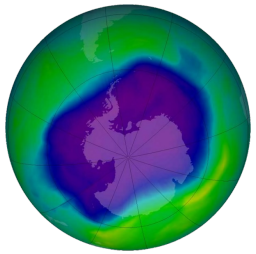
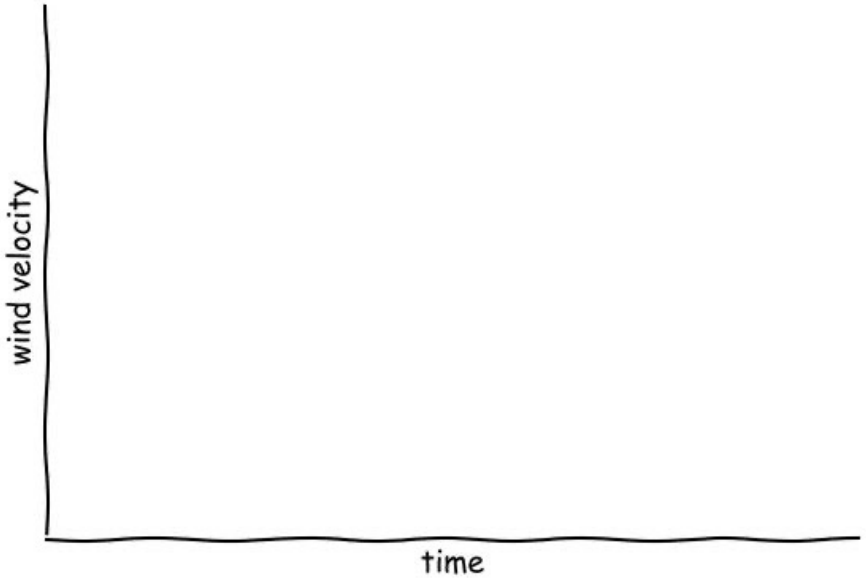
# The Evolving Relative Role of Stratospheric Ozone and Greenhouse Gasses in Modifying the Southern Ocean Carbon Sink from 1950 to 2100

Tereza Jarníková, Corinne Le Quéré, Colin Jones, Steven Rumbold



# Changing polar climate due to ozone depletion and greenhouse gas emissions





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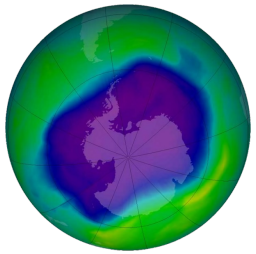

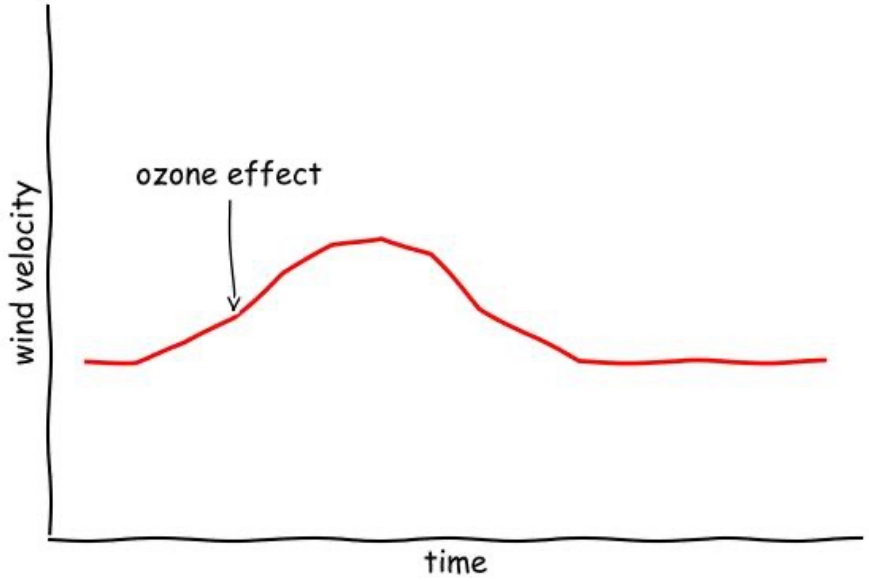


- Historically, ozone depletion increased the SAM index → stronger and more southerly winds, especially in summer

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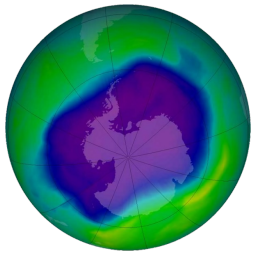

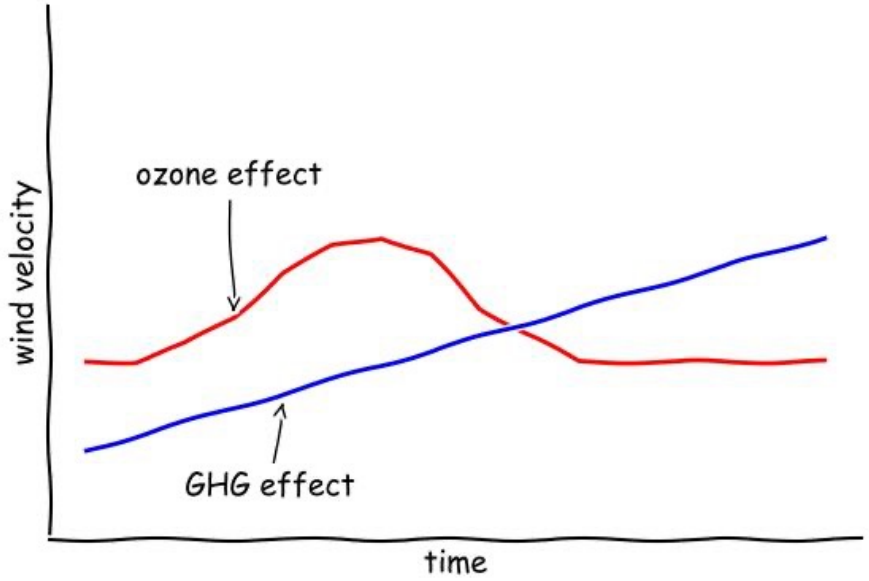


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- Ozone is recovering, but GHG emissions are expected to continue increasing winds, year-round

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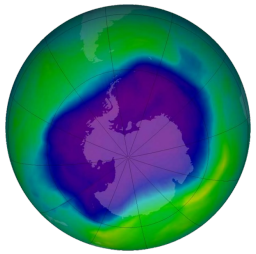
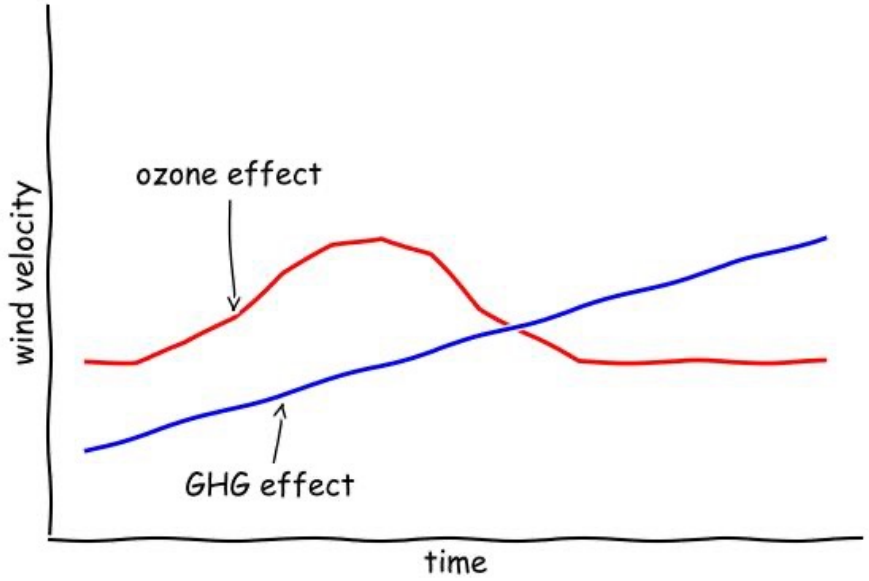




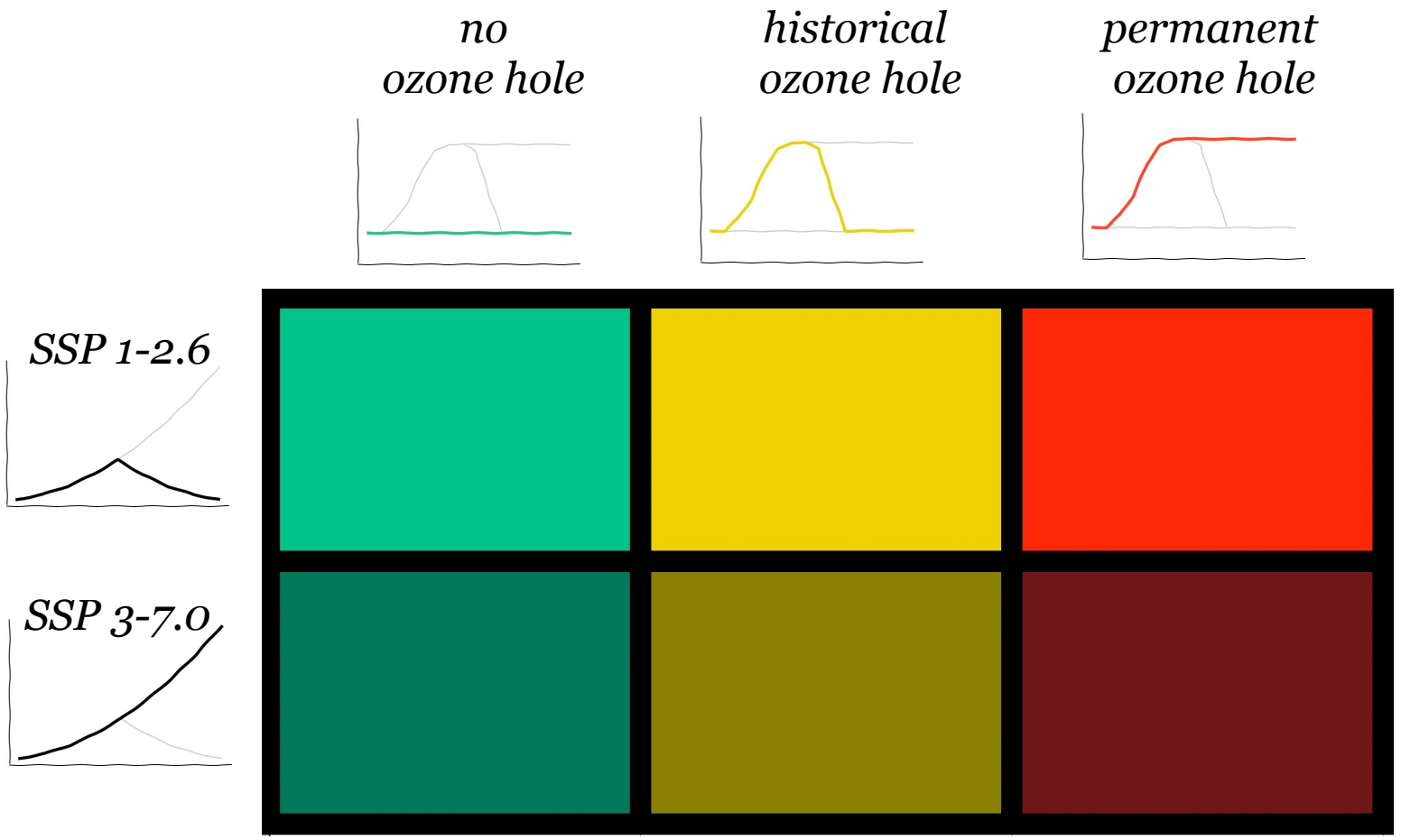

1. How are the Southern Ocean wind patterns projected to change over the coming century under different ozone and SSP scenarios?

2. What are the effects of changing wind patterns on the physical ocean sea state?

3. What are the relative controls on the carbon flux?

# Experimental Design

## 3 ozone scenarios, 2 GHG scenarios

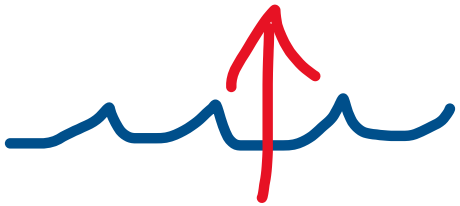



UKESM

1950-2100

# What are the major physical controls on the Southern Ocean carbon sink, and how will they change due to GHG emissions and ozone depletion?

