



CriticalEarth



Universiteit Utrecht



University of  
Reading

# Global stability of the AMOC under CO<sub>2</sub> forcing: Boundary crisis, ensemble splitting & oscillatory edge state

Reyk Börner

with Oliver Mehling, Jost v. Hardenberg & Valerio Lucarini

Image: Greg Shira, NASA Visualization Studios

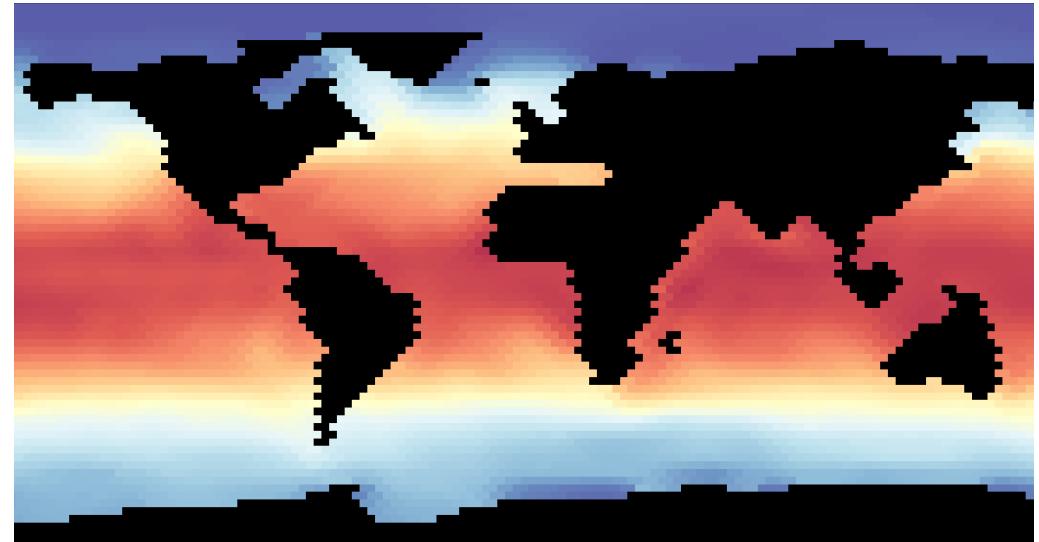


# AMOC under future CO<sub>2</sub> emissions

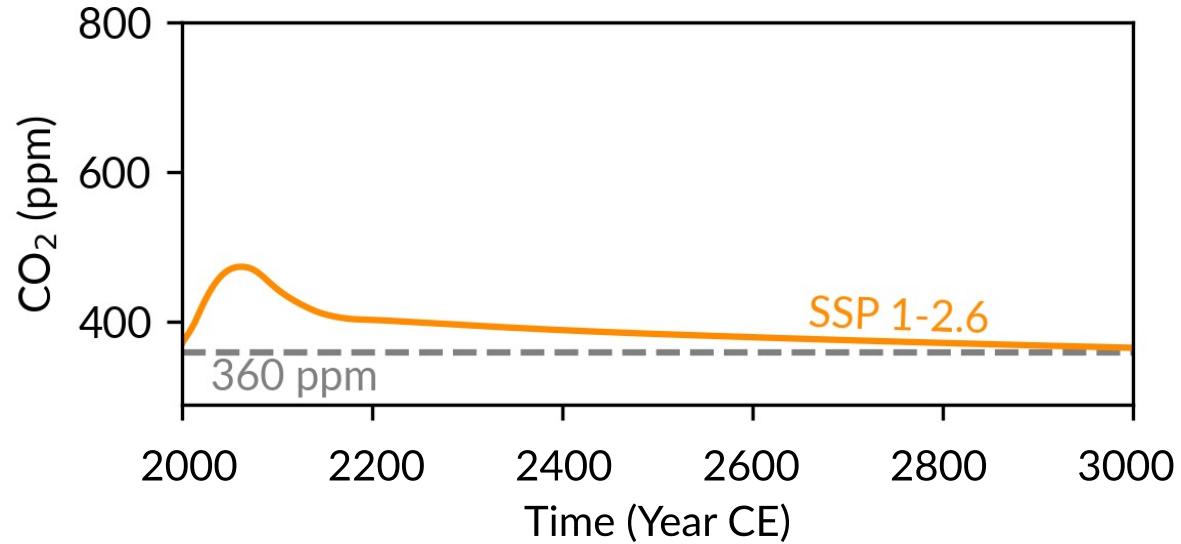
