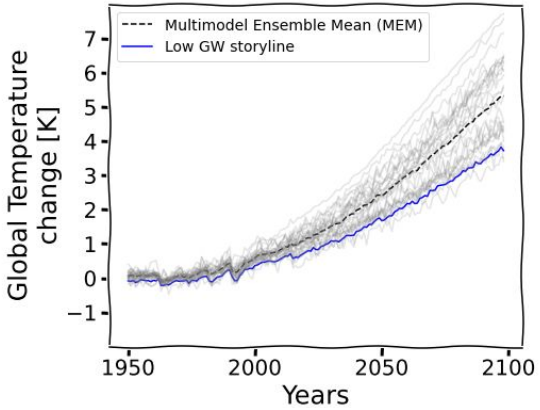
IPCC AR6 WGI Chapter 10, Box 10.2, Figure 1

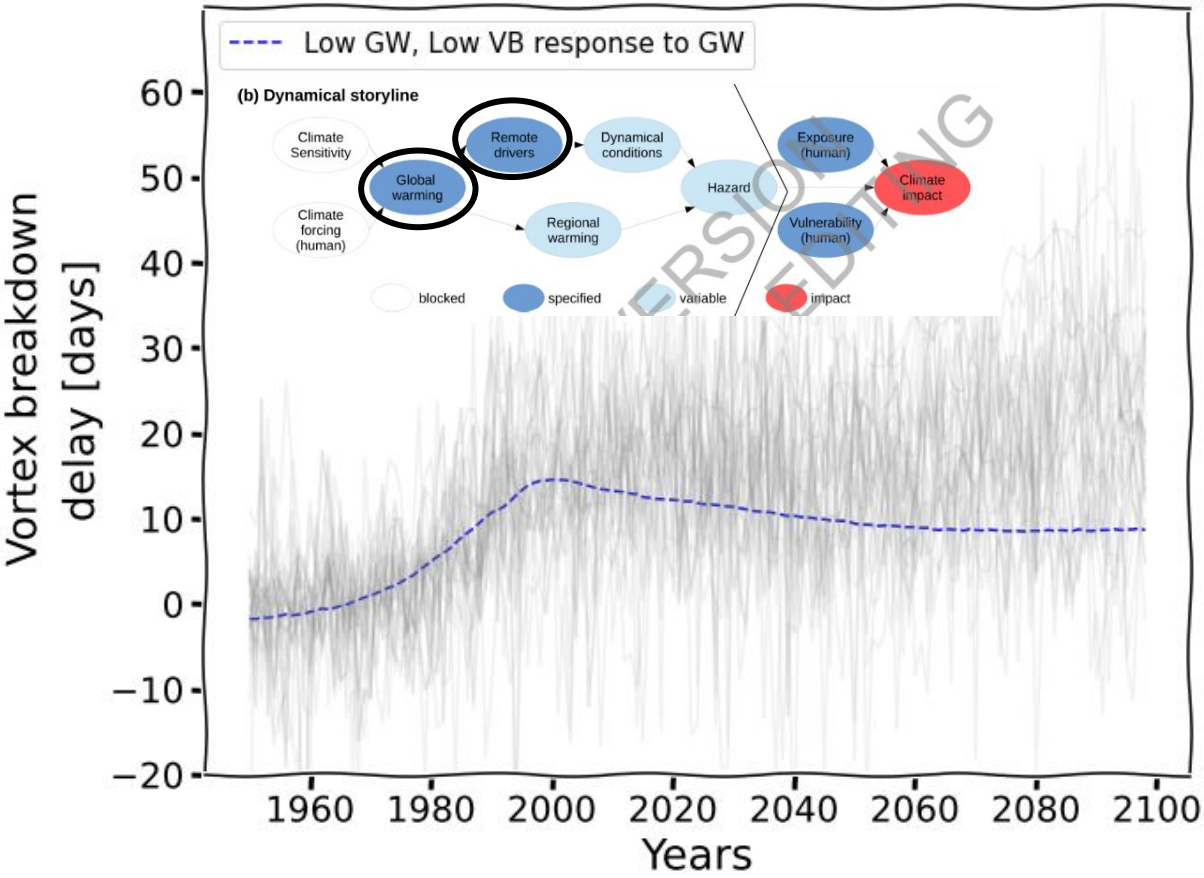


From this point on all **red** and **blue** **curves or dots** are statistically defined **storylines** (unless mentioned differently)