**sea surface temperature (SST)**



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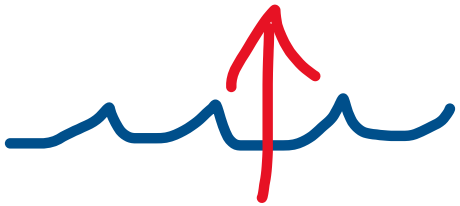

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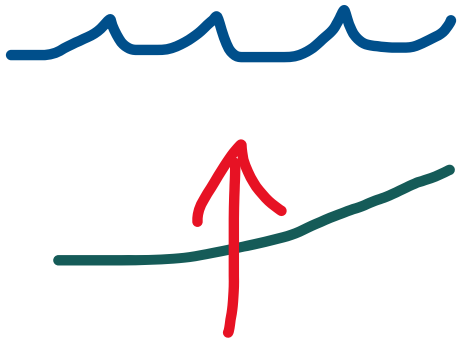
**mixed layer depth (MLD)**



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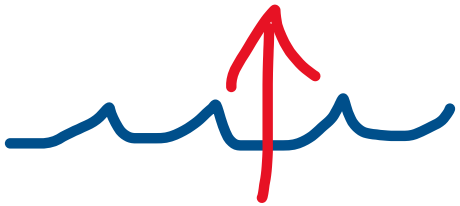

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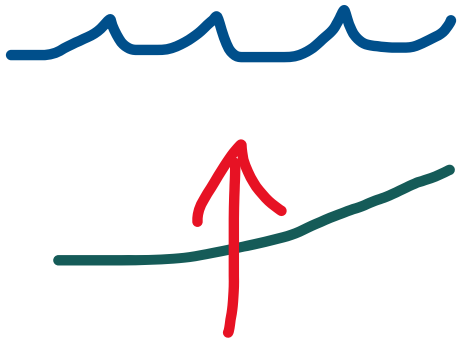

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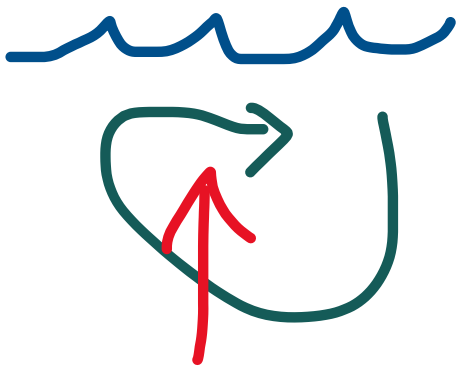
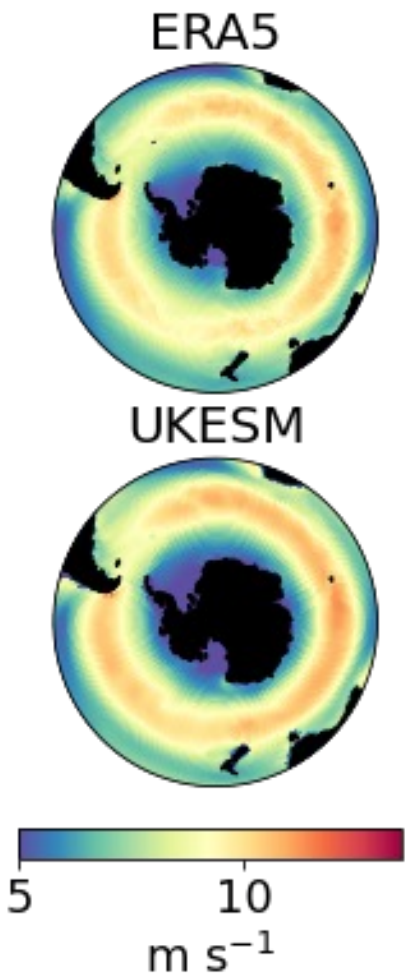
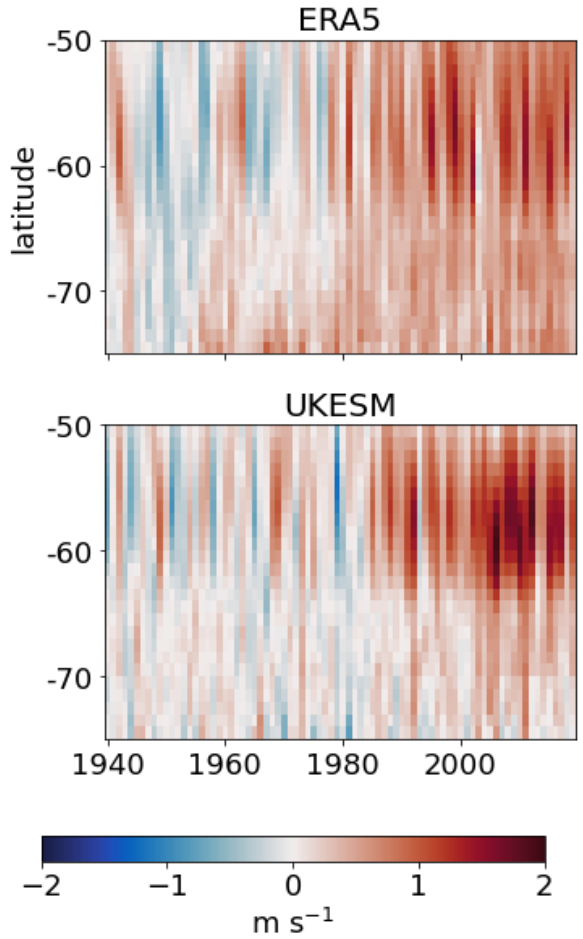
**overturning (OT)**

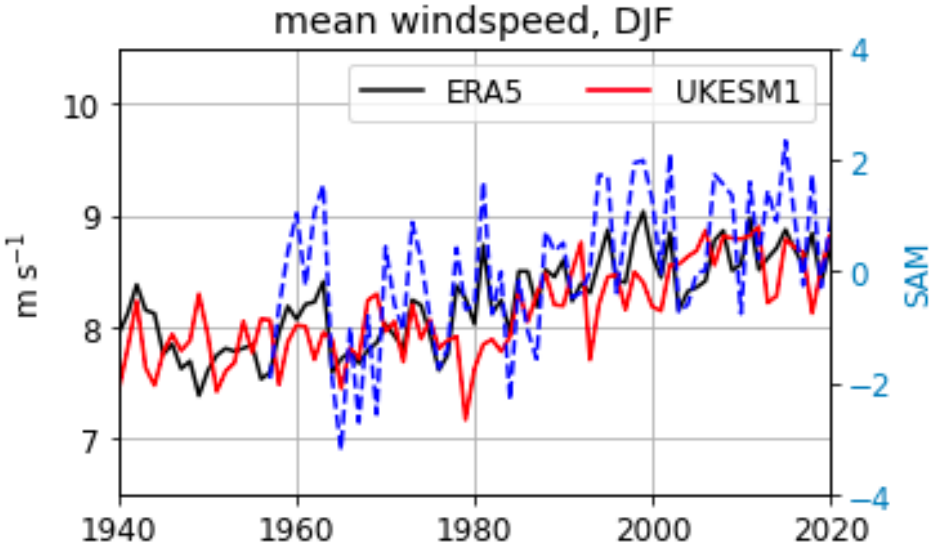


*enhanced OT brings up high-carbon water and nutrients*

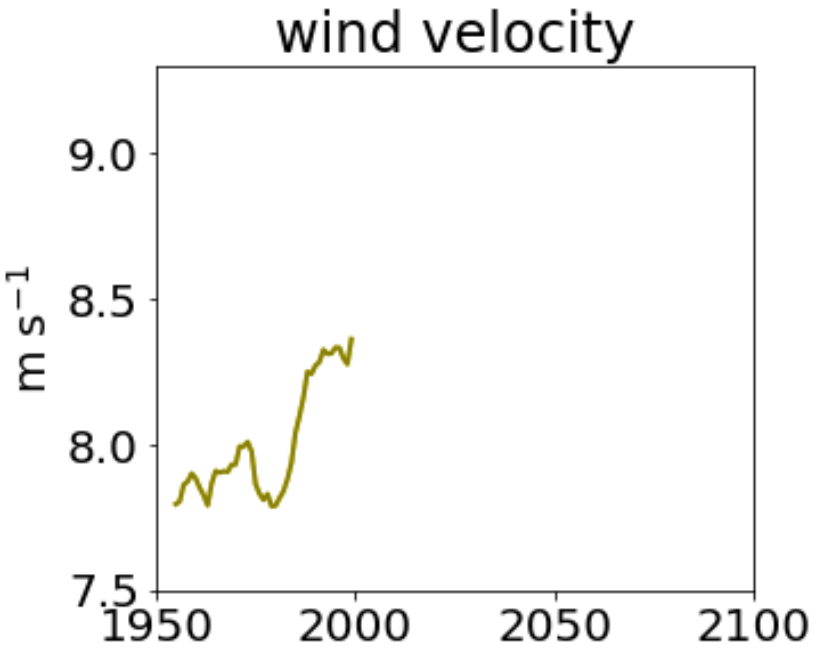
# Can we learn from the UKESM1 winds?
# Yes, they perform well against the ERA5 reanalysis

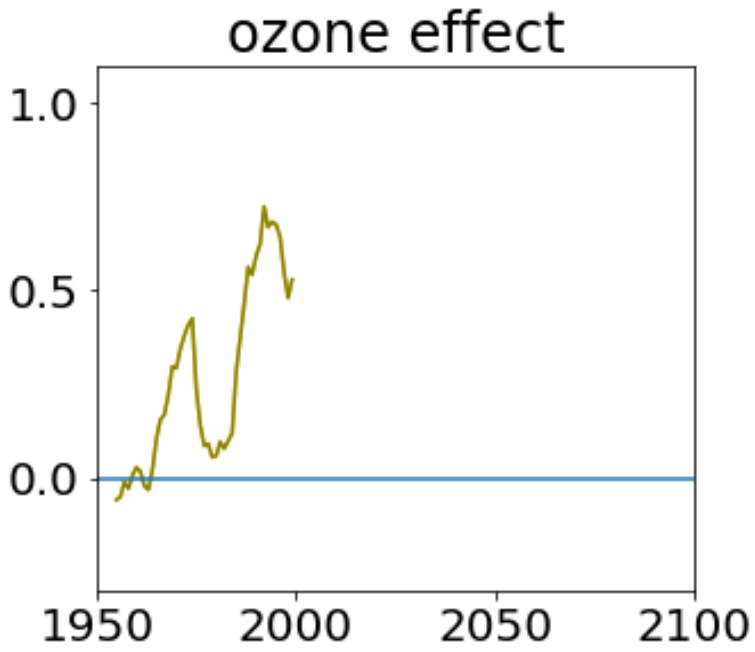


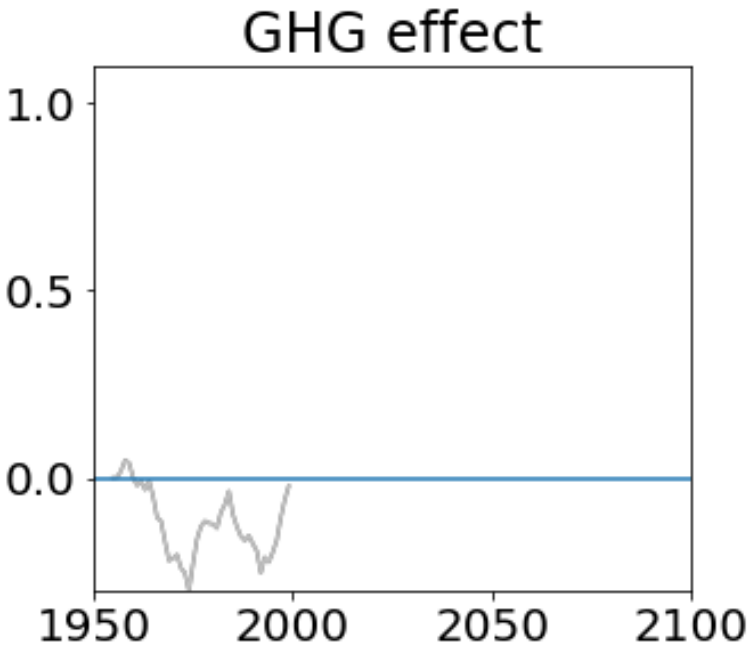



# Ozone and GHG effect on wind speed, 1950-2100




*austral summer, DJF*

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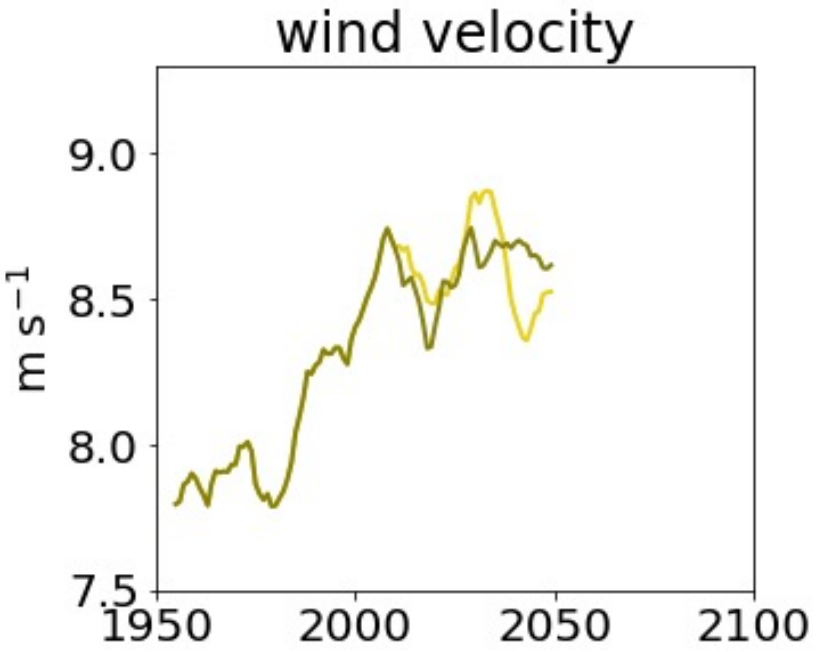