**PlaSim-LSG**

Intermediate-complexity climate model

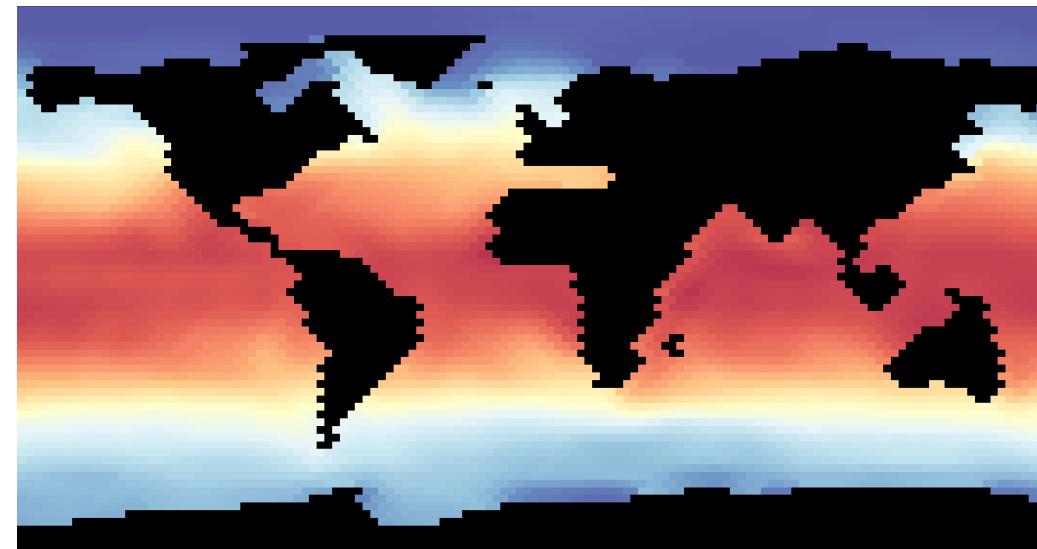
~  $10^5$  degrees of freedom



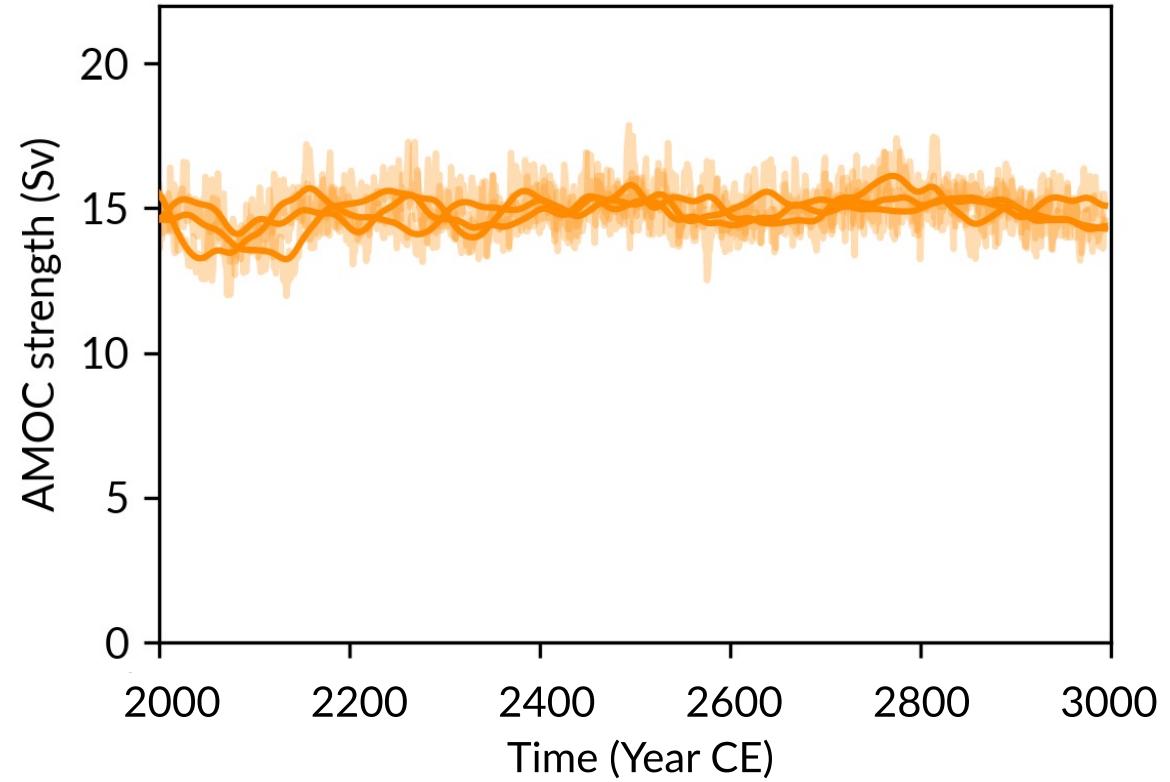
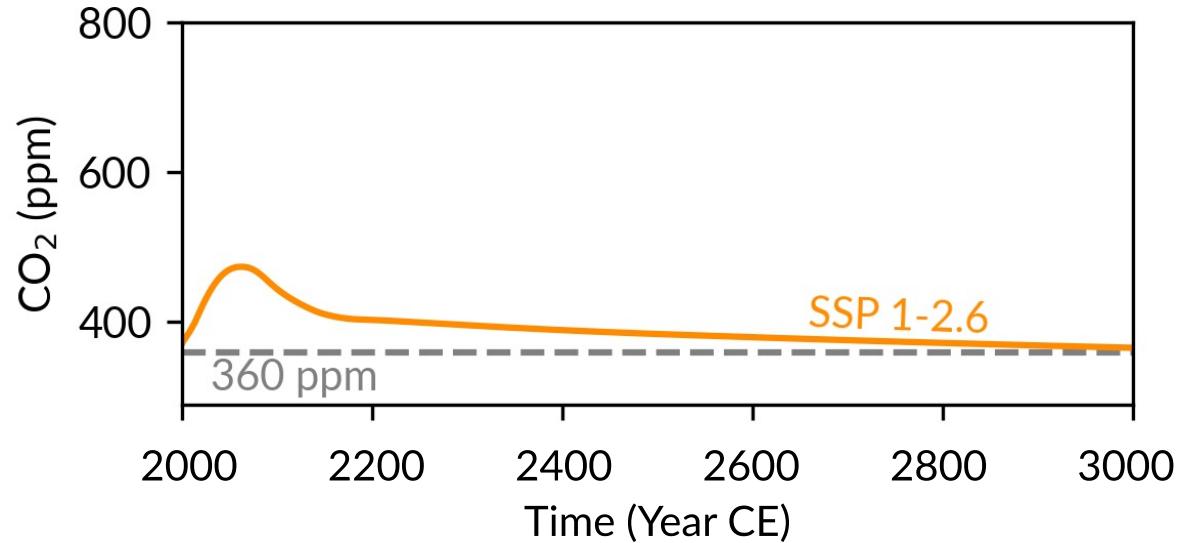
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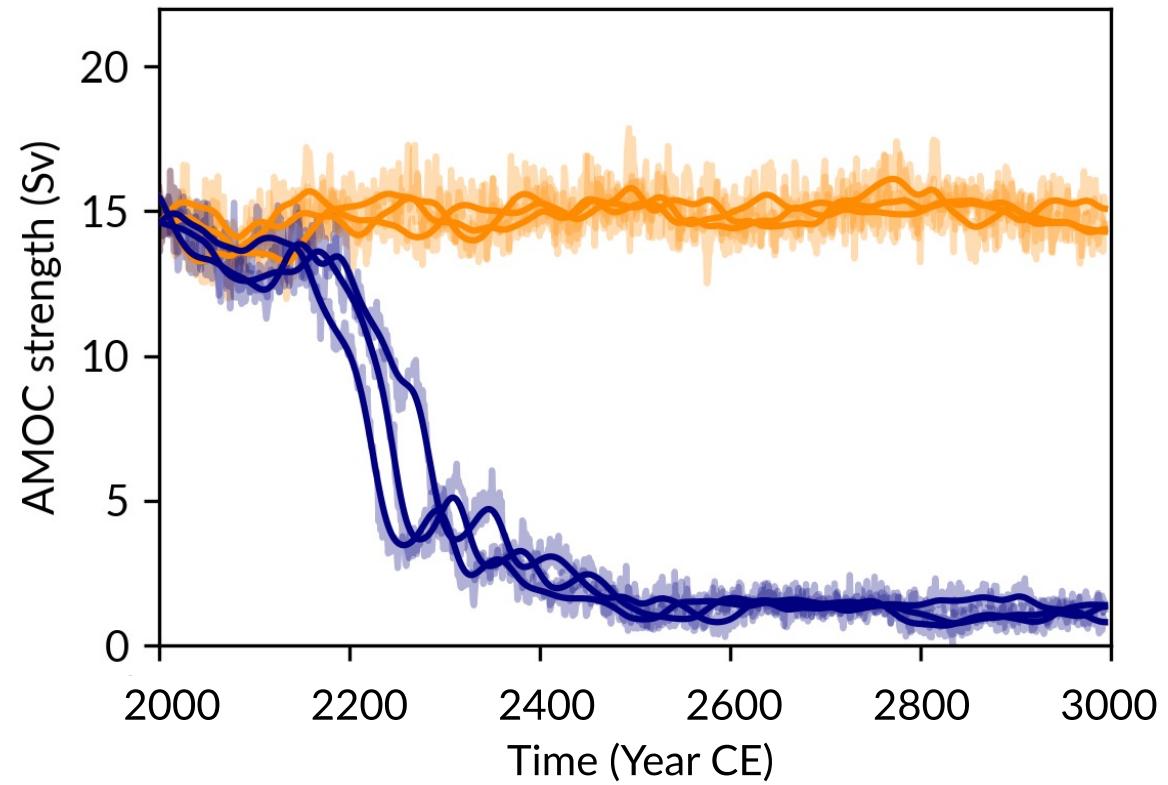
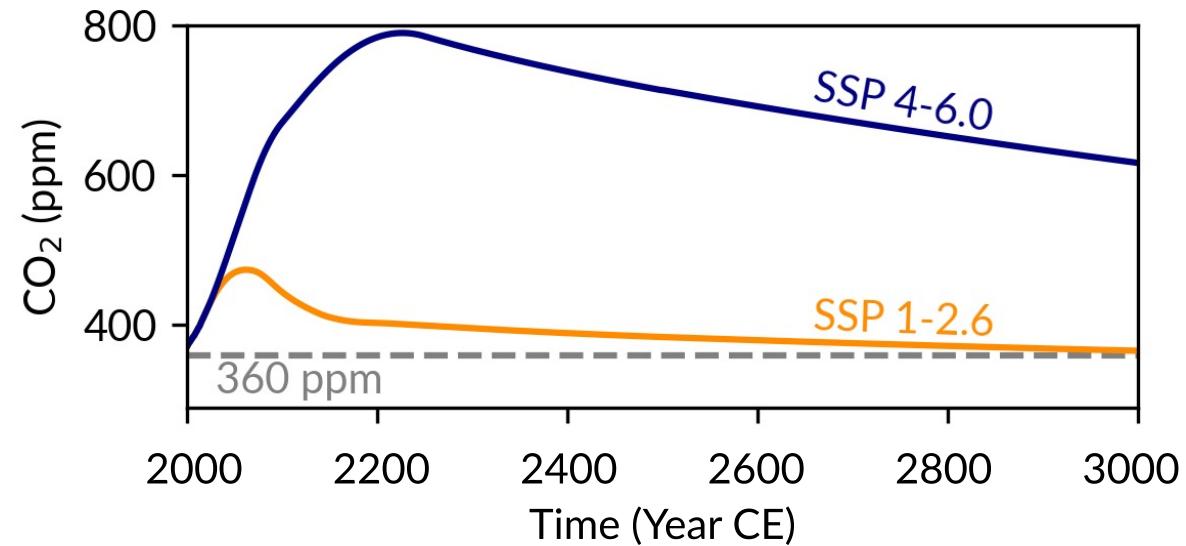
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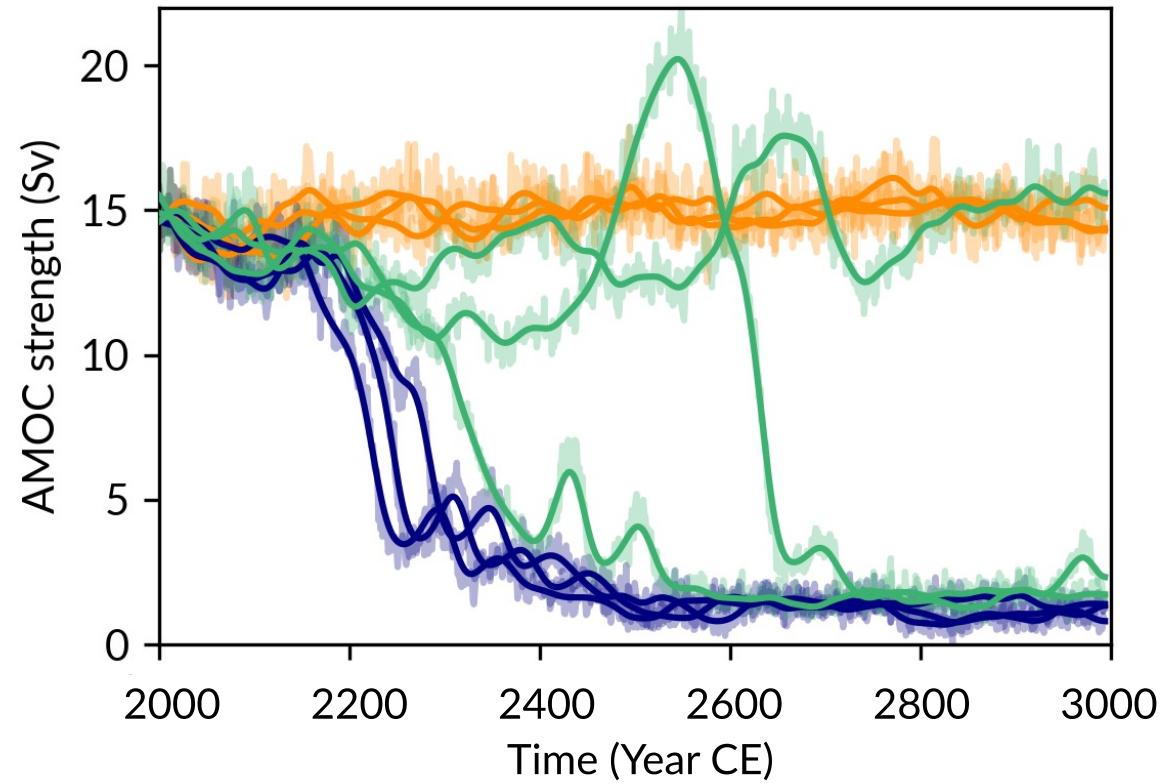
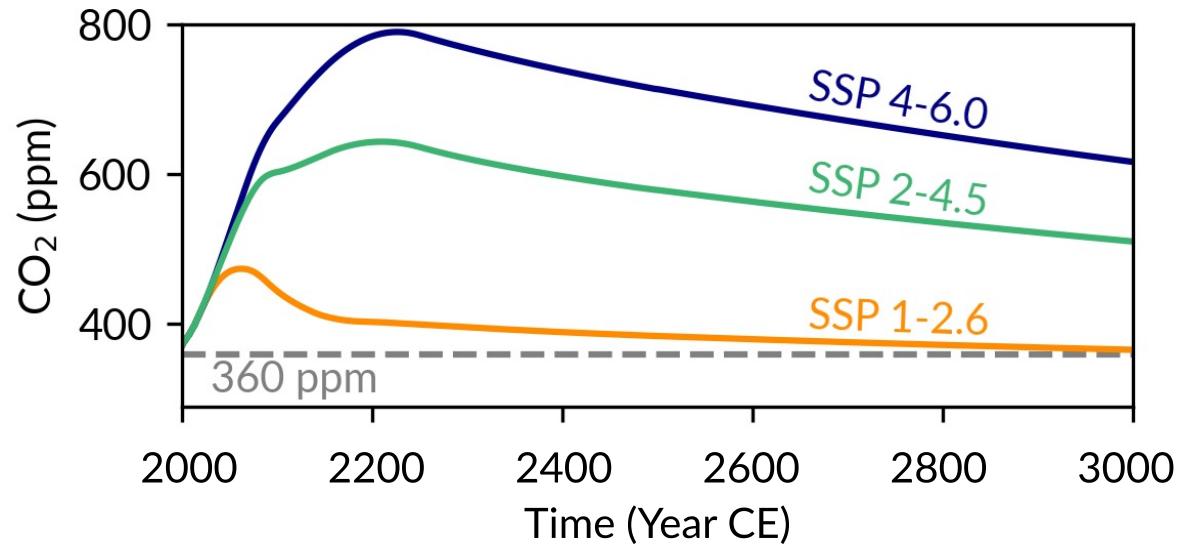