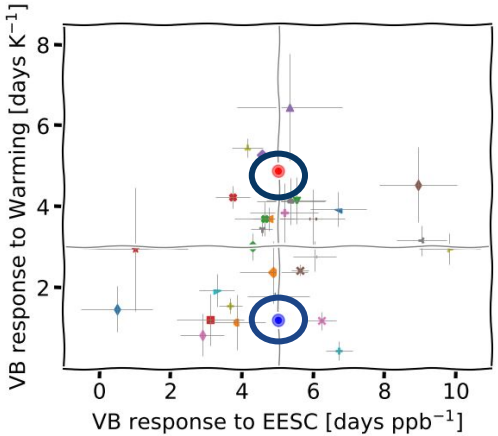
"Tug-of-war"

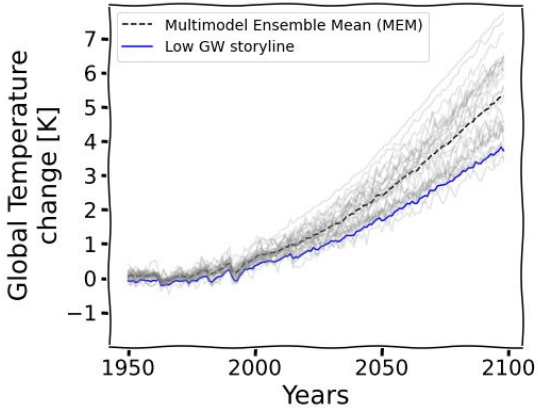

VB response to Warming [days K^{-1}]
VB response to EESC [days ppb^{-1}]

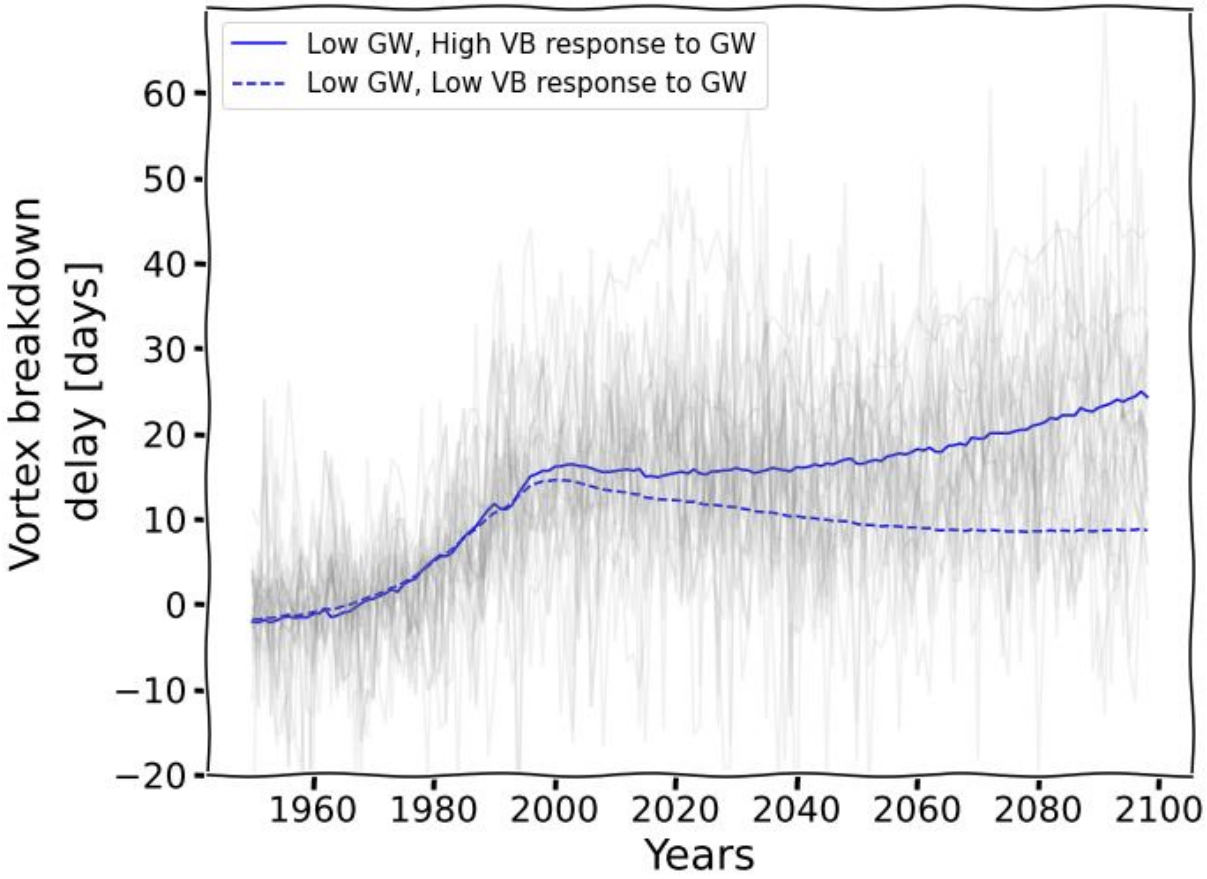

Multimodel Ensemble Mean (MEM)
Low GW storyline
Global Temperature change [K]
Years