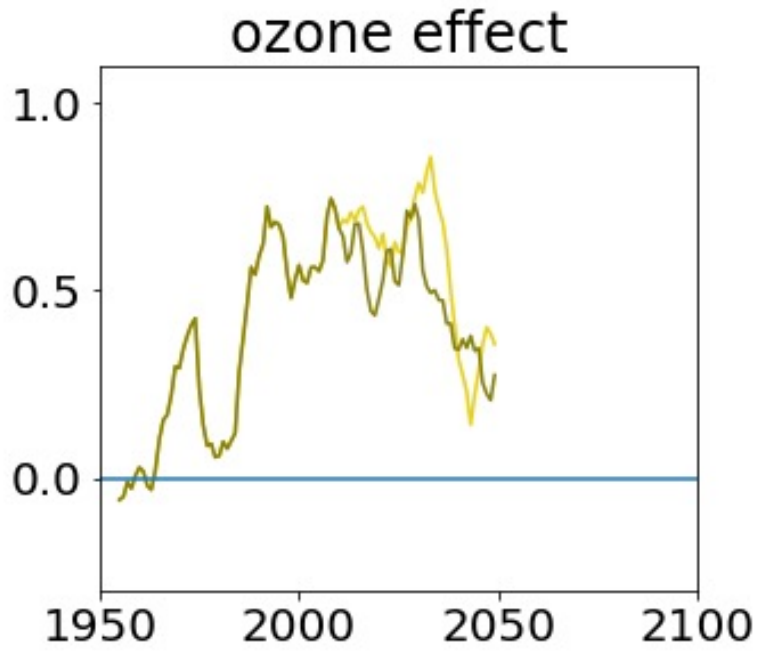


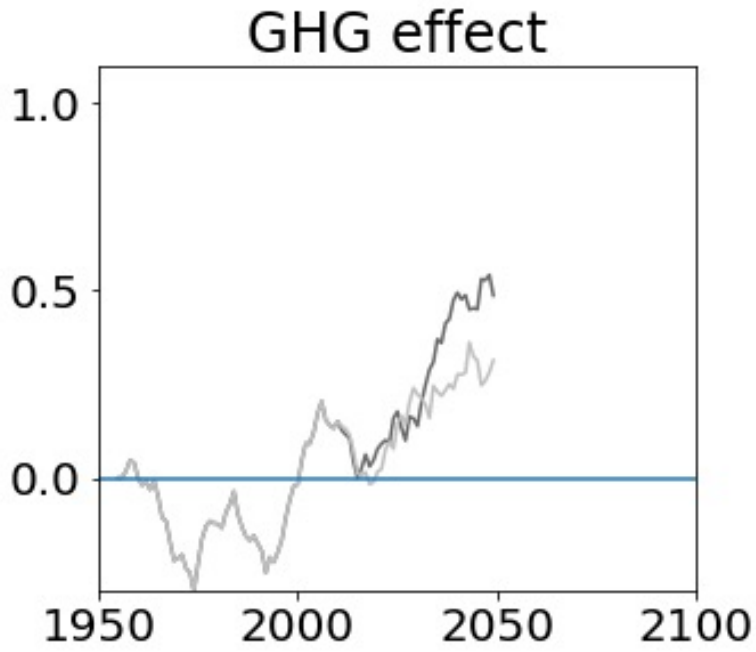


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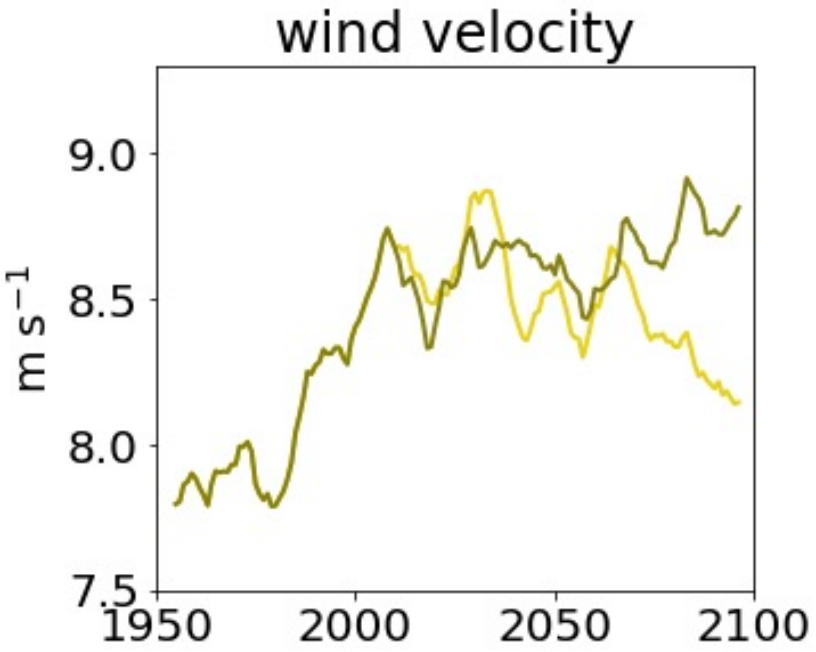


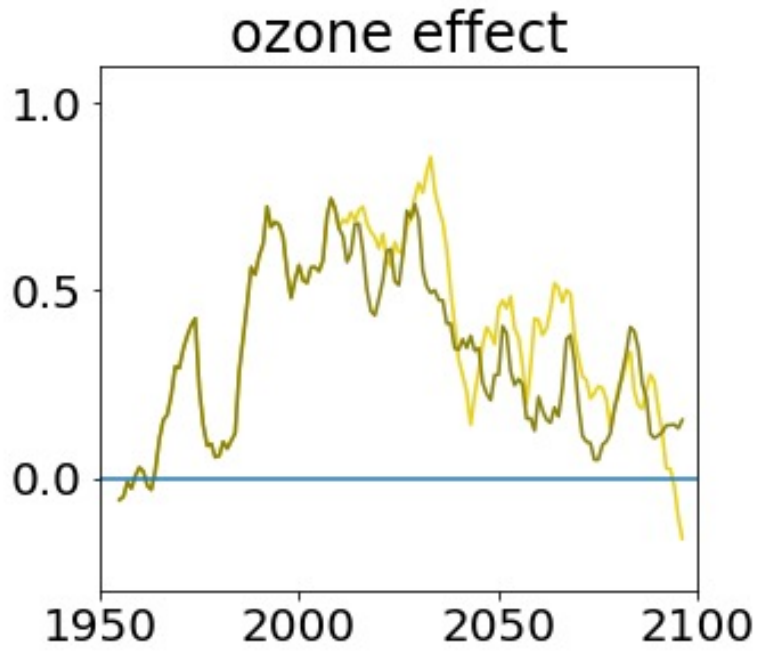


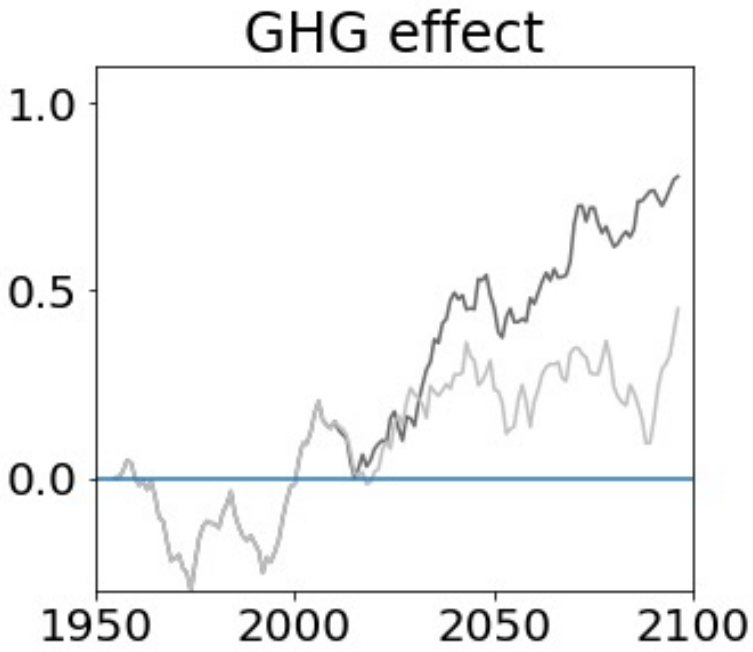


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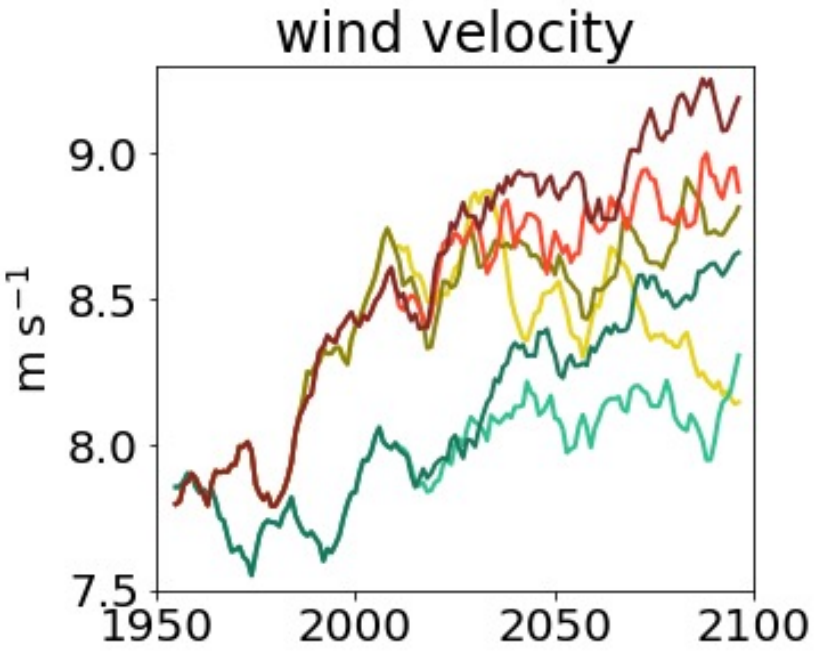