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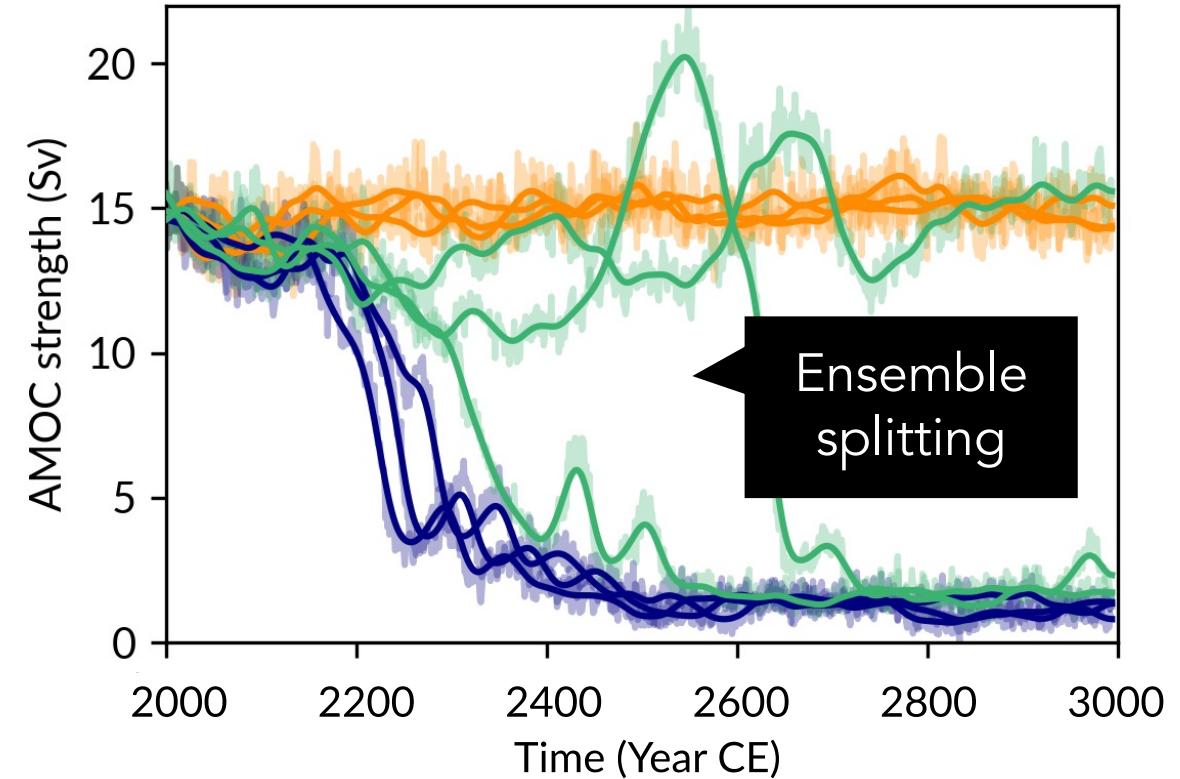
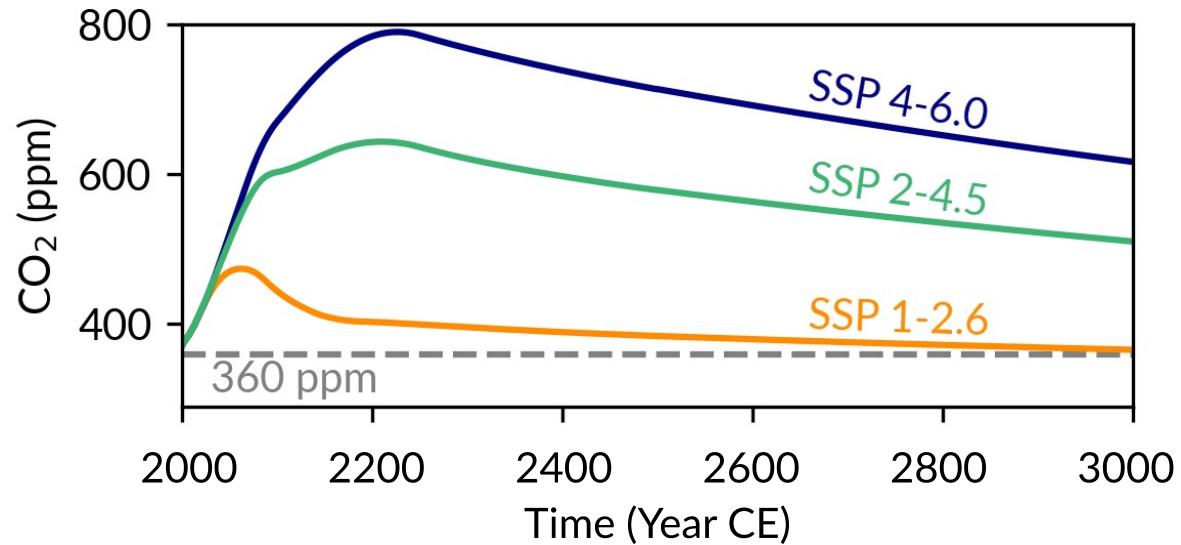
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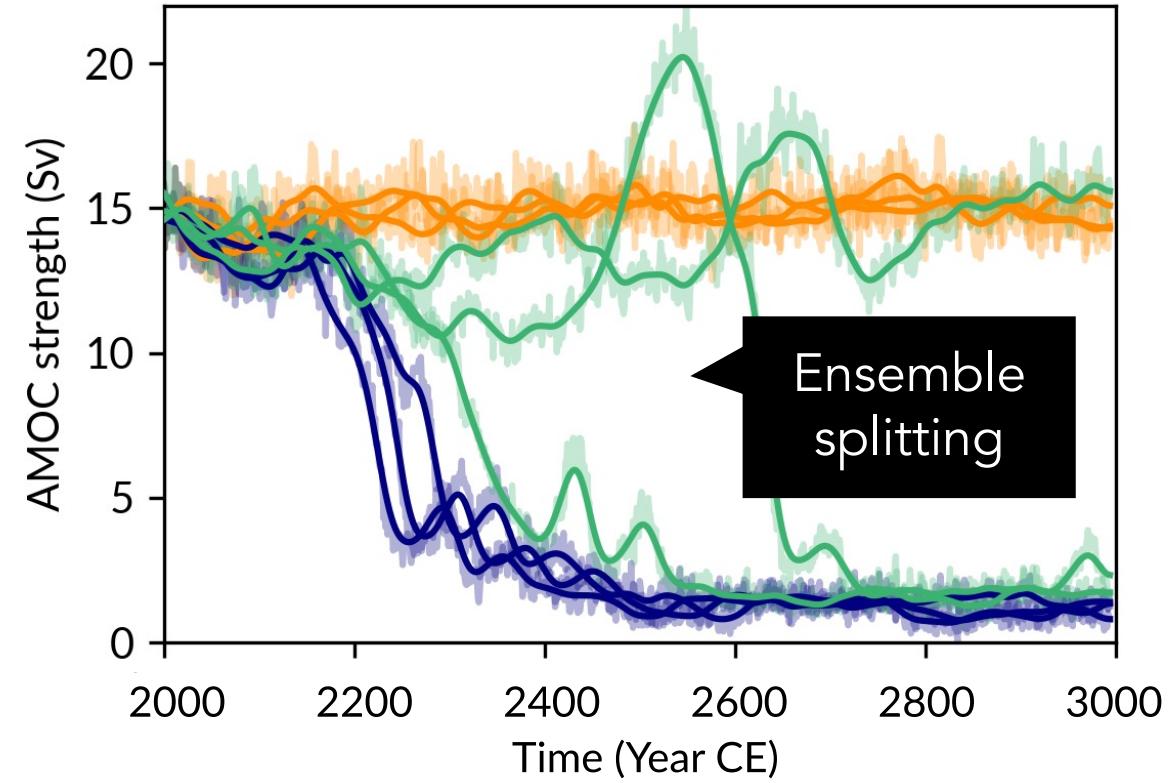
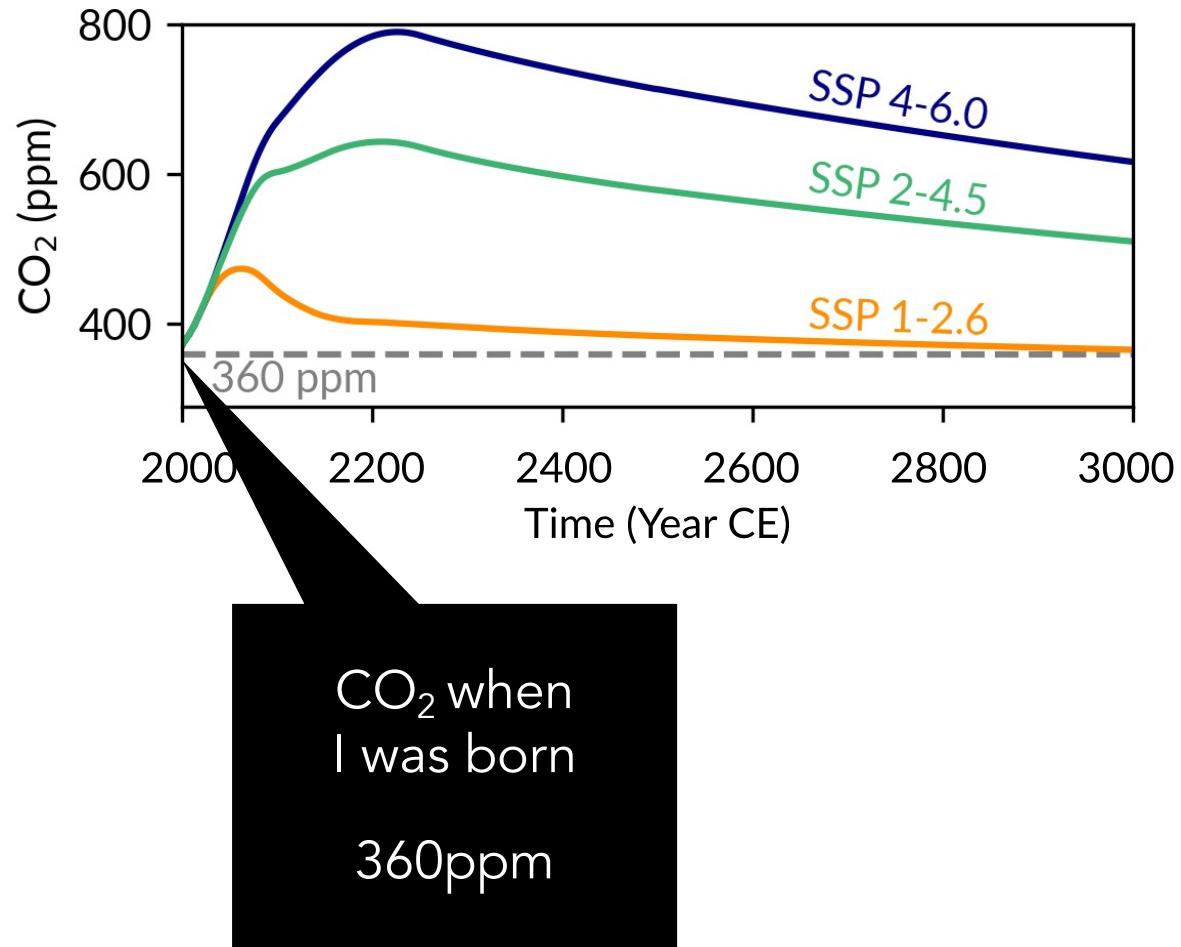
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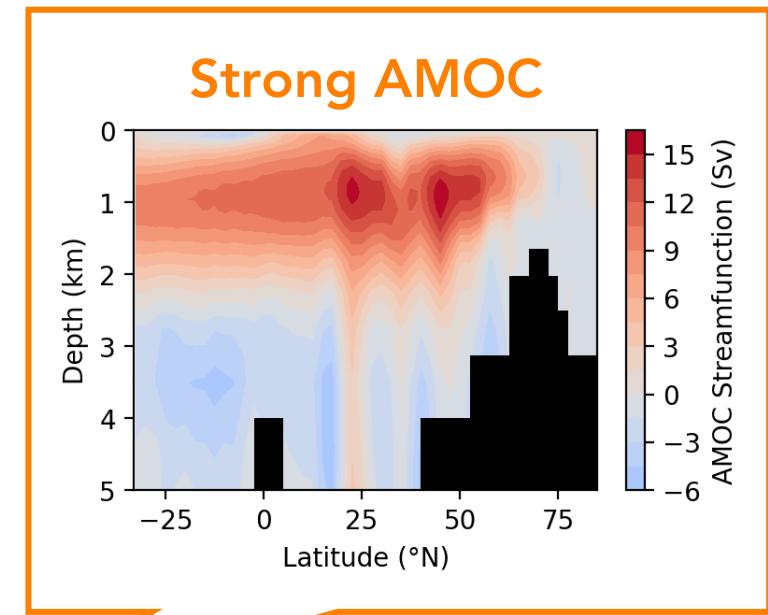
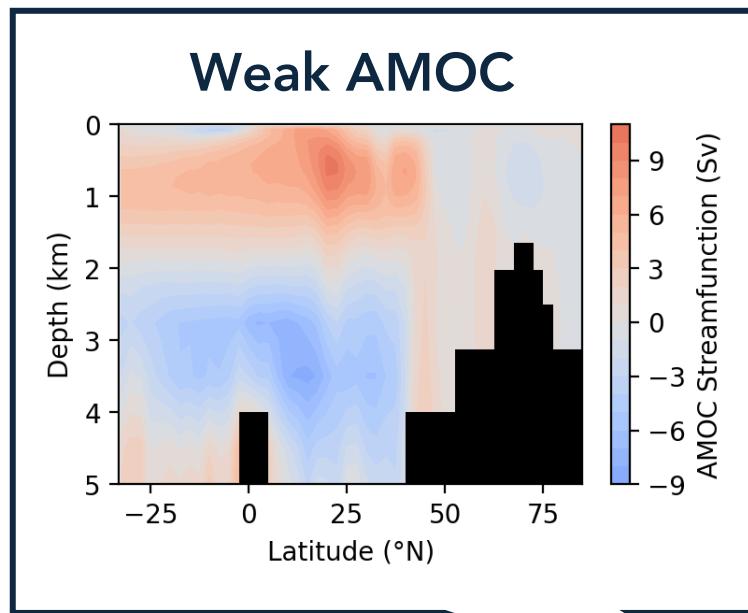
Local stability measures (e.g. critical slowing down) may not explain this