Low GW, Low VB response to GW
(b) Dynamical storyline
Climate Sensitivity
Climate forcing (human)
Global warming
Remote drivers
Regional warming
Dynamical conditions
Hazard
Exposure (human)
Vulnerability (human)
Climate impact
blocked
specified
variable
impact
Vortex breakdown delay [days]
Years

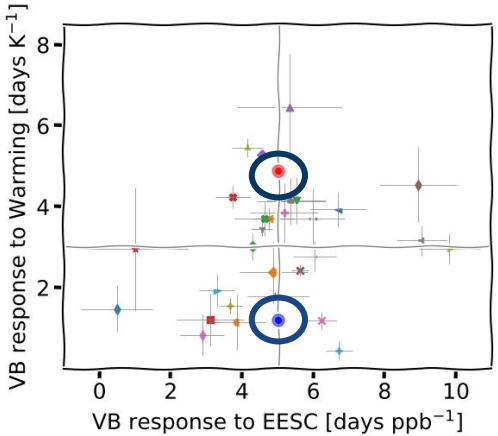
"Tug-of-war"

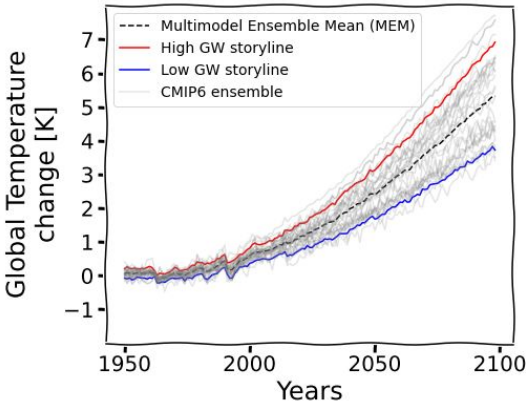

VB response to Warming [days K^{-1}]
VB response to EESC [days ppb^{-1}]