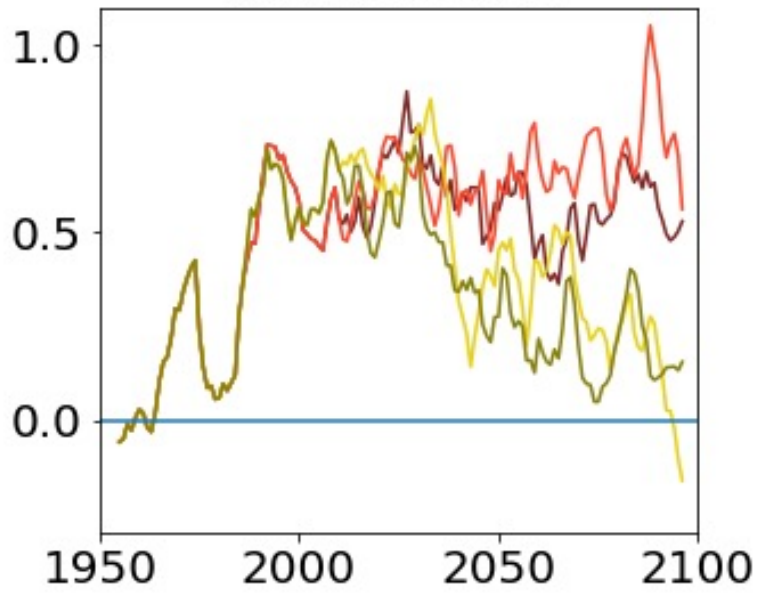


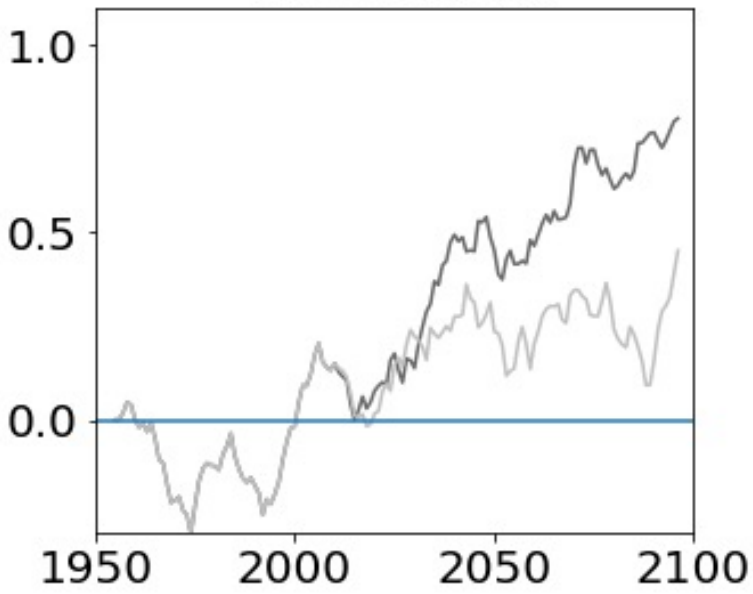


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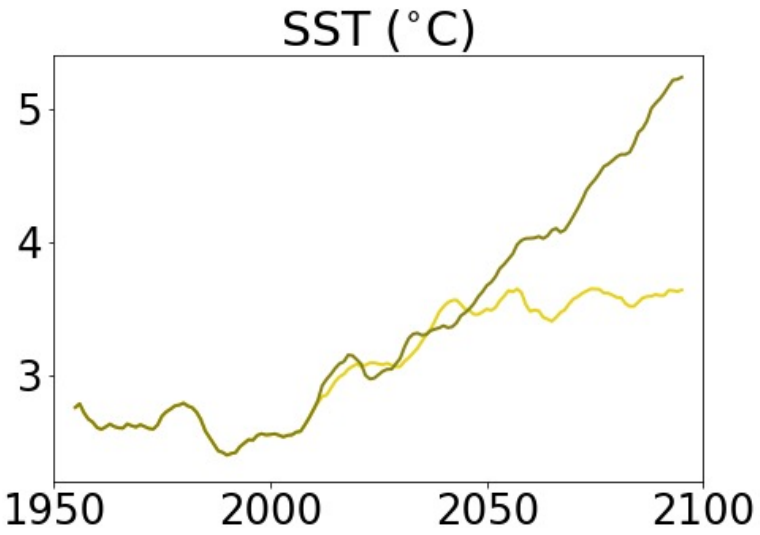
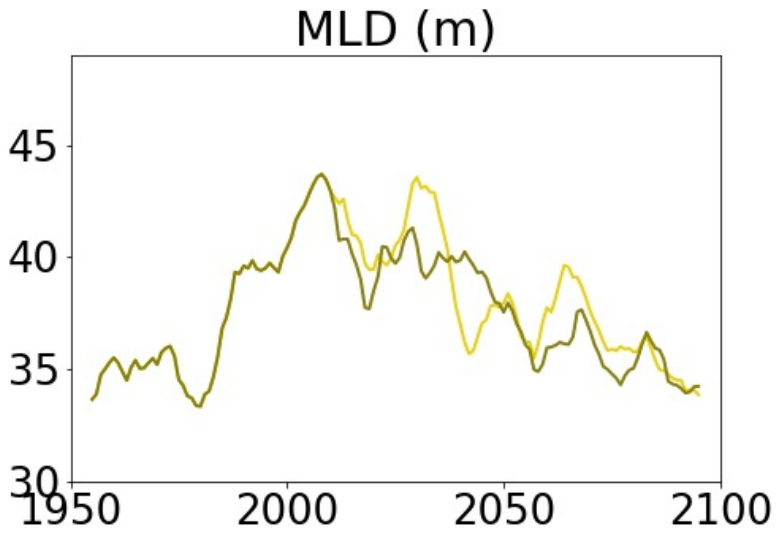
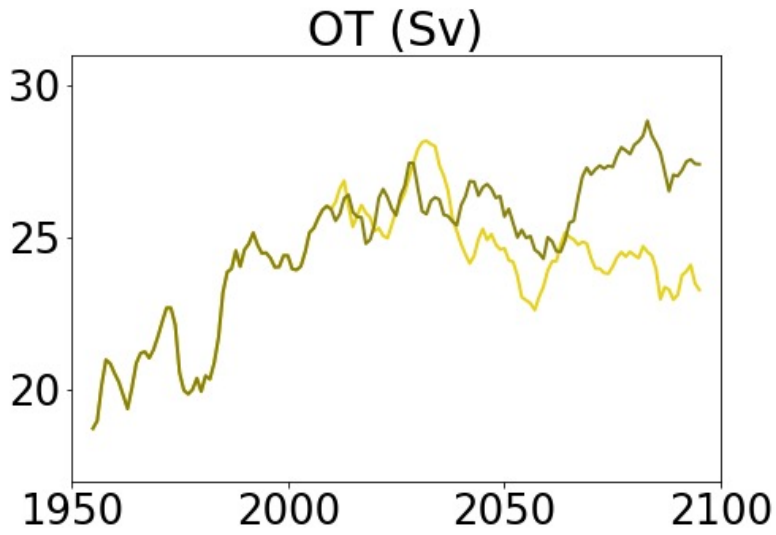
# Results: Physical Sea State

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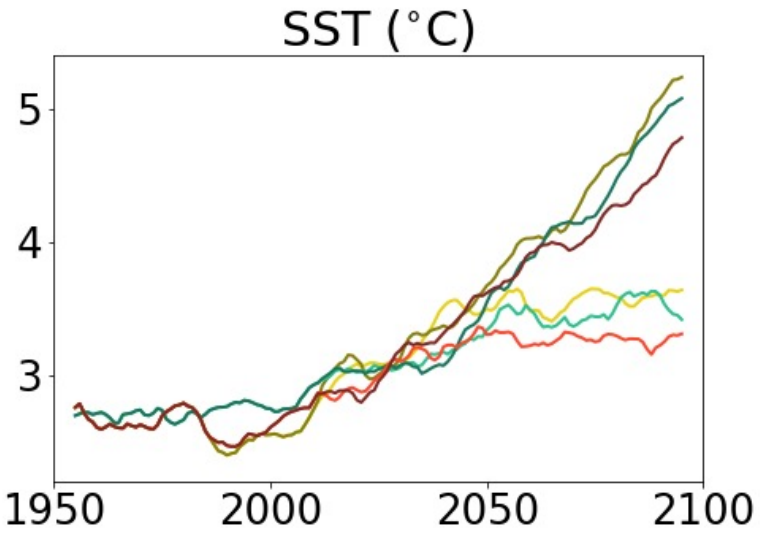


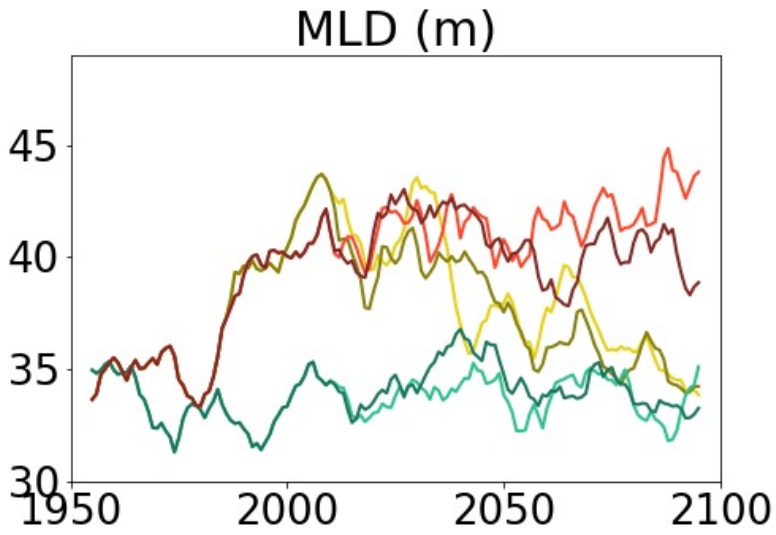


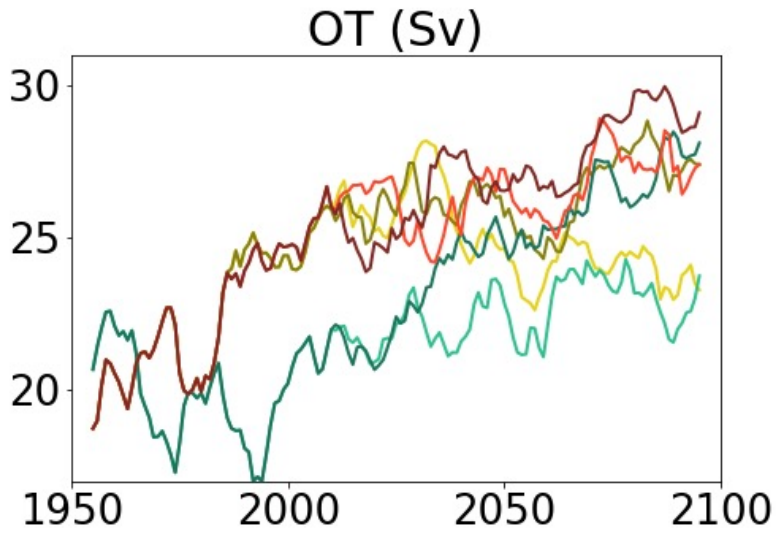


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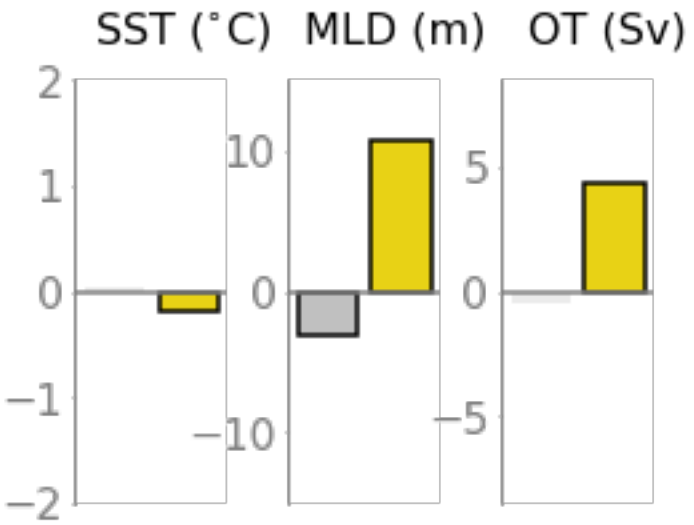
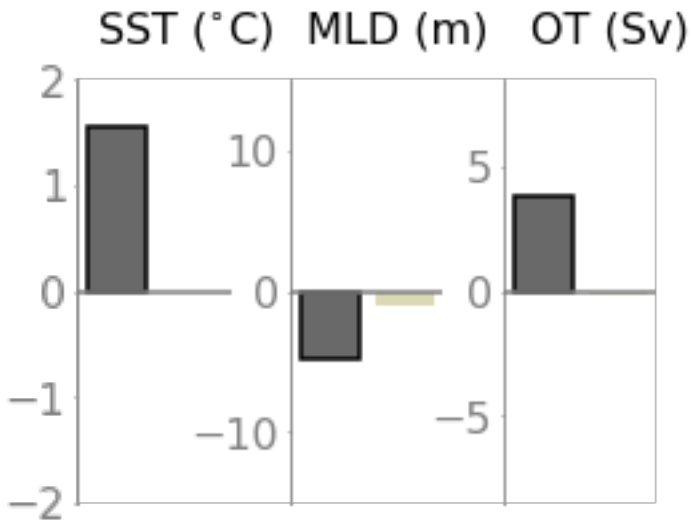
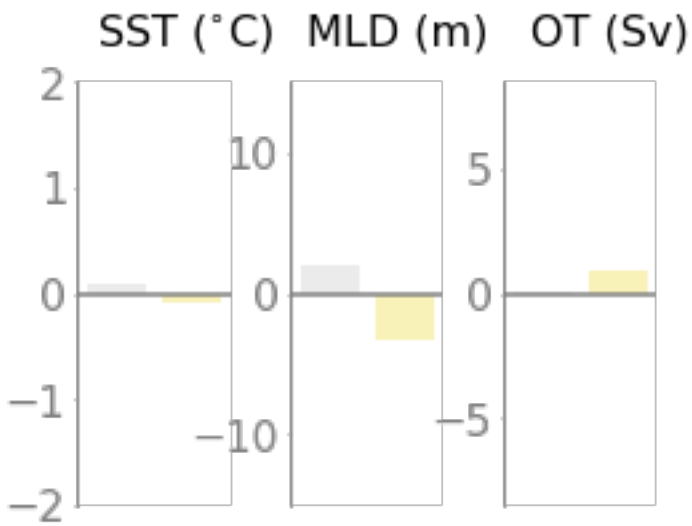