- ▶ Need a **global view** of the dynamics

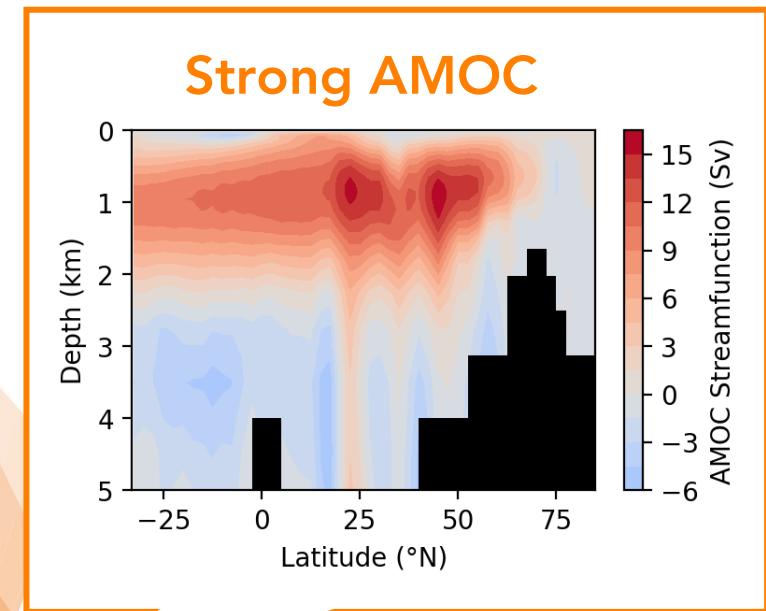
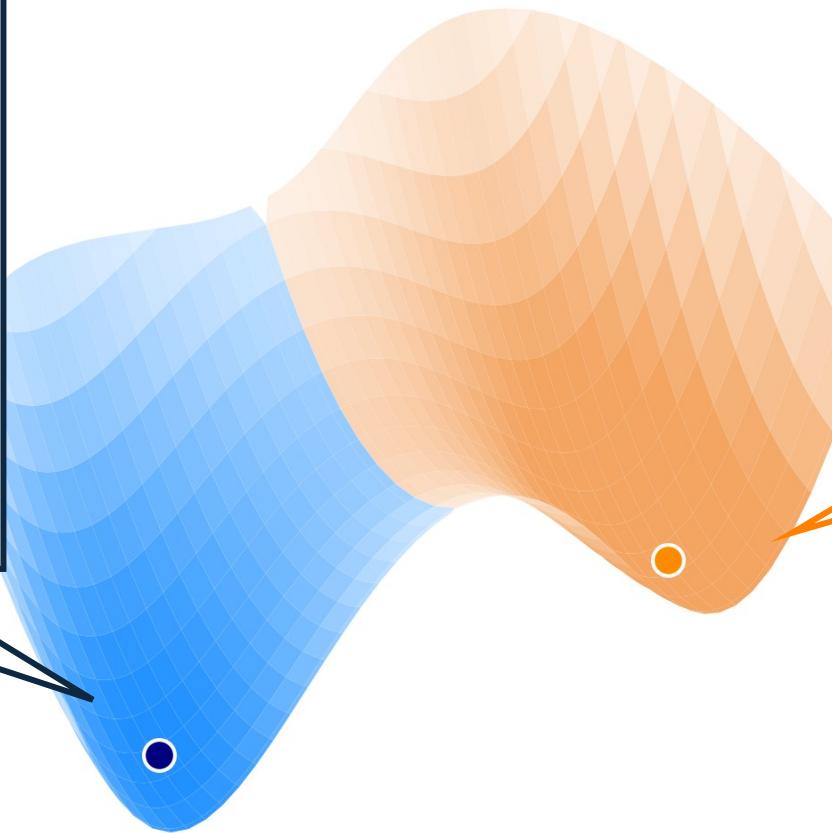
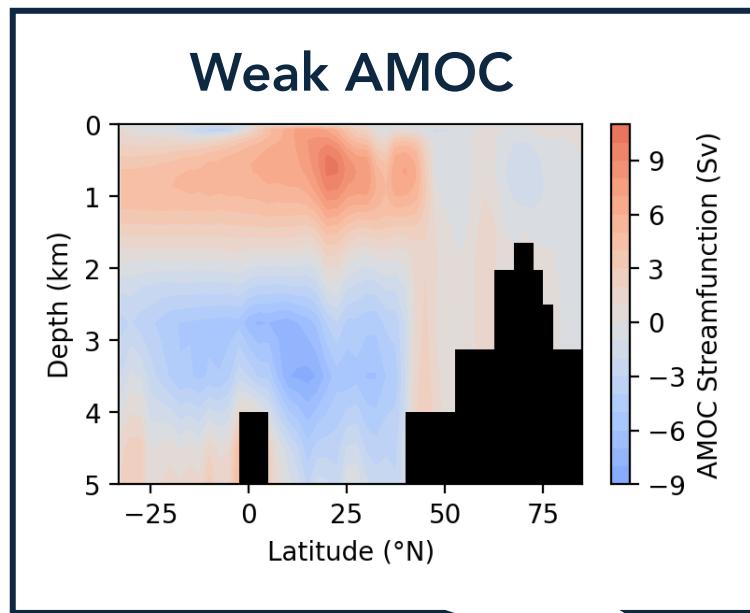
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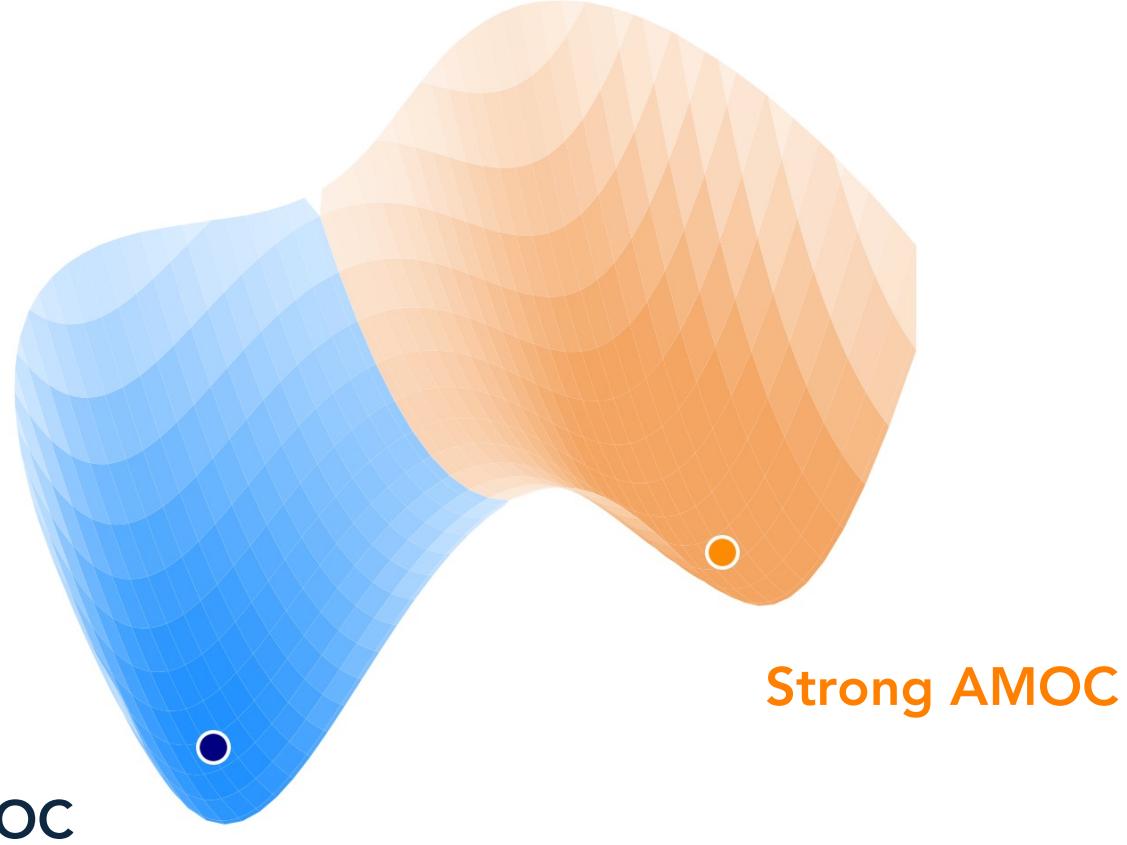
# 360ppm: AMOC as a bistable system