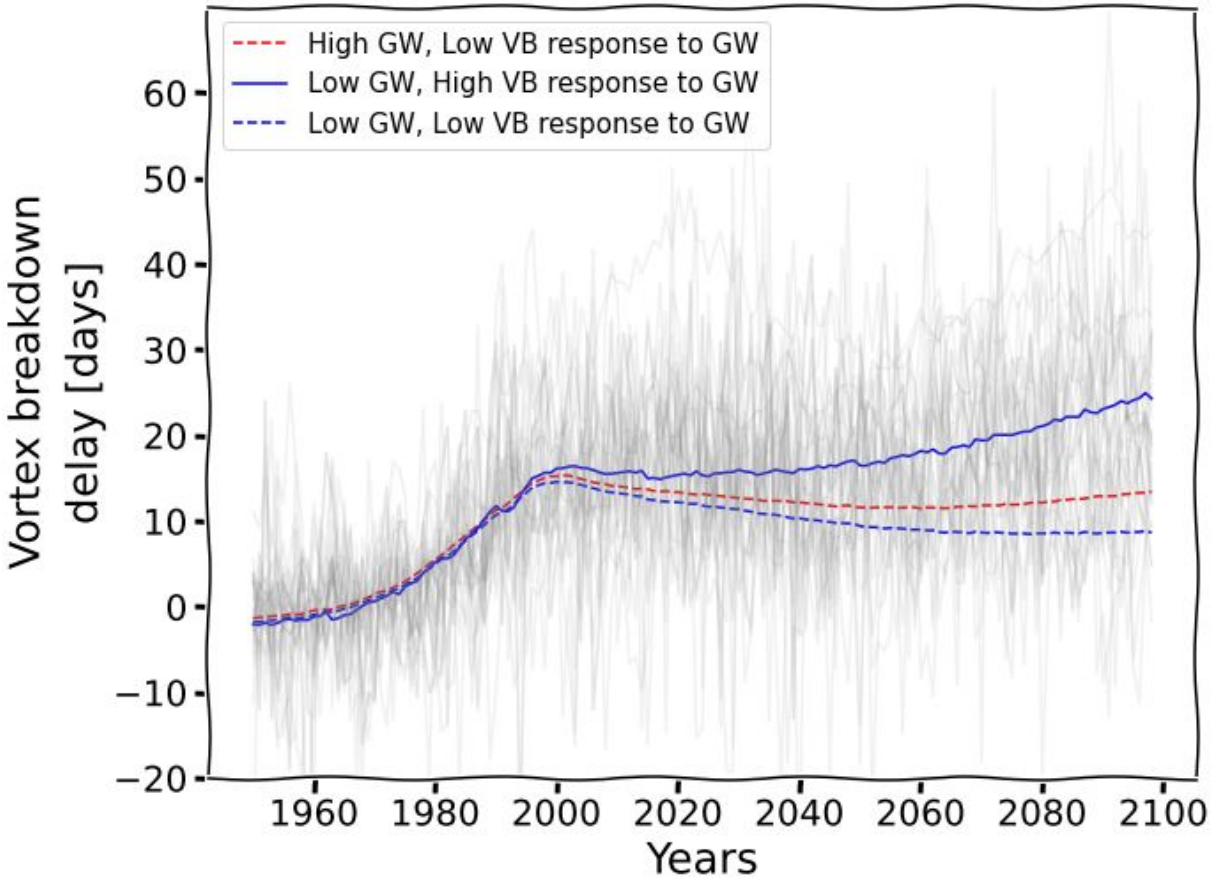

Multimodel Ensemble Mean (MEM)
Low GW storyline
Global Temperature change [K]
Years


Low GW, High VB response to GW
Low GW, Low VB response to GW
Vortex breakdown delay [days]
Years

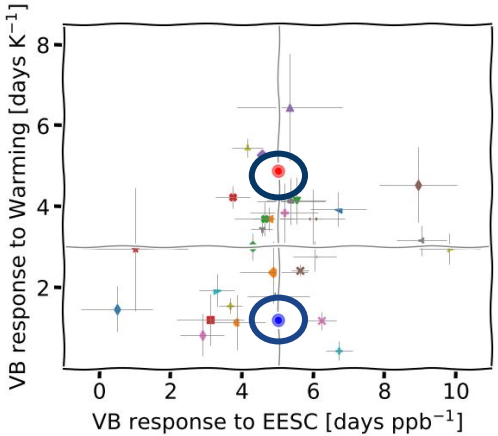
"Tug-of-war"

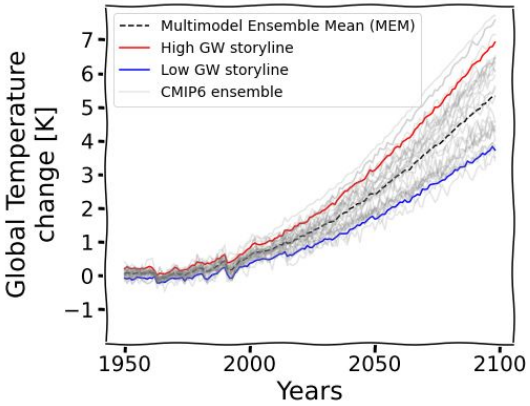

VB response to Warming [days K^{-1}]
VB response to EESC [days ppb^{-1}]


Multimodel Ensemble Mean (MEM)
High GW storyline
Low GW storyline
CMIP6 ensemble
Global Temperature change [K]
Years


High GW, Low VB response to GW
Low GW, High VB response to GW
Low GW, Low VB response to GW
Vortex breakdown delay [days]
Years

"Tug-of-war"


VB response to Warming [days K^{-1}]
VB response to EESC [days ppb^{-1}]