*historical*
*1950-2000*

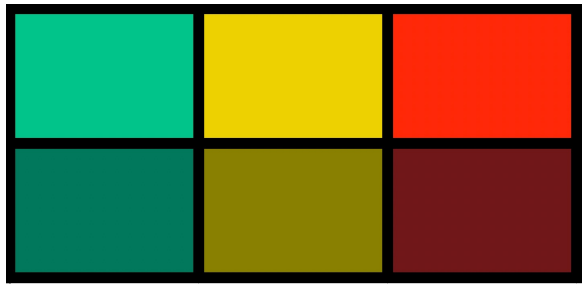



*SSP3*
*2050-2100*




*SSP1*
*2050-2100*

*year average*



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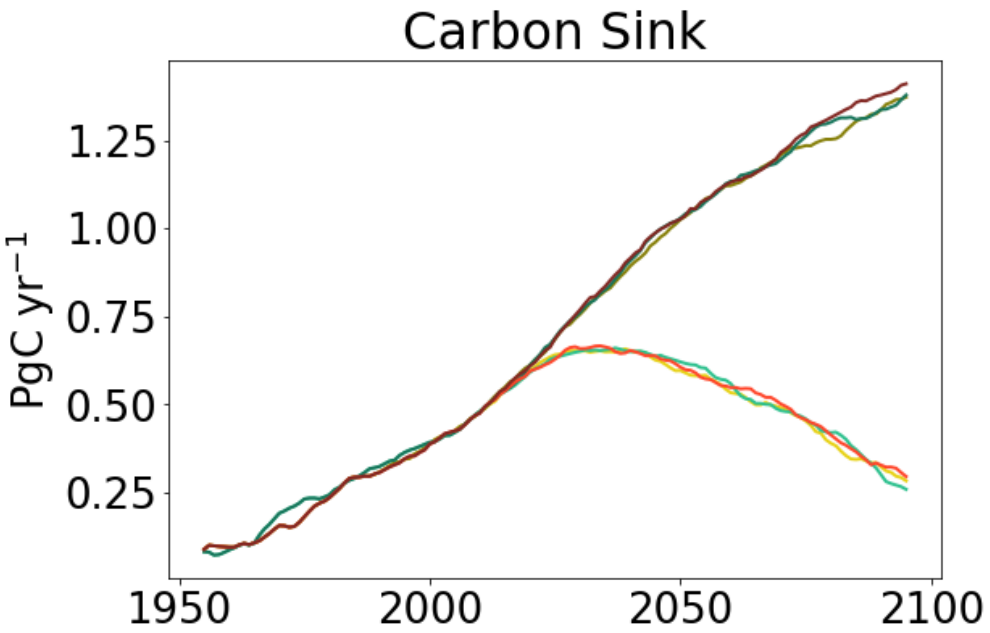


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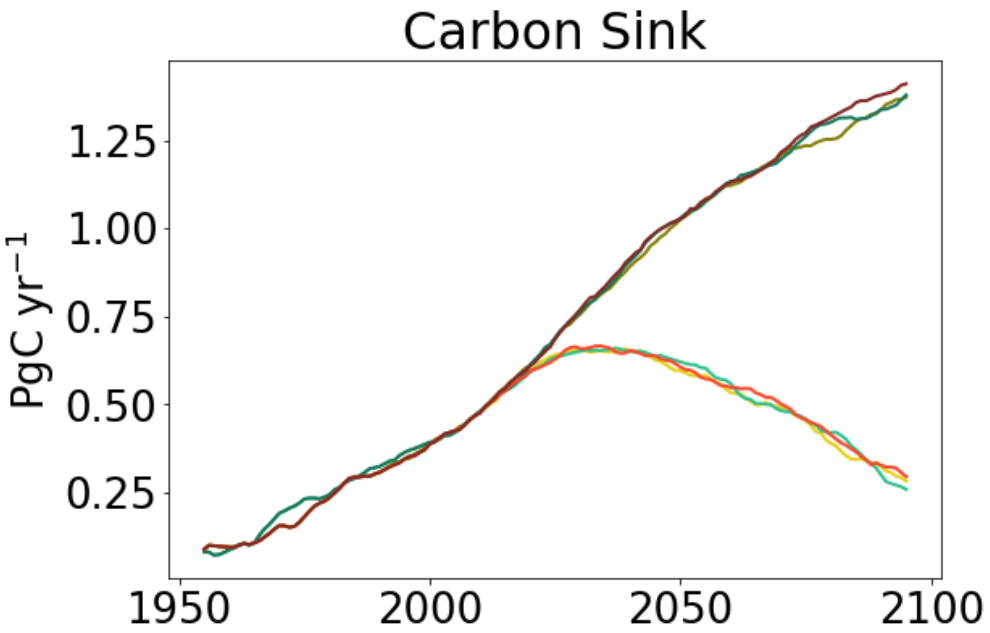


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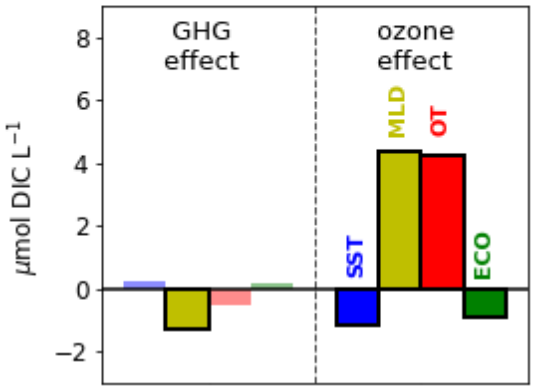
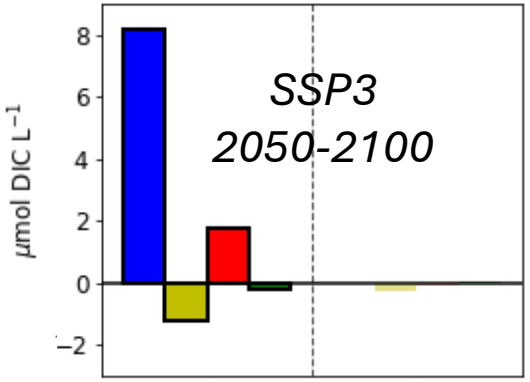
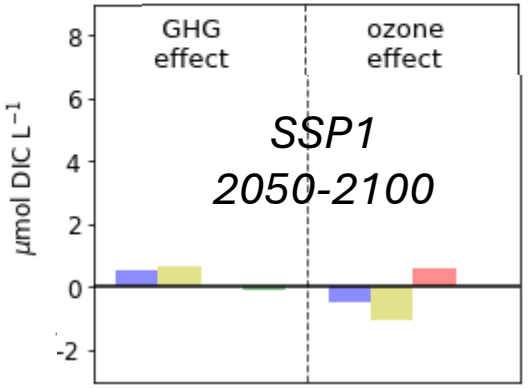



*historical 1950-2000*



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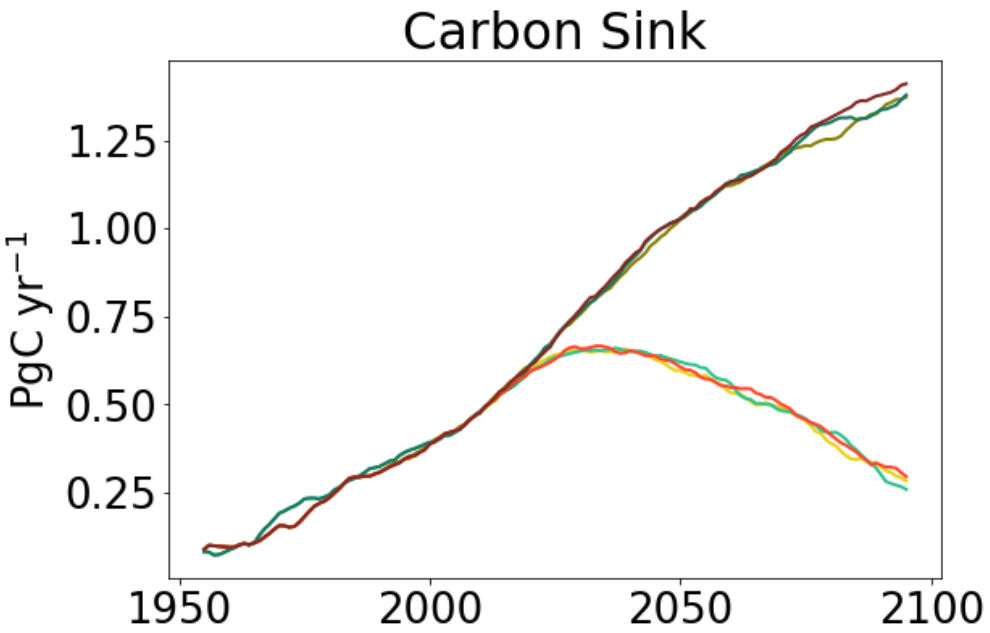


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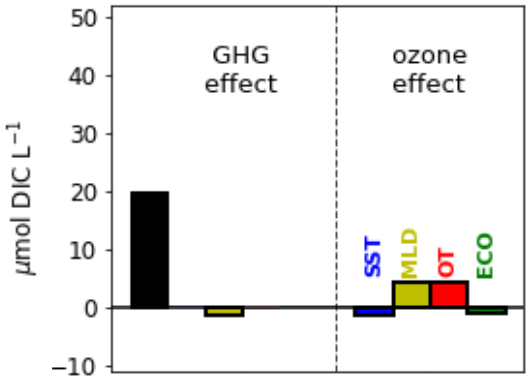
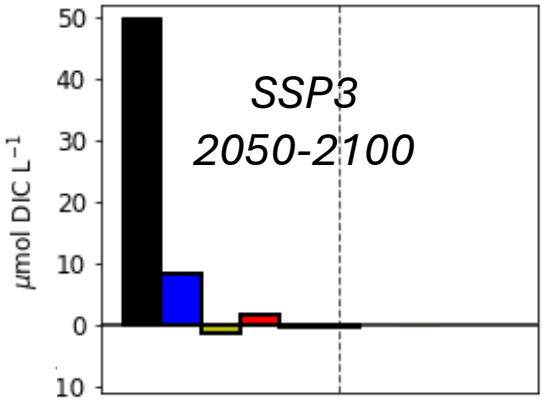
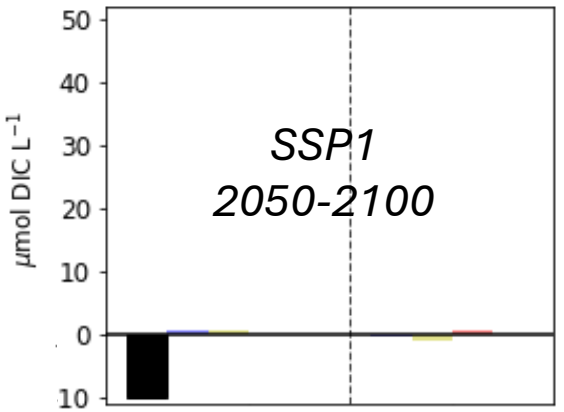
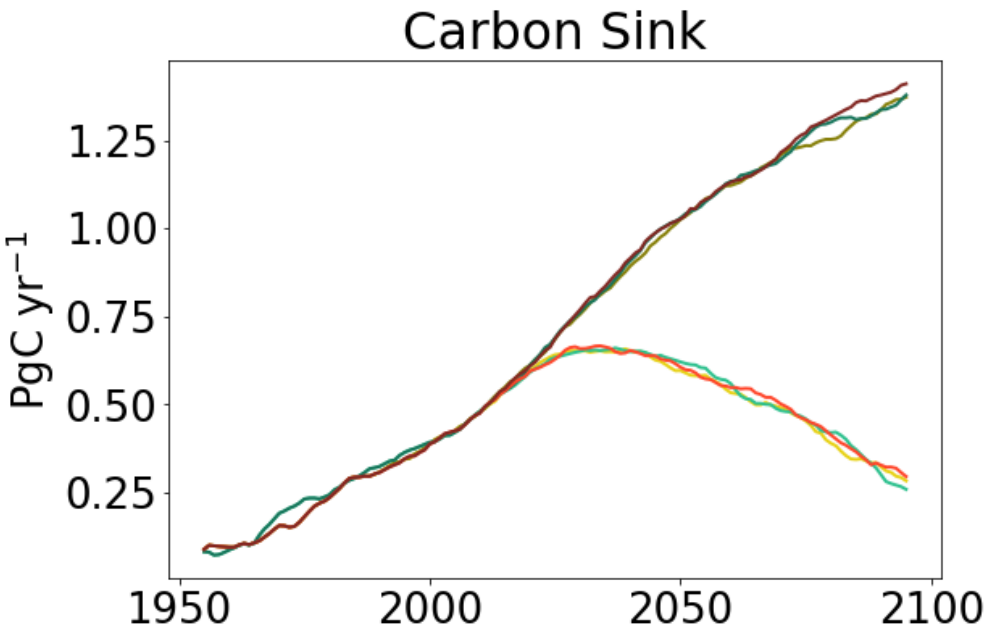



*historical 1950-2000*



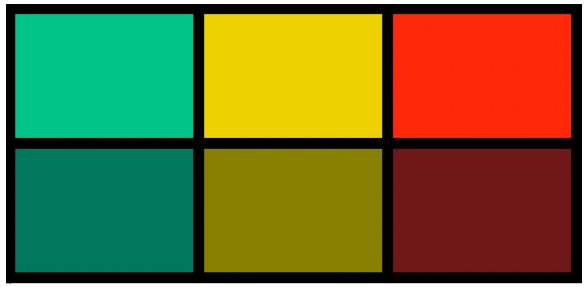
# Ok, but what does it mean for the $CO_2$ sink?