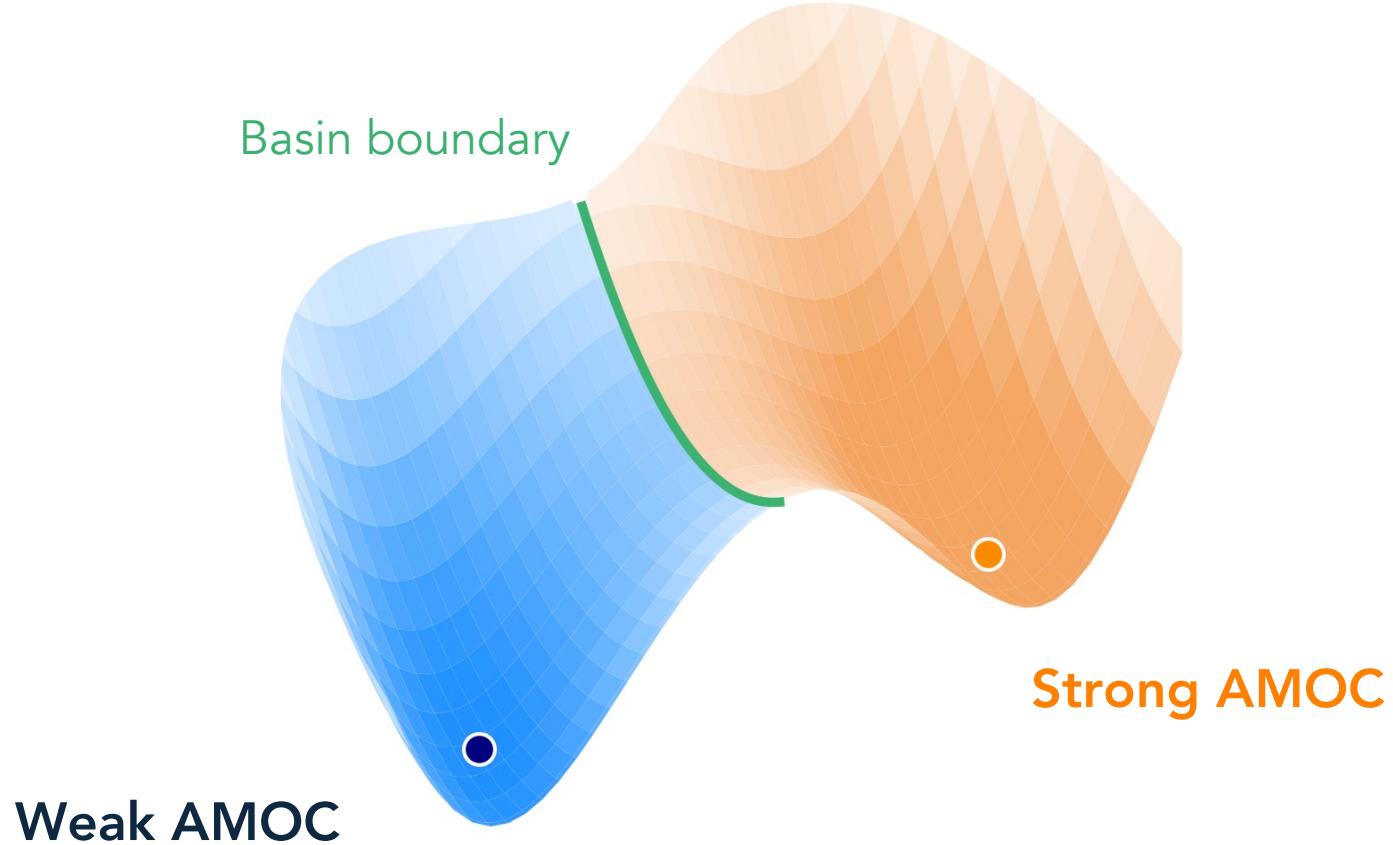
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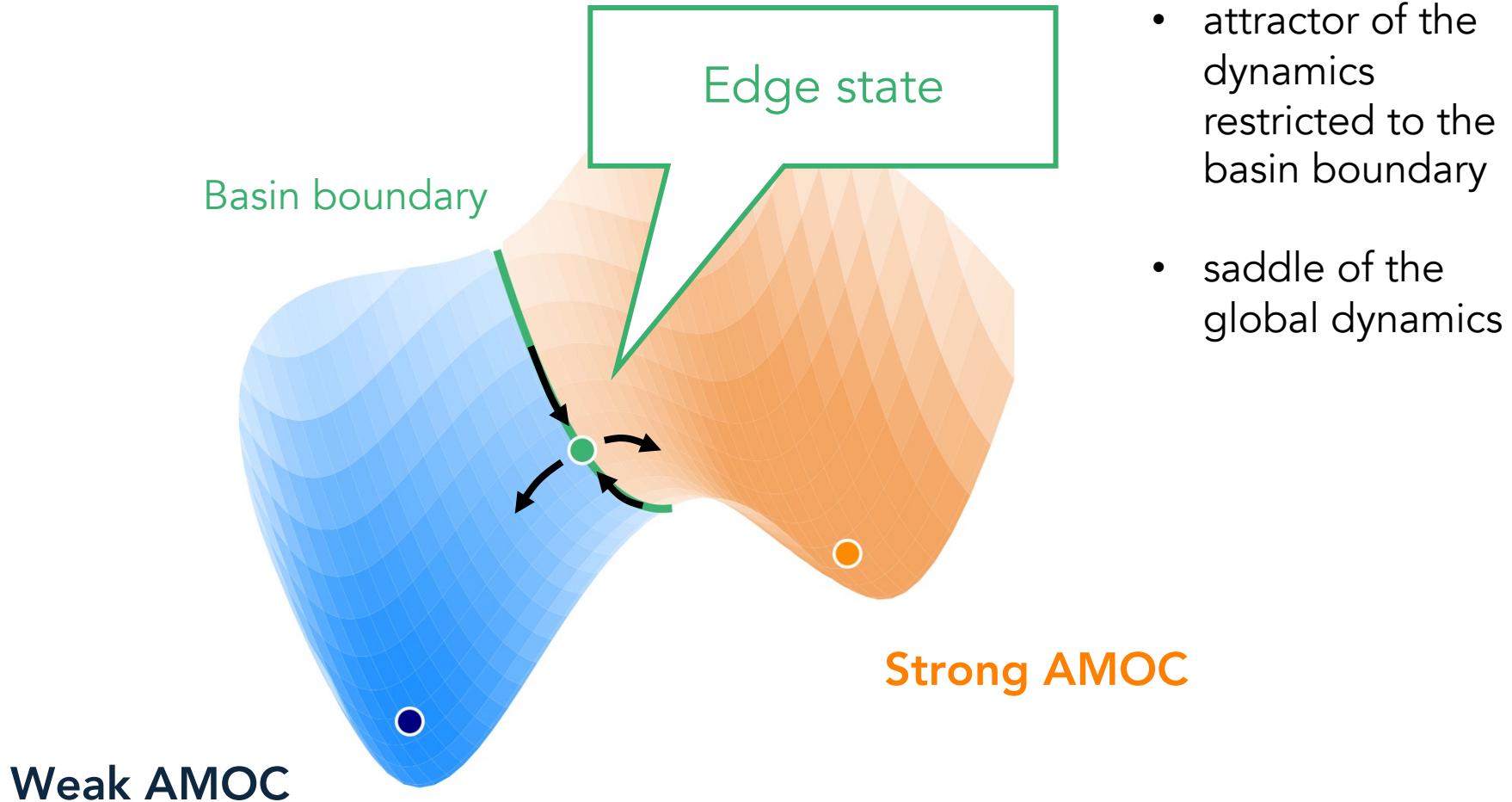
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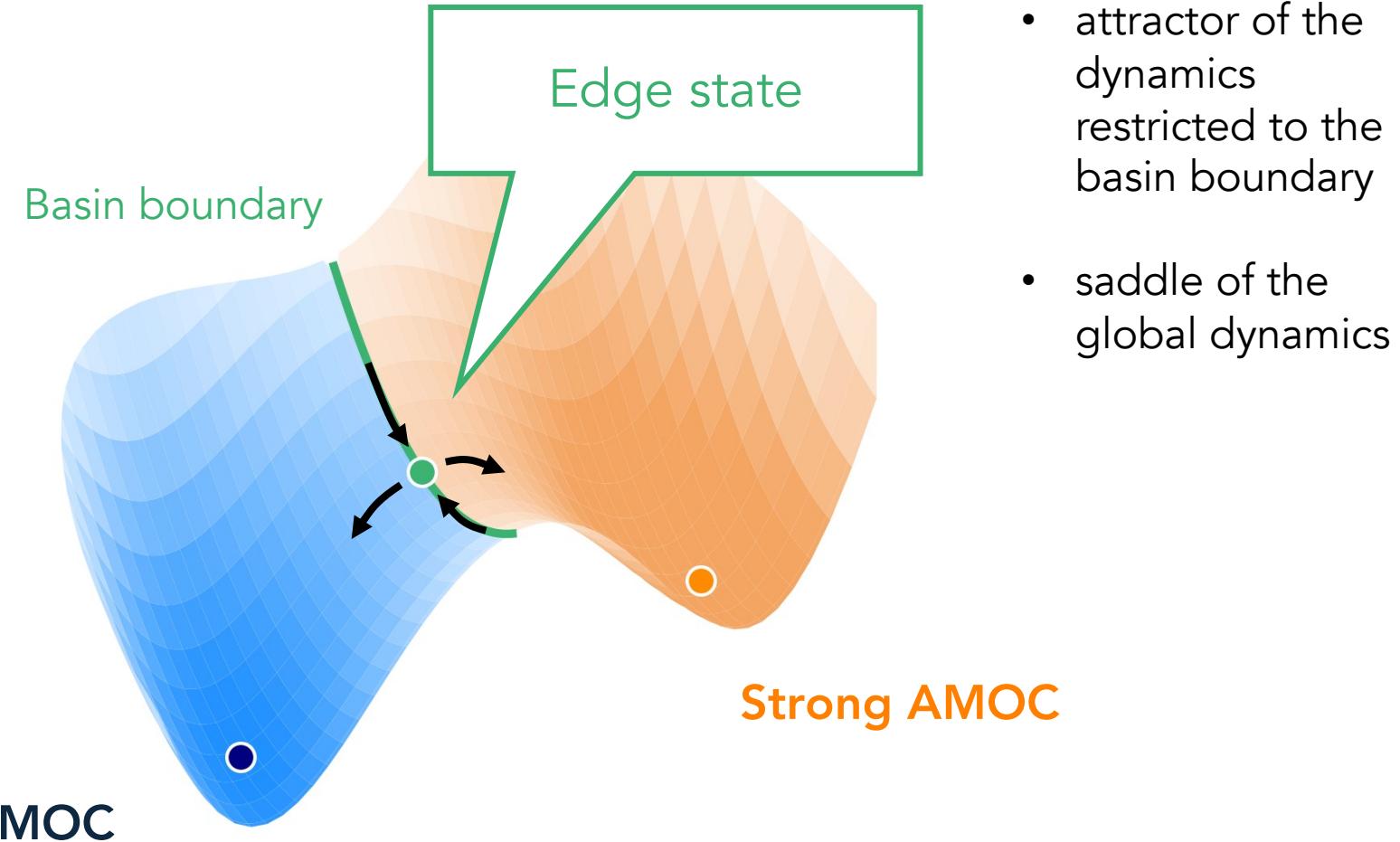