Multimodel Ensemble Mean (MEM)
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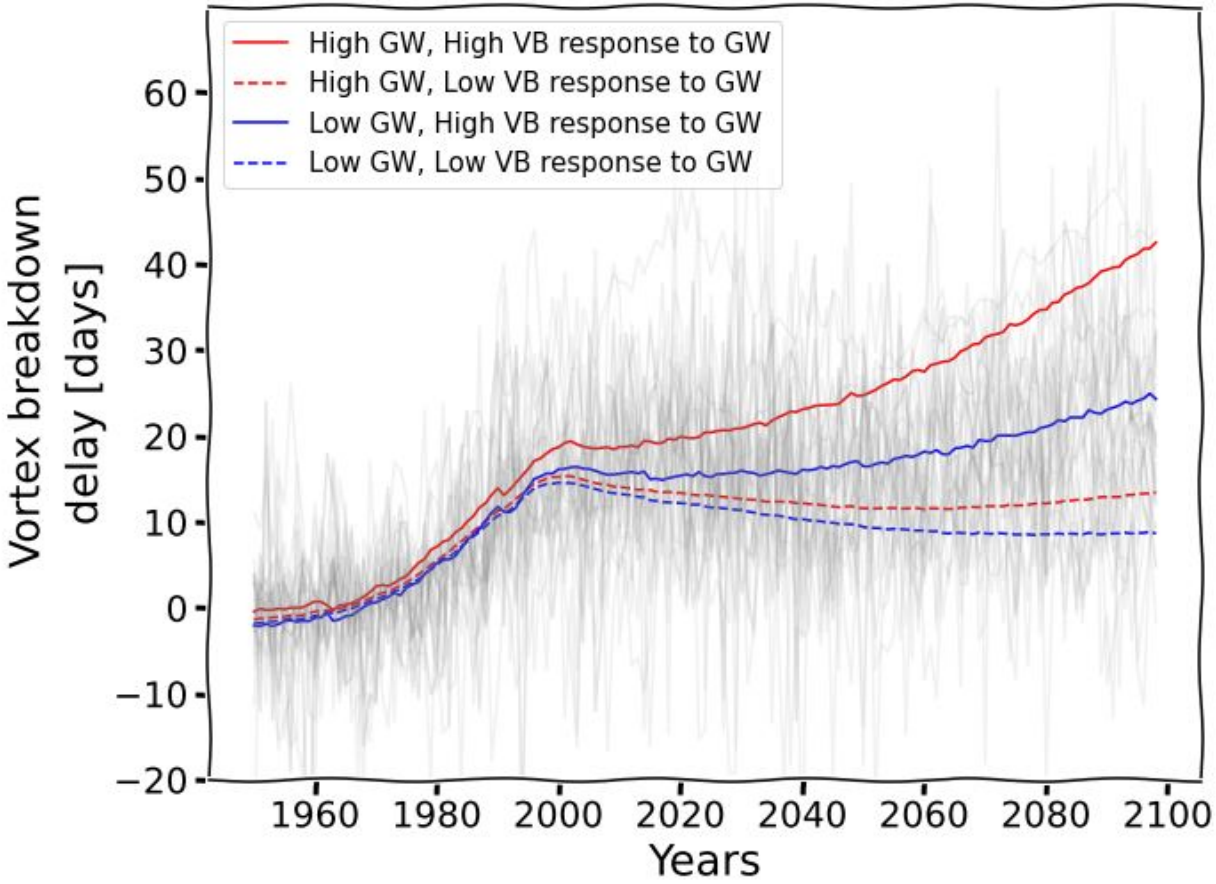
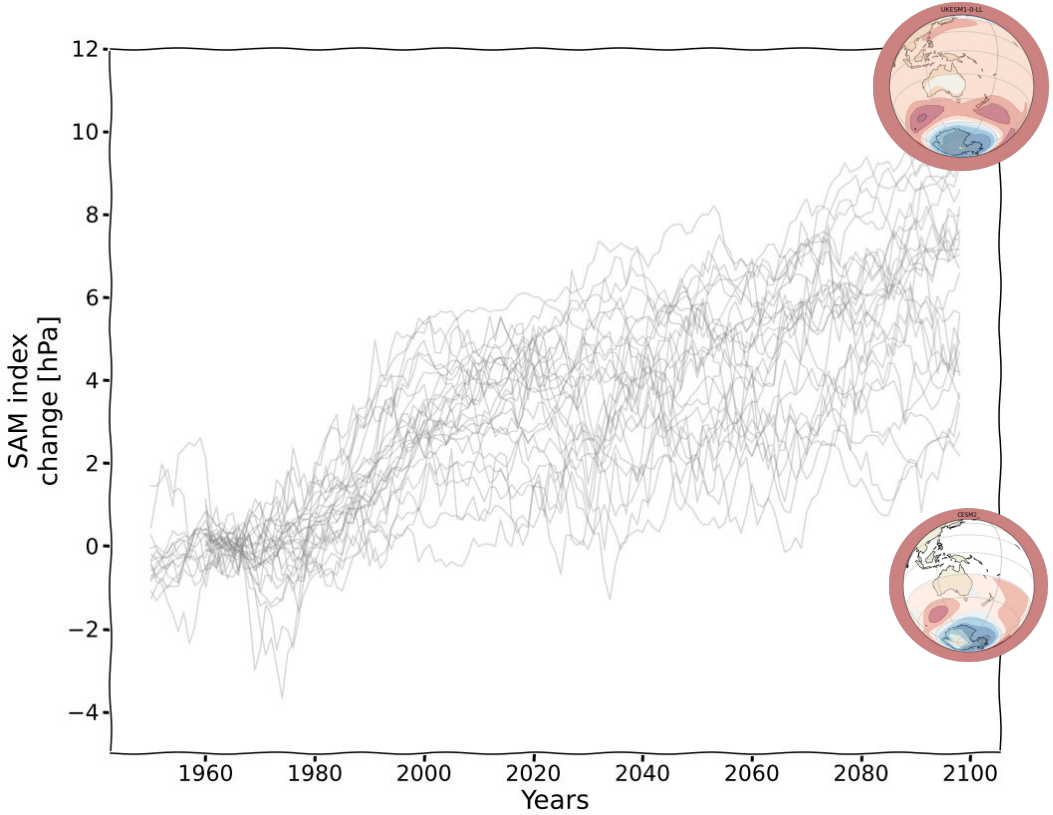