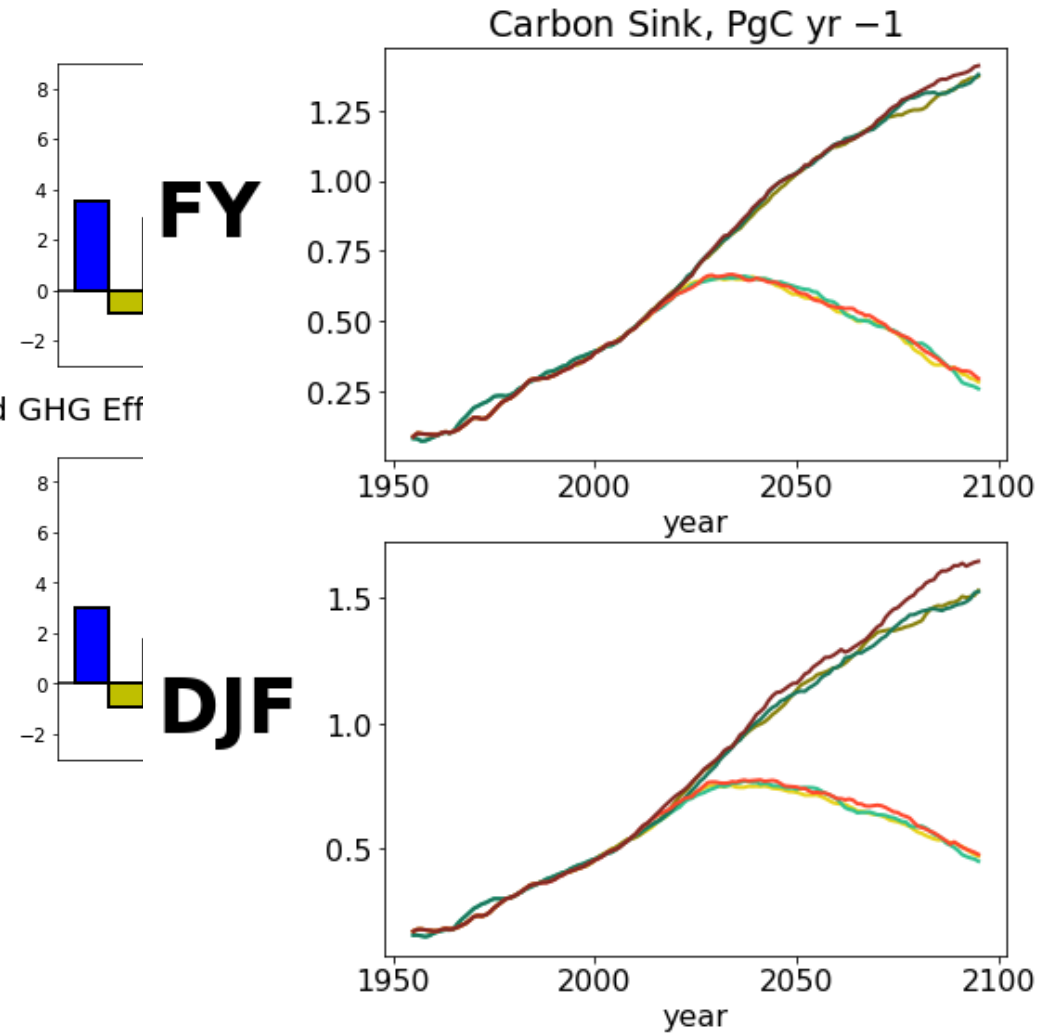

1. Both ozone and GHG act to modulate the winds and physical oceanographic conditions
2. Controls shift from ozone to GHG dominance over the course of the 21st century
3. Climate feedbacks, especially temperature, are important, but for the CO2 sink are secondary to the atmospheric CO2 effect

*year average*

# RANDOM OTHER SLIDES BEGIN HERE



d GHG Effects on Surface DIC change, SSP3

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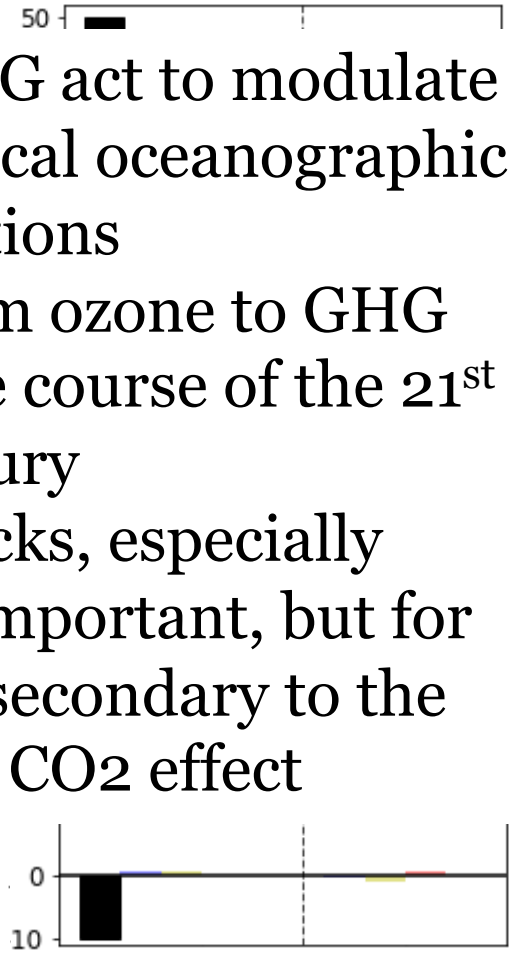

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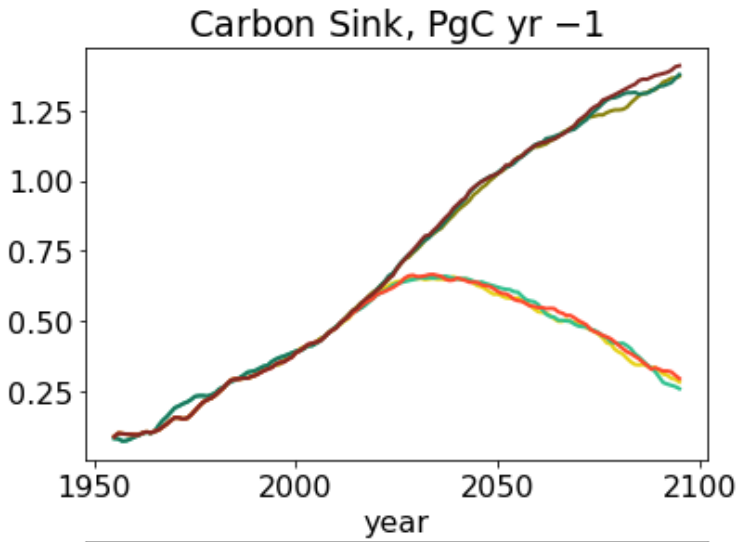
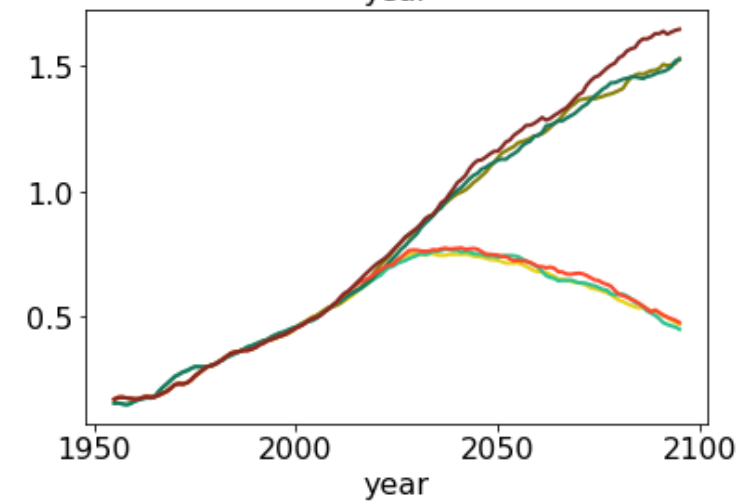
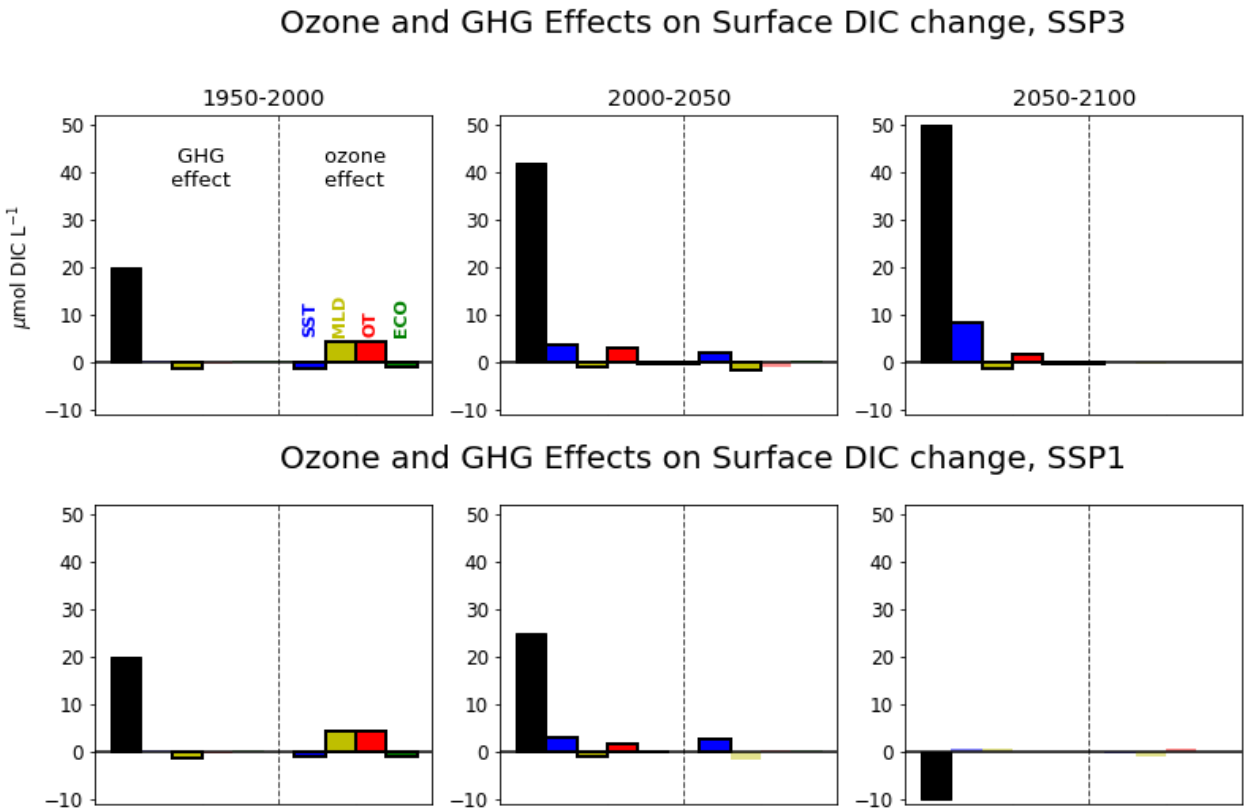
**FY**