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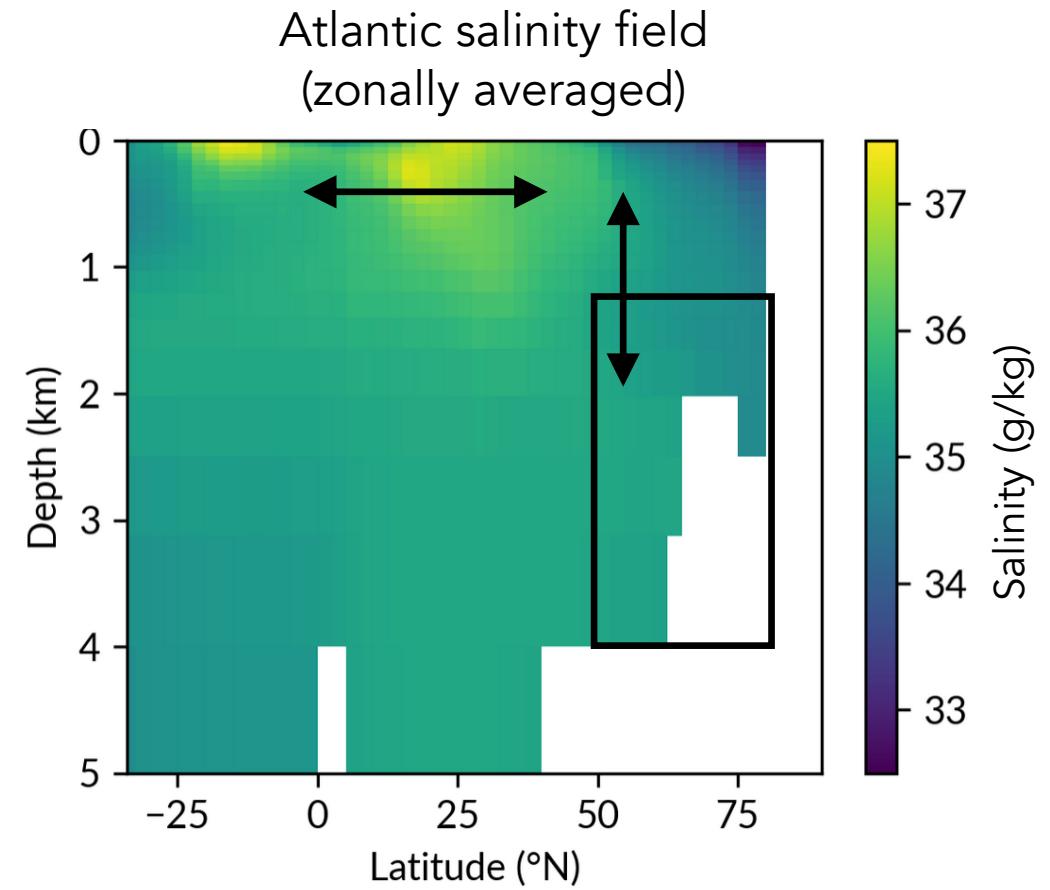


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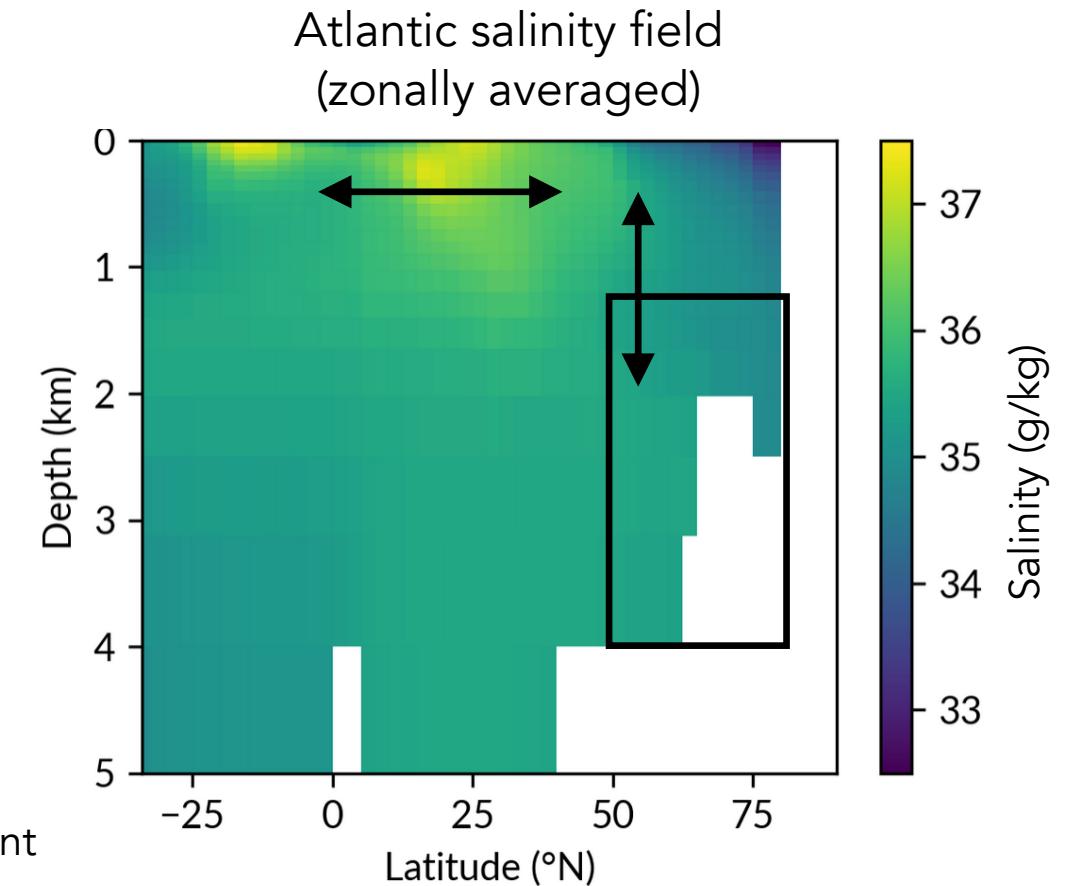
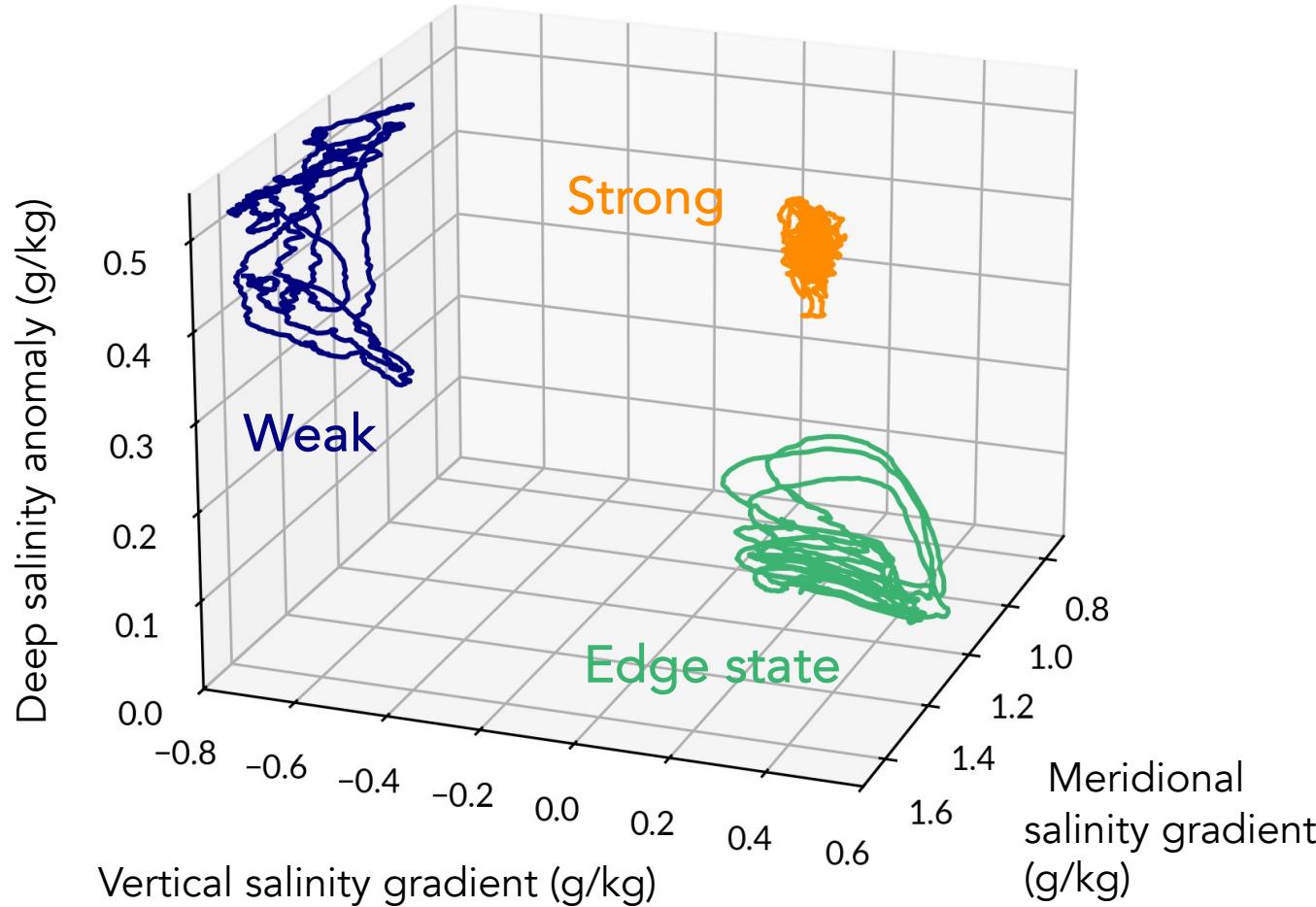
Edge tracking  
algorithm  
Battelino et al. (1988)  
Skufca et al. (2006)  
Lucarini & Bódai (2017)