High GW, High VB response to GW
High GW, Low VB response to GW
Low GW, High VB response to GW
Low GW, Low VB response to GW
Vortex breakdown delay [days]
Years

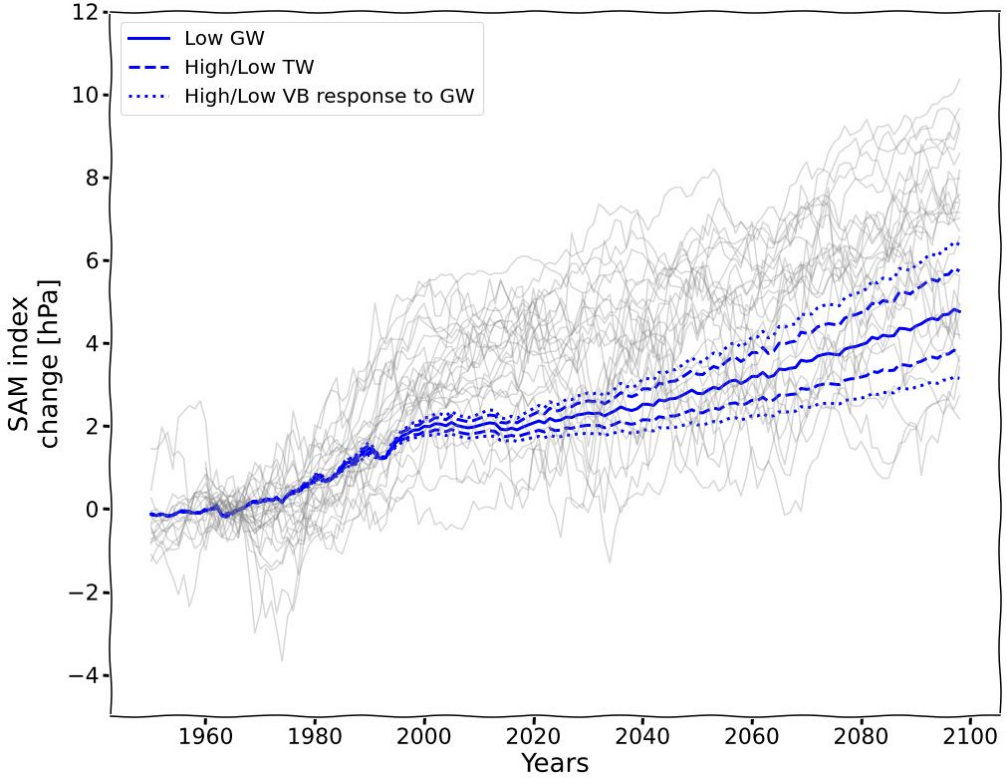
Propagation to the tropospheric circulation



Southern Annular Mode (SAM)
Summer (DJF)
Marshall index:
ΔSLP = SLP zonally averaged
40°S – 65°S