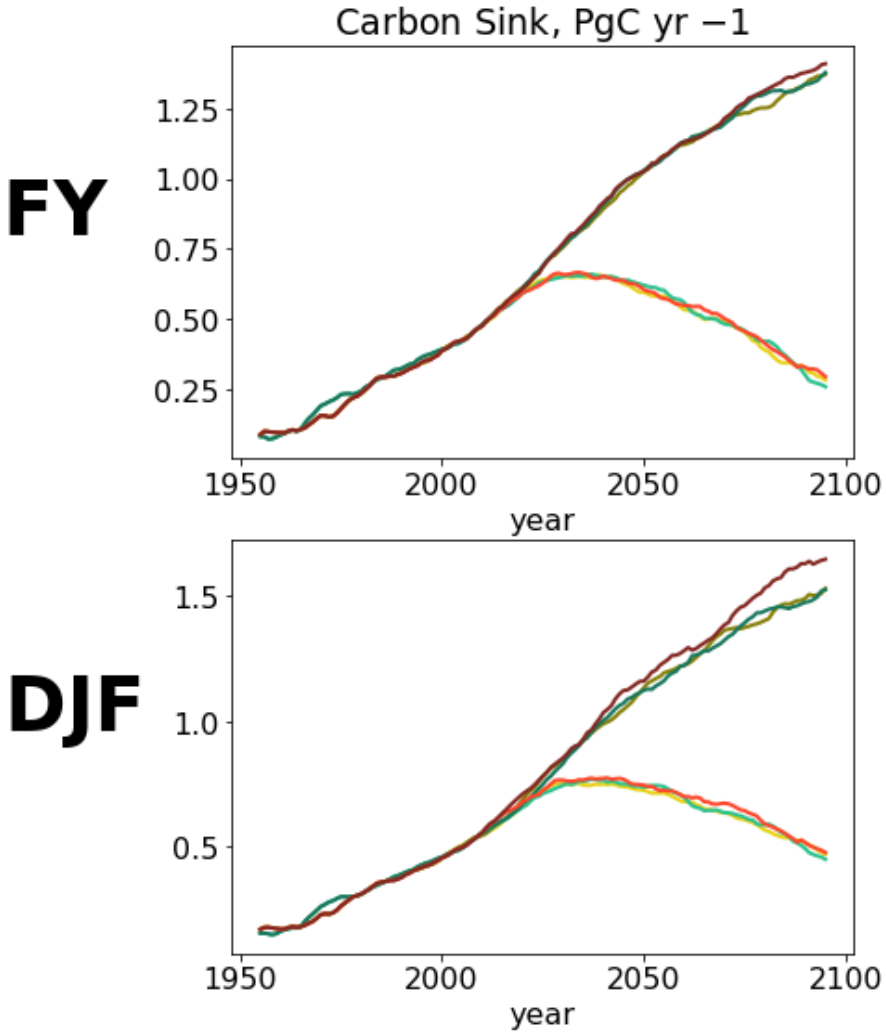



**DJF**



# Summary

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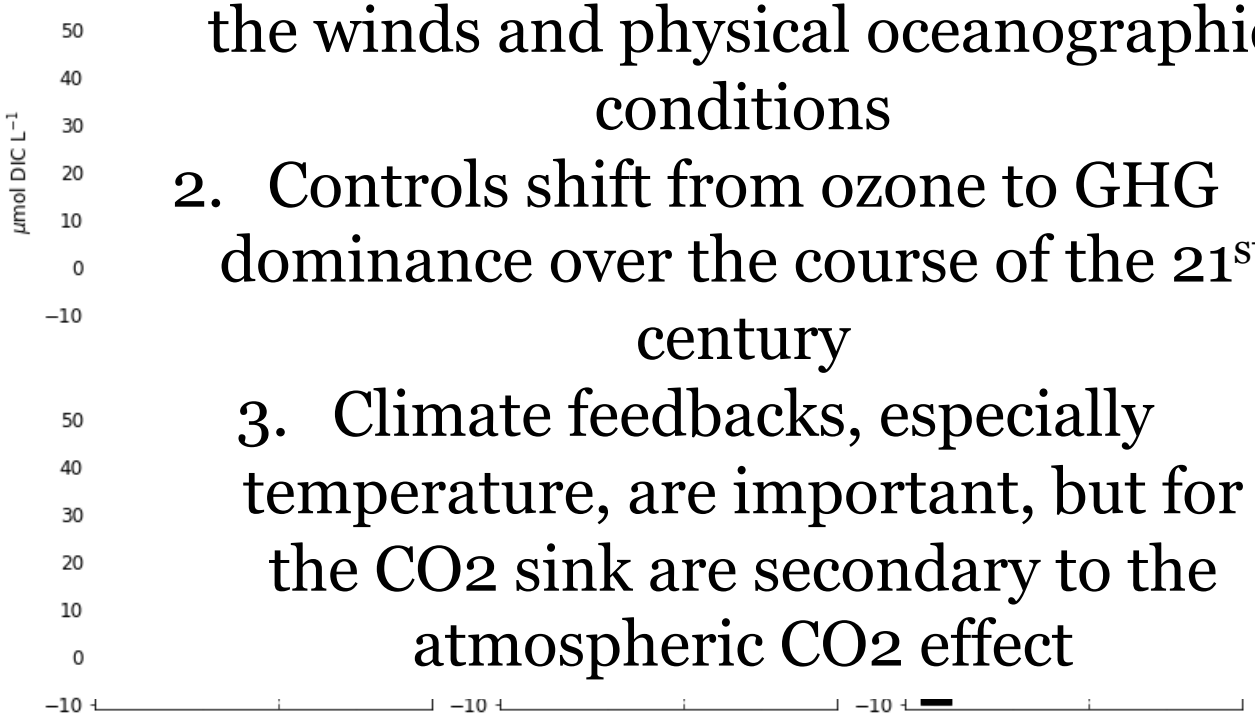

| ozone-depleting substances → / SSP ↓ | FIXED | HISTORIC | 1990 |
|---|---|---|---|
| SSP 1-2.6 | ODS fixed at 1950 levels SSP 1-2.6 | ODS evolve historically SSP 1-2.6 | ODS fixed at 1990 levels SSP 1-2.6 |
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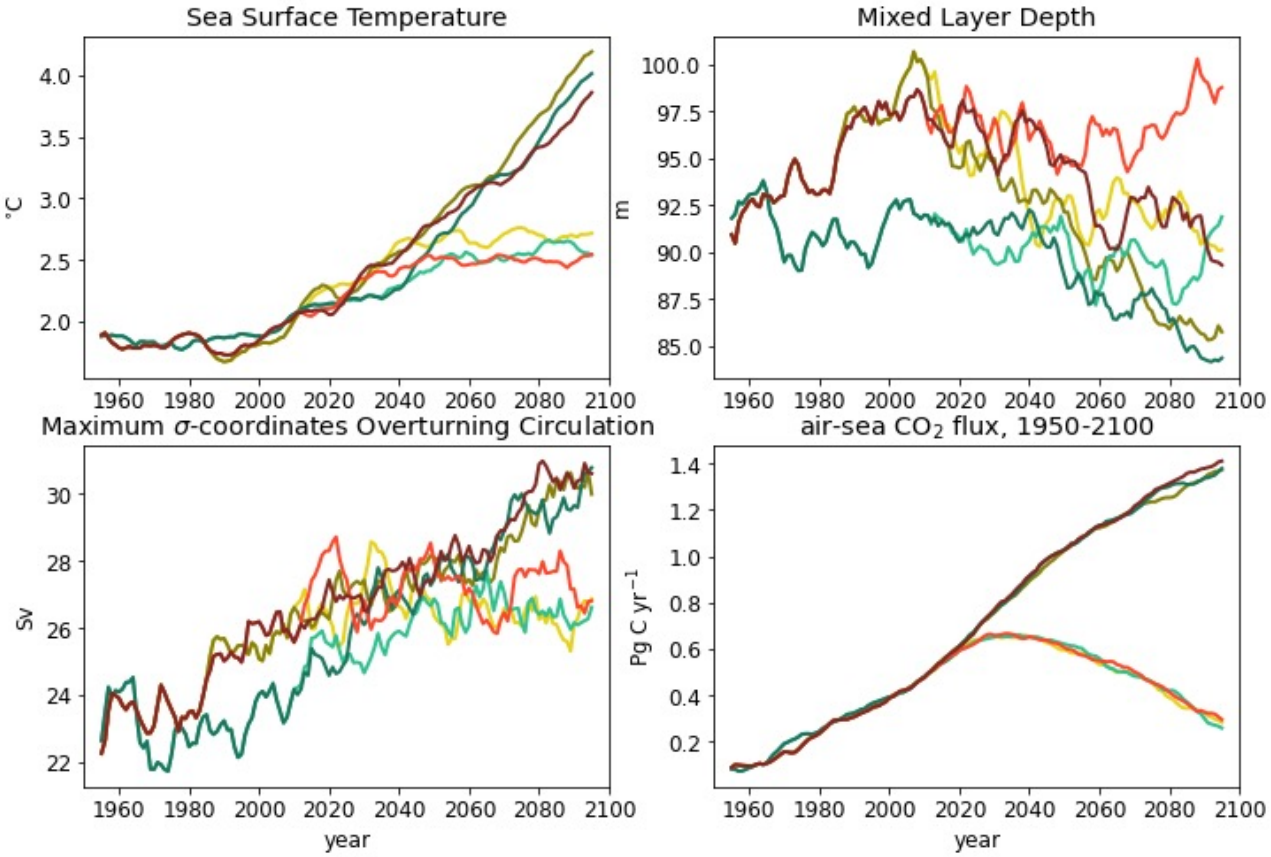
# RANDOM OTHER SLIDES BEGIN HERE

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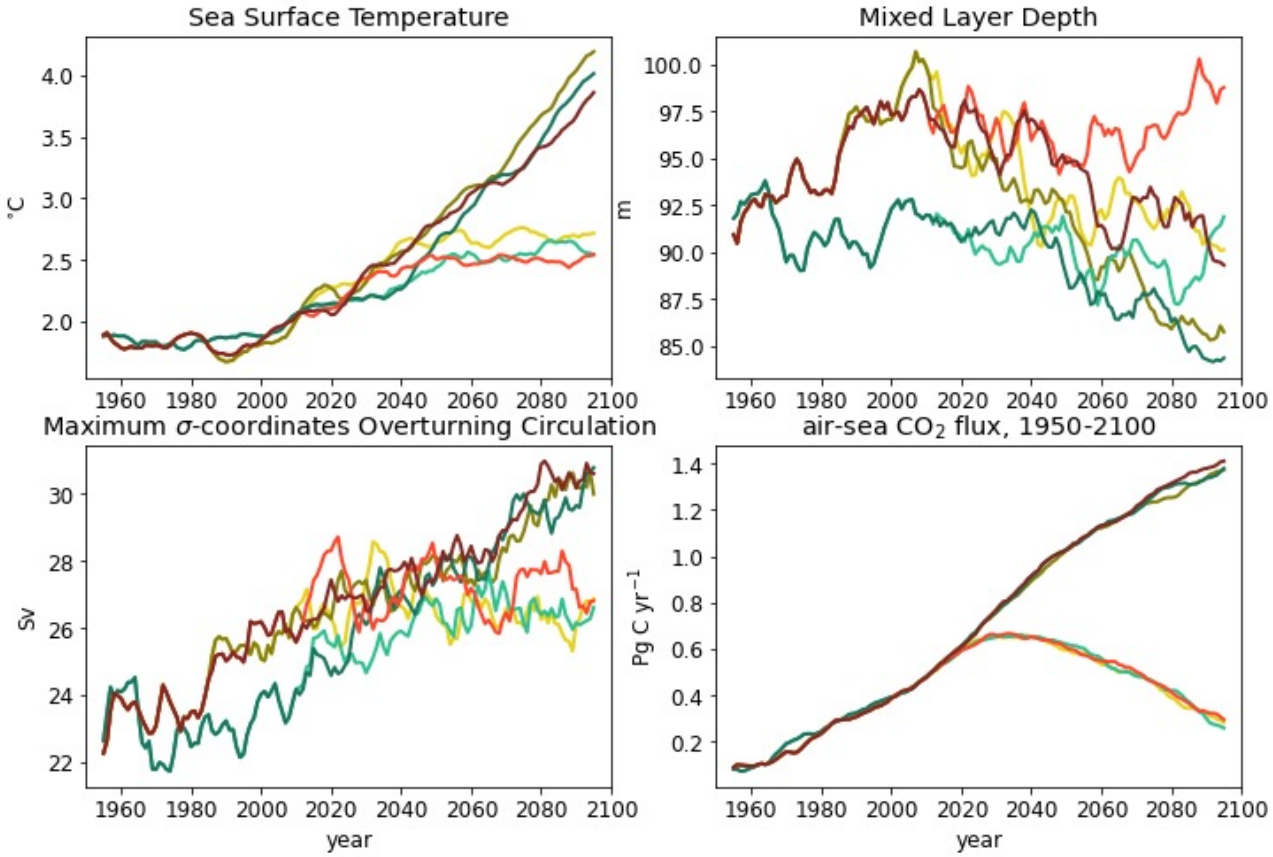


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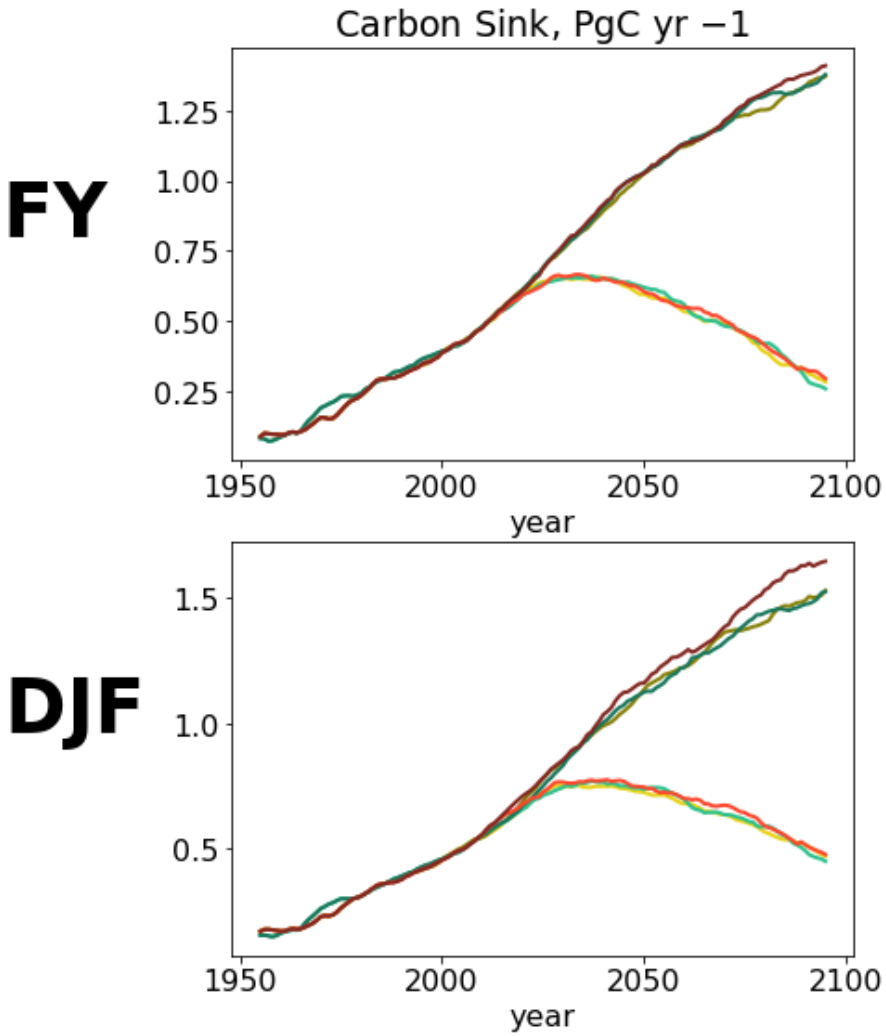


| quantity | Mechanism of change |
|---|---|
| sea surface temperature (SST) | $CO_2$ solubility change with temperature (~4% pCO2 / degree) |
| mixed layer depth (MLD) | Changes in near-surface DIC gradient |
| overturning (OT) | Changes in delivery of deep DIC to surface |