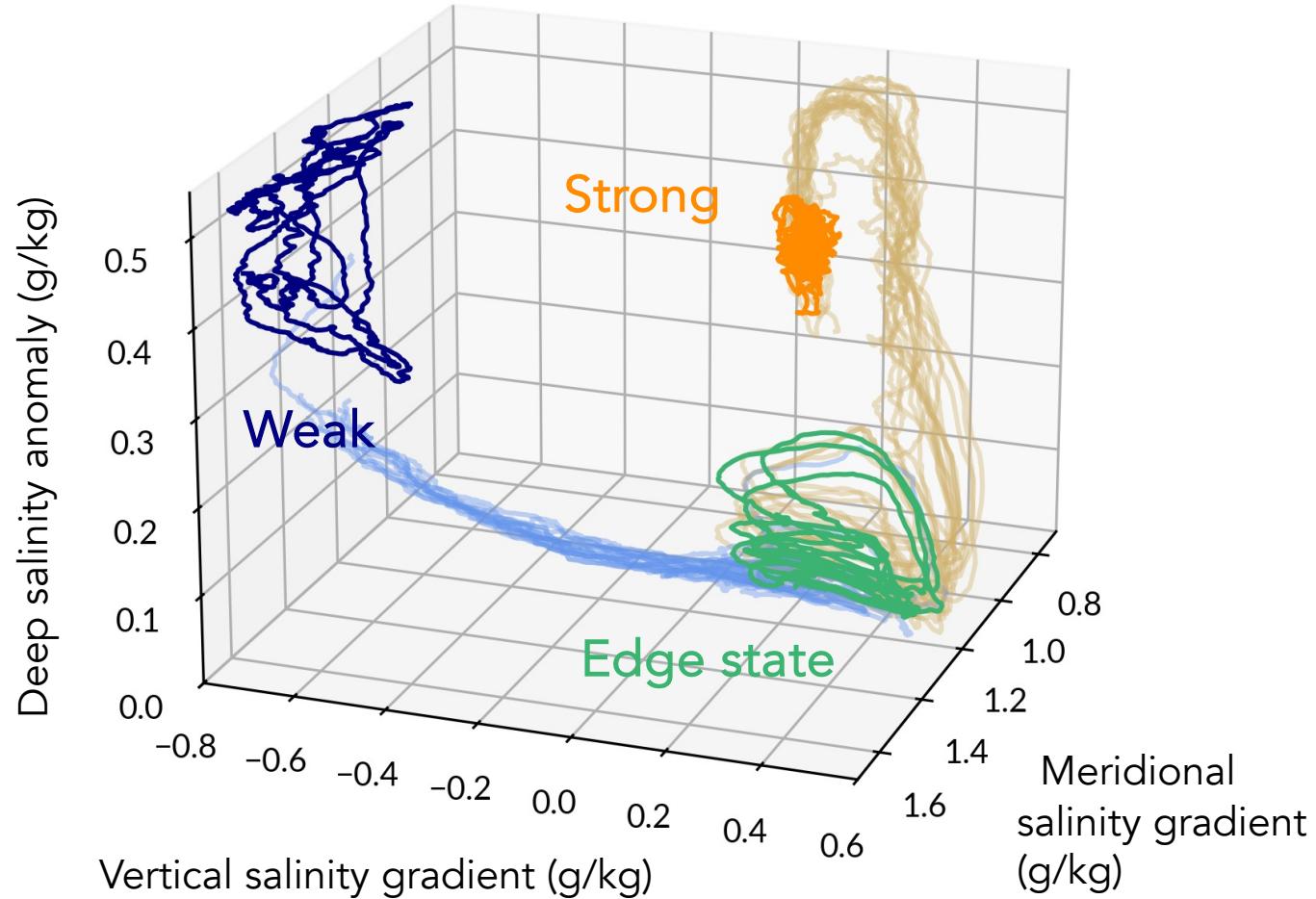
# Stability landscape in a reduced phase space