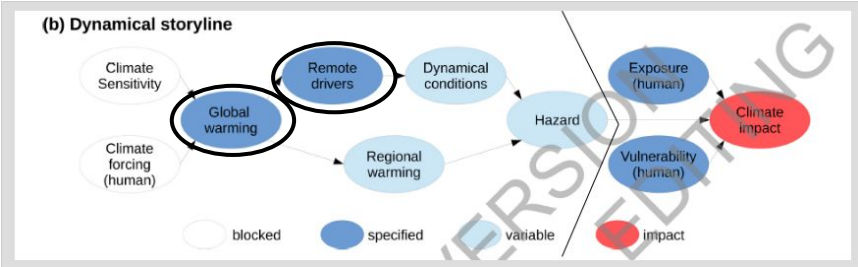
CMIP6 models
10-year moving average

Propagation to the tropospheric circulation

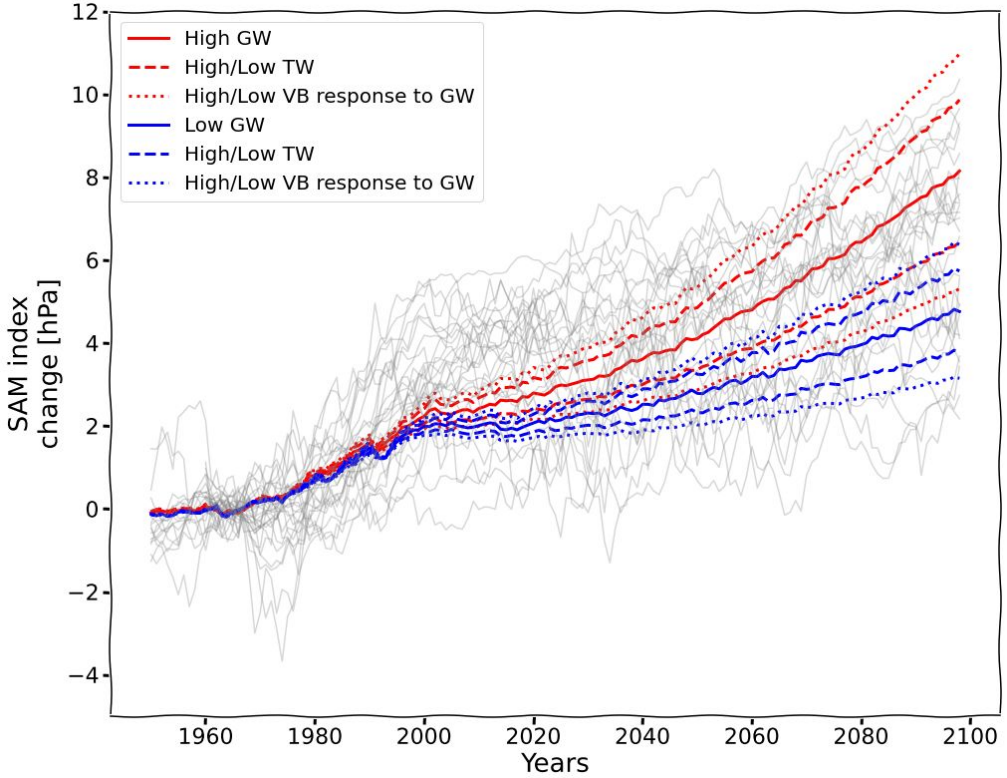


Marshall SAM index:
ΔSLP = SLP 40°S – SLP 65°S

CMIP6 models
10-year moving average

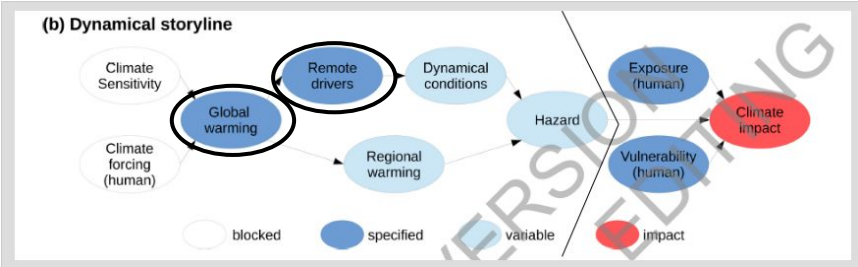


Propagation to the tropospheric circulation

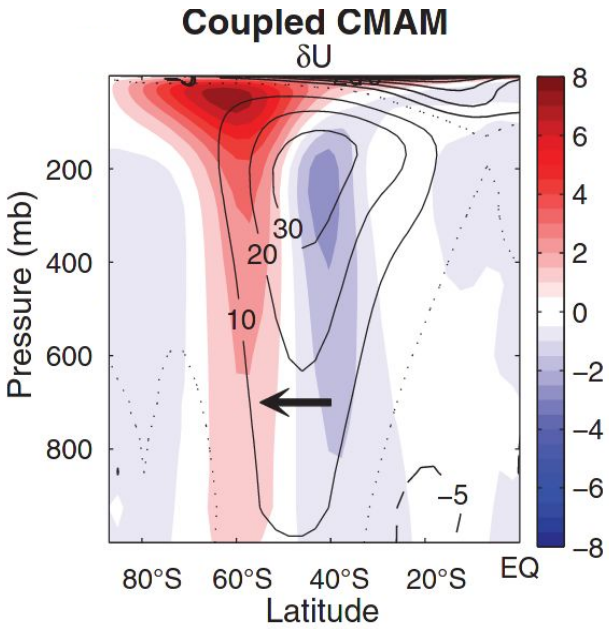


Marshall SAM index:
ΔSLP = SLP 40°S – SLP 65°S

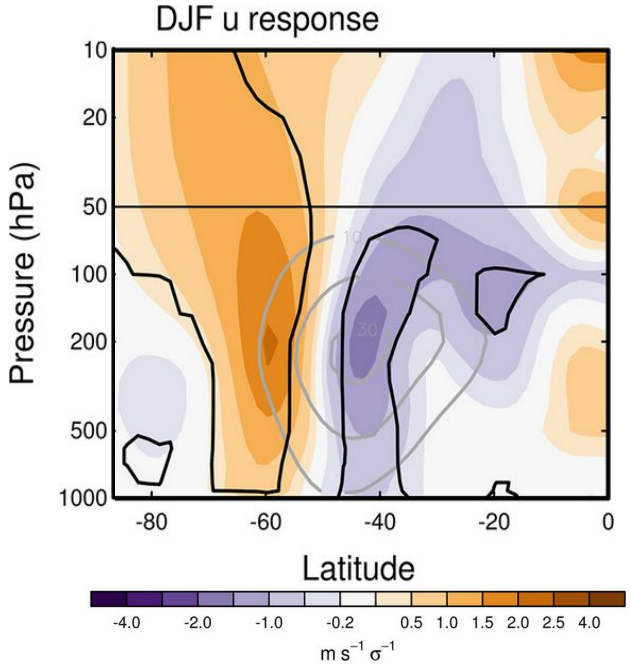
CMIP6 models
10-year moving average



Motivation - Tropospheric response to vortex changes



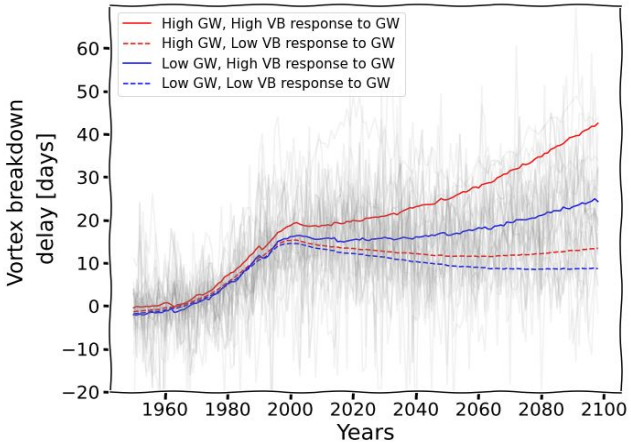
Zonal mean zonal wind response Ozone - CTRL experiments with Canadian Middle Atmosphere Model.
From Fig 4 in Kang et al. Science (2011) DOI: 10.1126/science.1202131

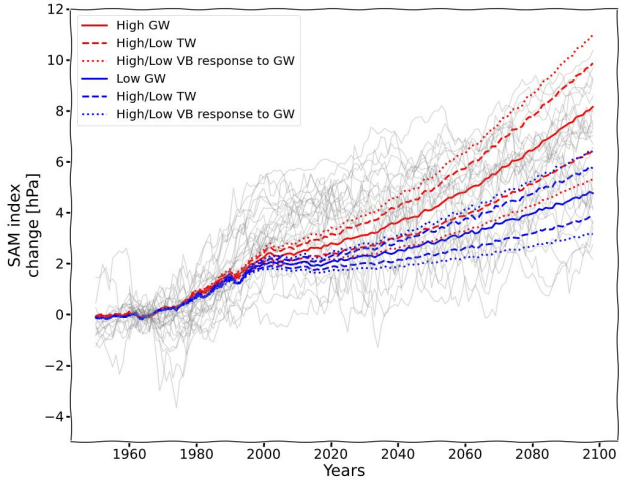


Zonal mean zonal wind response to 1σ in VB response to GHG
From Fig 3 in Ceppi & Shepherd (2019) DOI: 10.1029/2019GL082883

Summary

- **Long-term changes in the delay** of the breakdown of the Southern Hemisphere stratospheric polar vortex can be largely **explained by a linear response to ozone-depleting substances and to global warming**
- The tug-of-war between ozone recovery and global warming manifests itself in the stratospheric vortex breakdown delay and **propagates to the troposphere**
- The **uncertainty in future changes in regional precipitation in the Southern Hemisphere** is subject to the combined effects of the uncertainty in tropical warming and in the vortex breakdown delay and climate sensitivity





Thank you!

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Mindlin et al. (2021) DOI: 10.1029/2021GL092568