# Experimental Design

| ozone-depleting substances → / SSP ↓ | FIXED | HISTORIC | 1990 |
|---|---|---|---|
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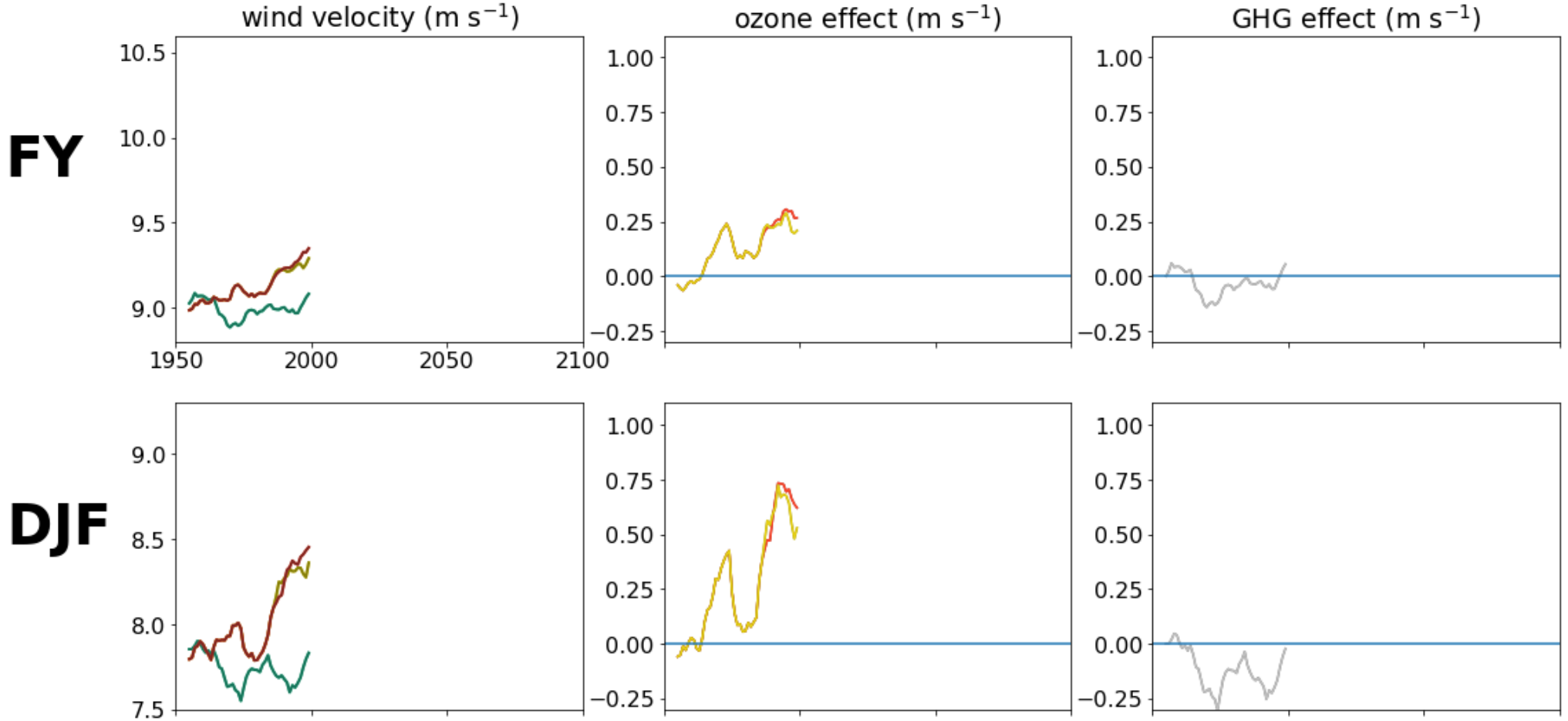
UKESM

UKESM1, 1950-2100

# What are the major physical controls on the Southern Ocean carbon sink, and how will they change due to GHG emissions and ozone depletion?

| quantity | expected effect of ozone depletion on quantity | expected effect of atmo. GHG increase on quantity | expected effect of quantity change on CO2 sink (↓: sink decrease) |
|---|---|---|---|
| wind velocity (WINDS) | ↑ | ↑ | ↓(↑) |
| sea surface temperature (SST) | ↓(↑) | ↑ | ↓(↑) |
| mixed layer depth (MLD) | ↑ | ↓ | ↓↑ |
| overturning (OT) | ↑ | ↑(↓) | ↓ |

# Ozone and GHG effect on wind speed, 1950-2100



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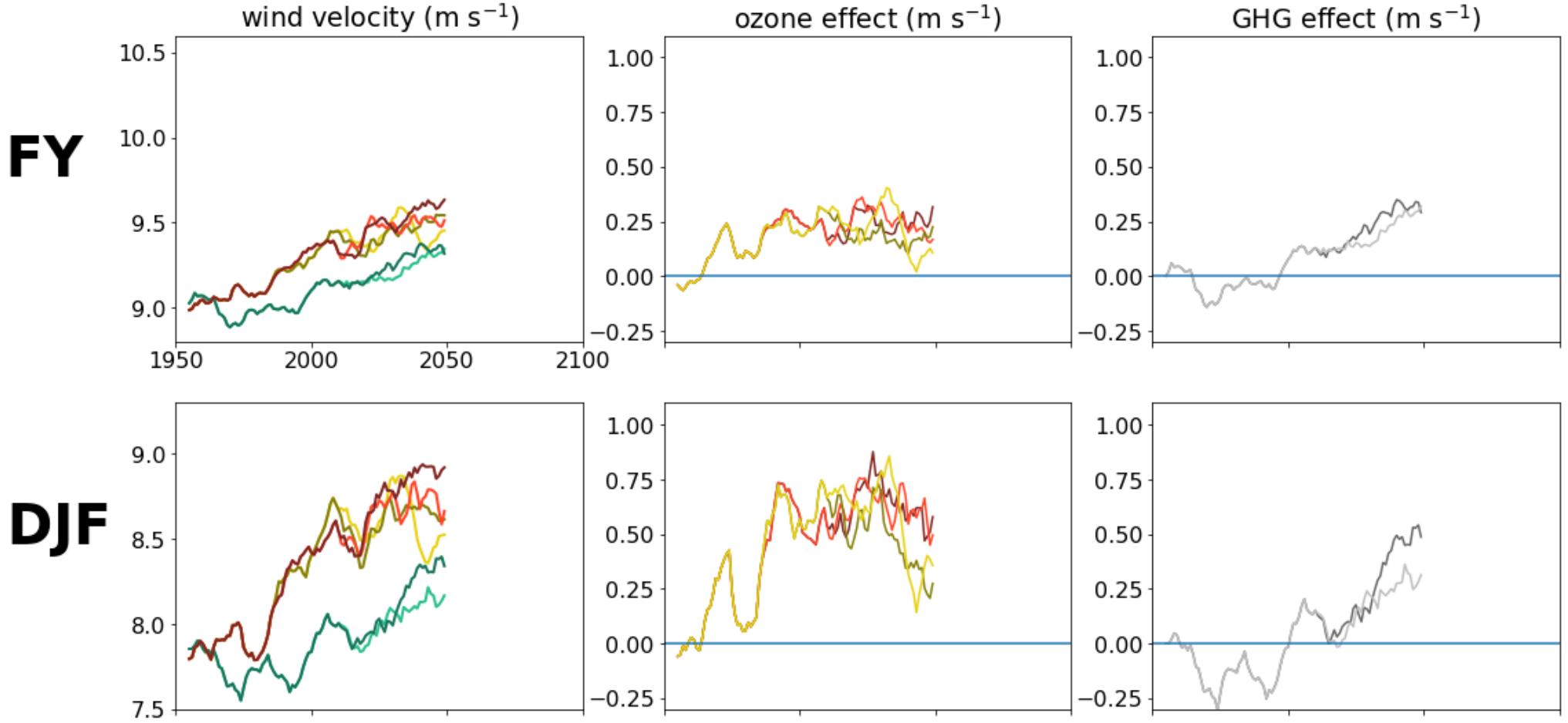

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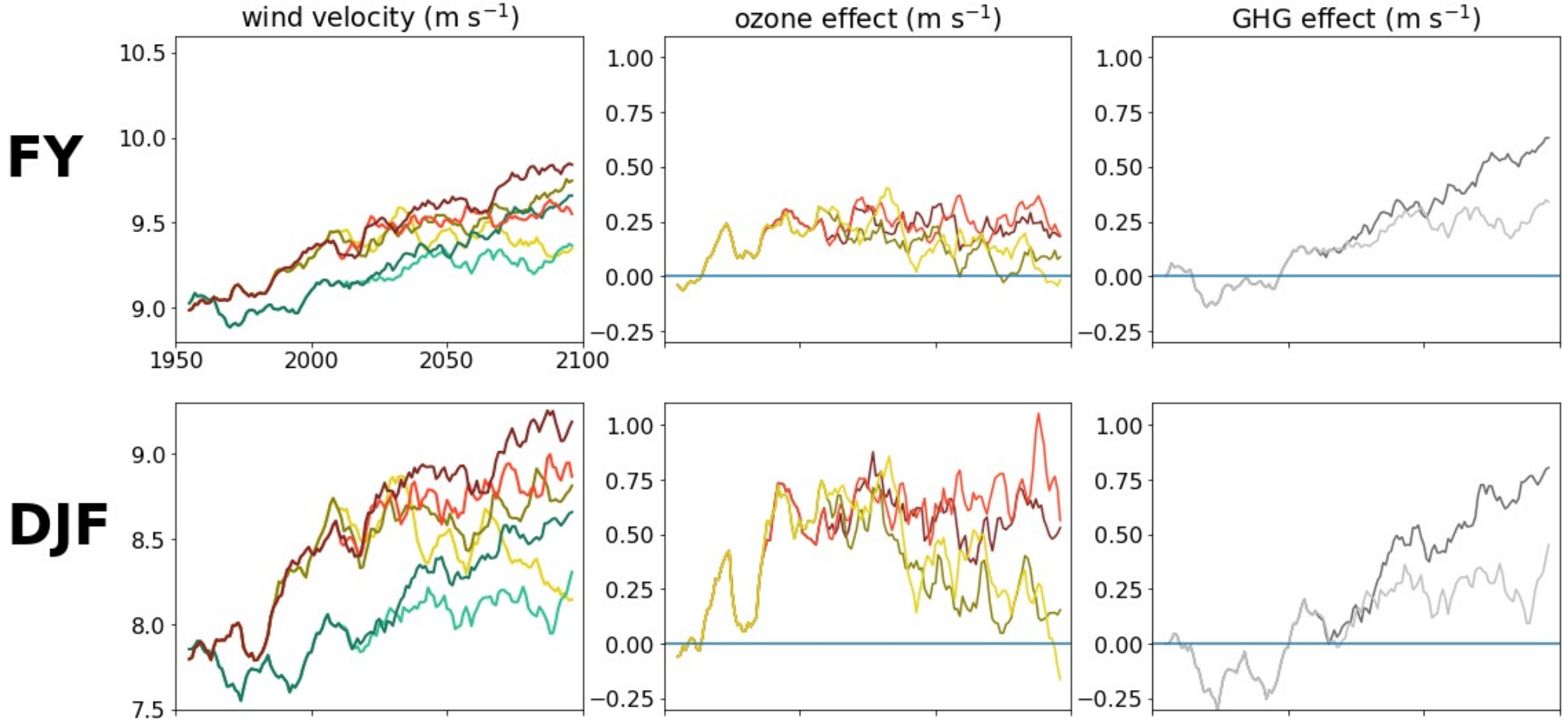

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| wind velocity (WINDS) | ↑ | ↑ | ↓(↑) |
| sea surface temperature (SST) | ↓(↑) | ↑ | ↓(↑) |
| mixed layer depth (MLD) | ↑ | ↓ | ↓↑ |
| overturning (OT) | ↑ | ↑(↓) | ↓ |

# A back of the envelope calculation: of non-$CO_2$ effects the thermal effect is most important, but non-$CO_2$ effects are dwarfed by the atmospheric carbon signal.