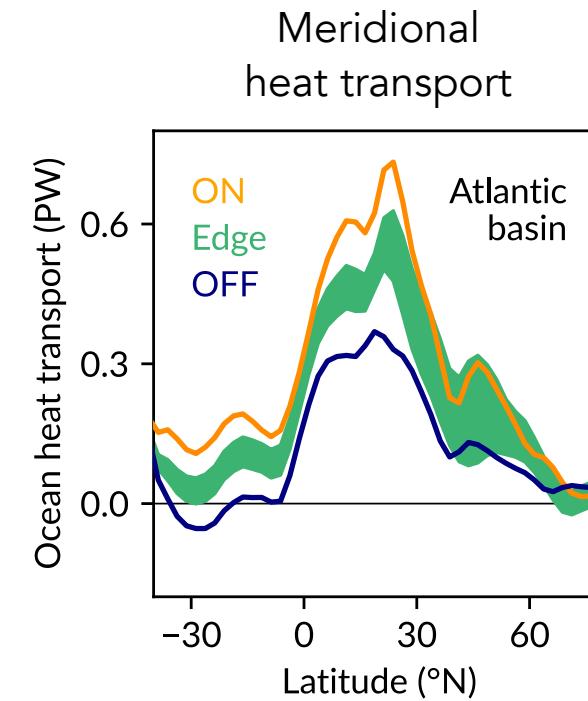
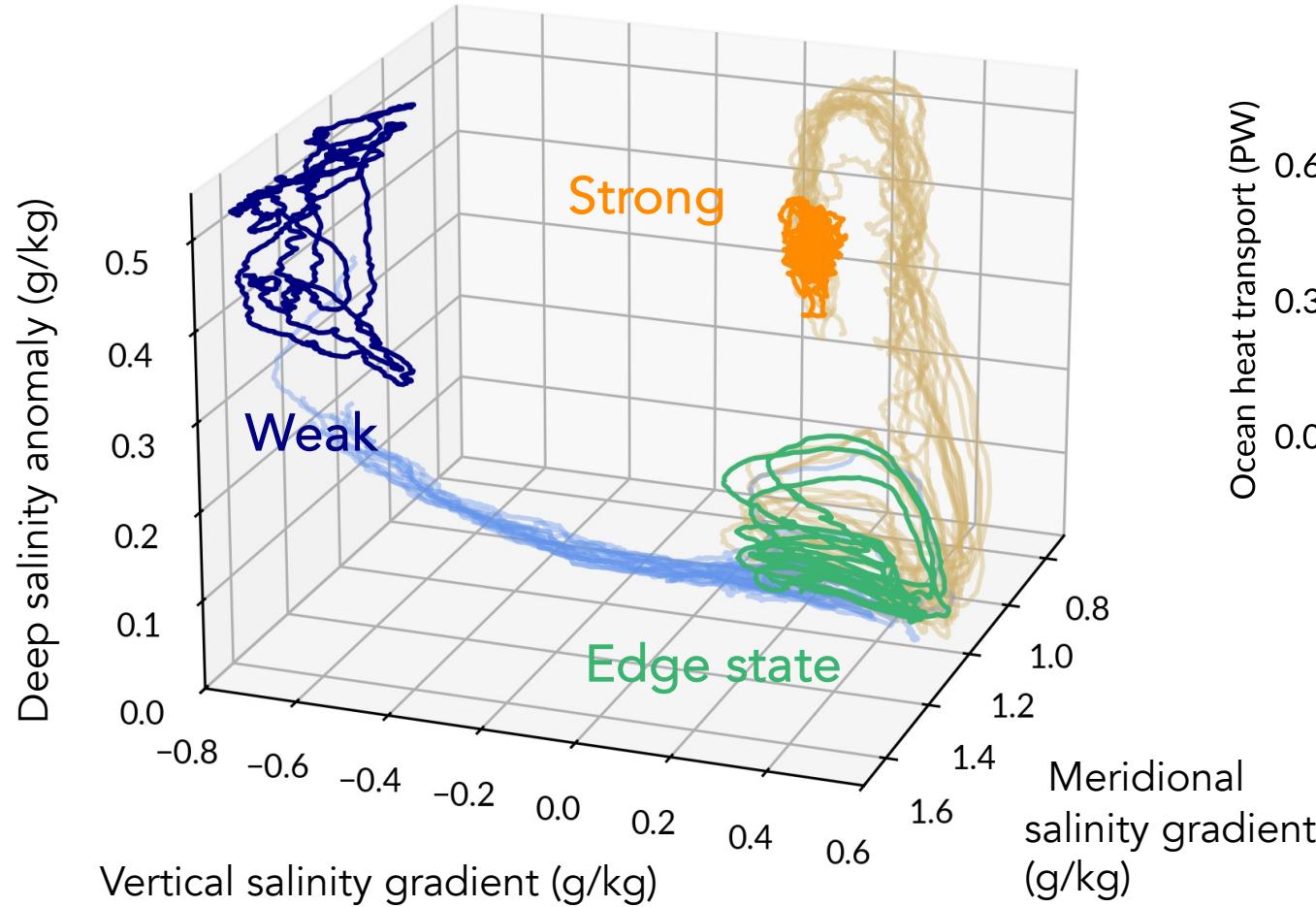
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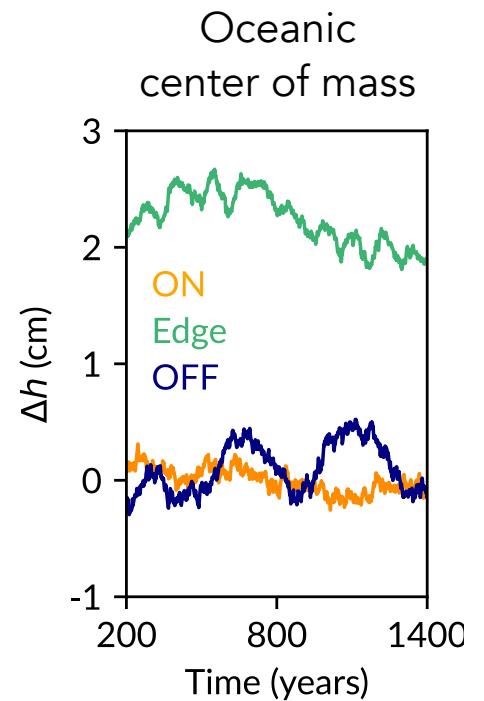
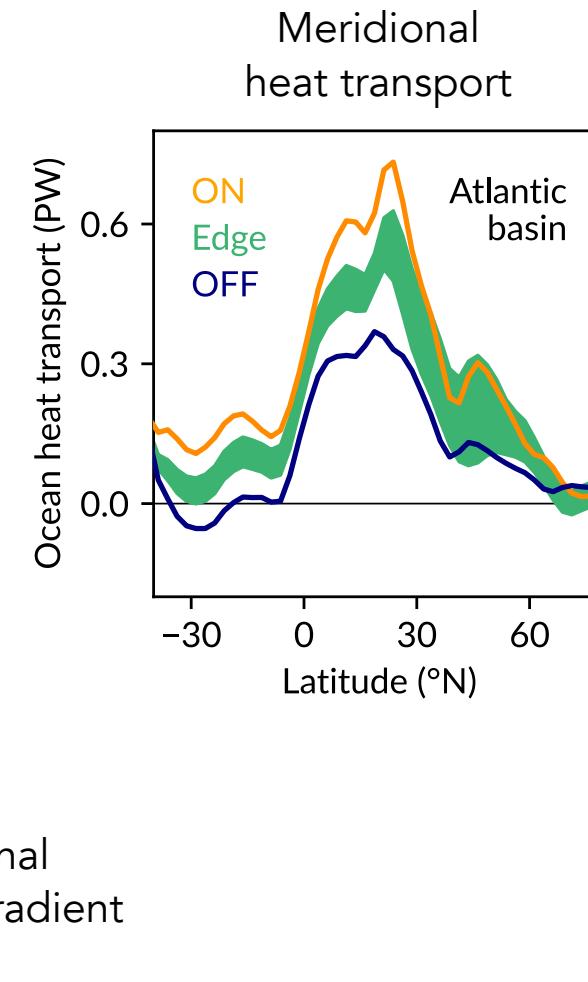
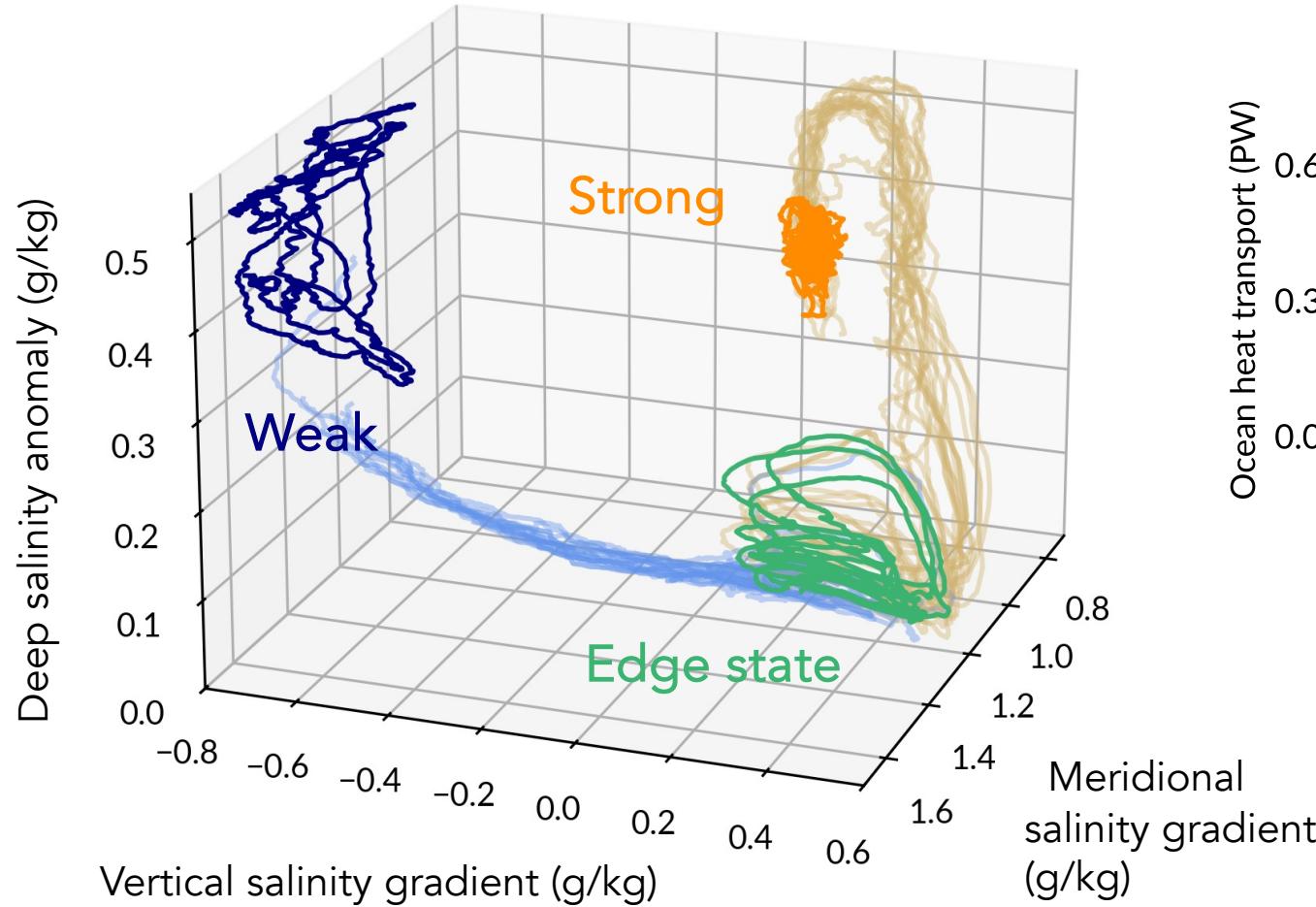
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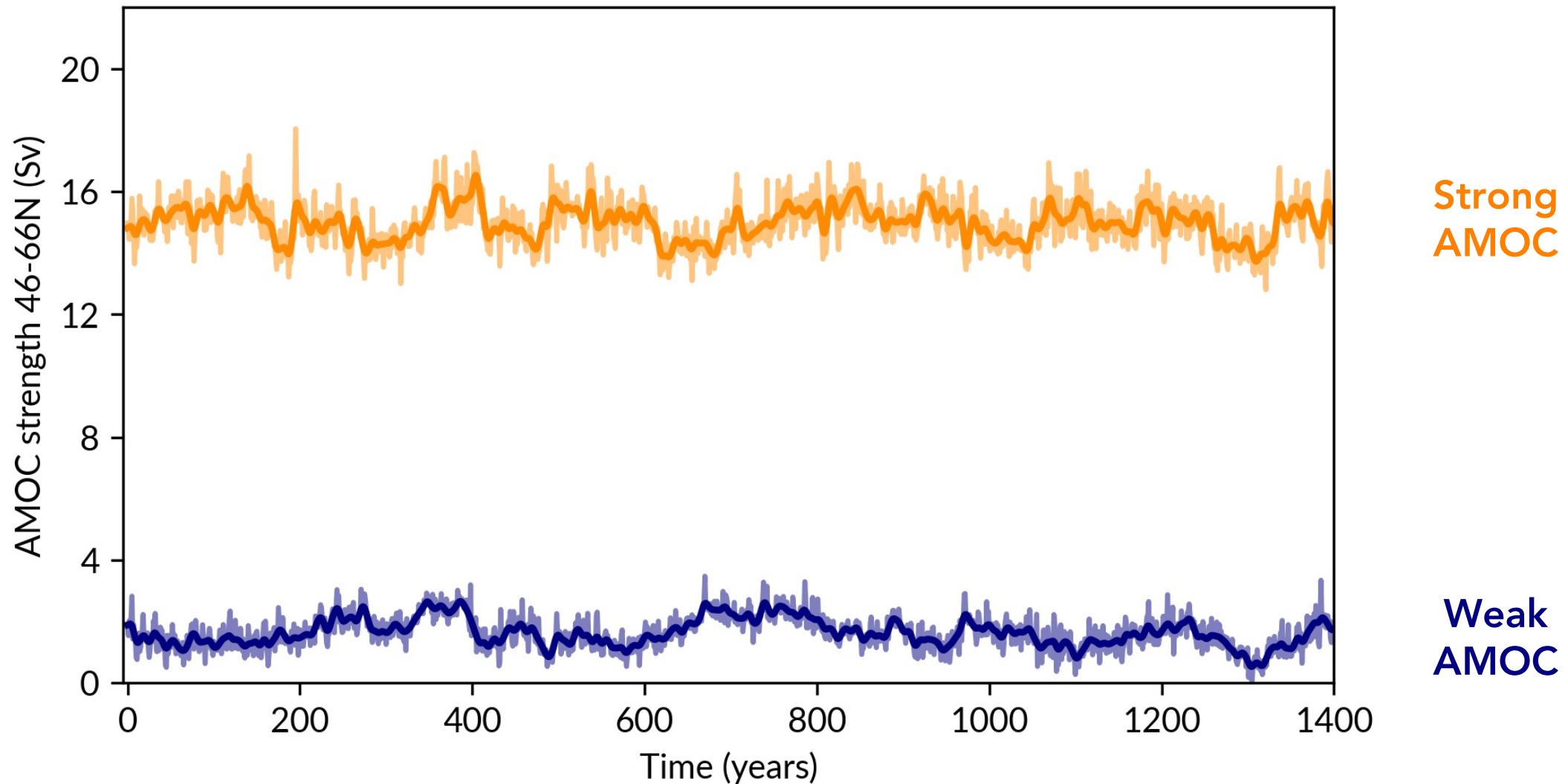
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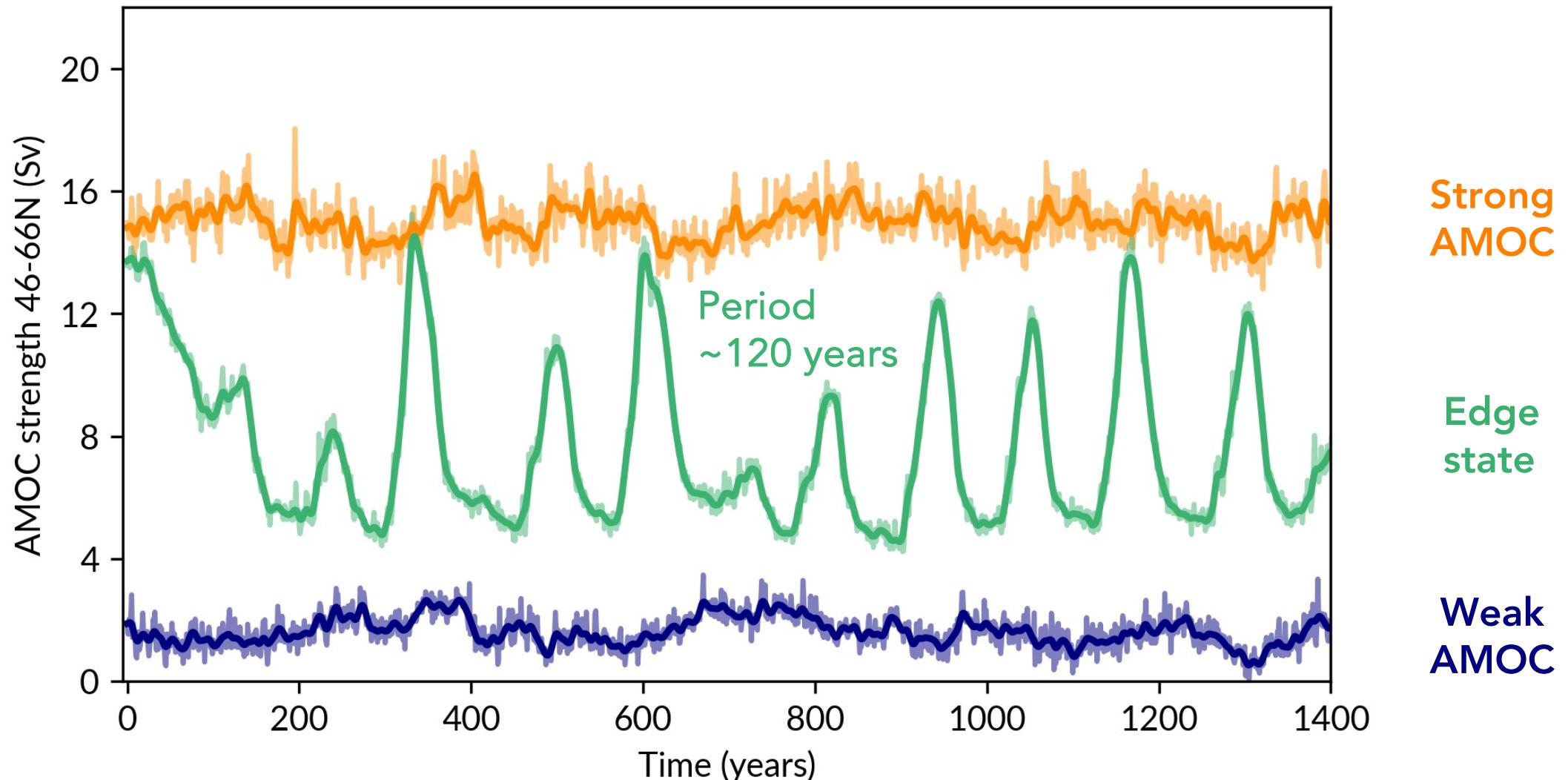
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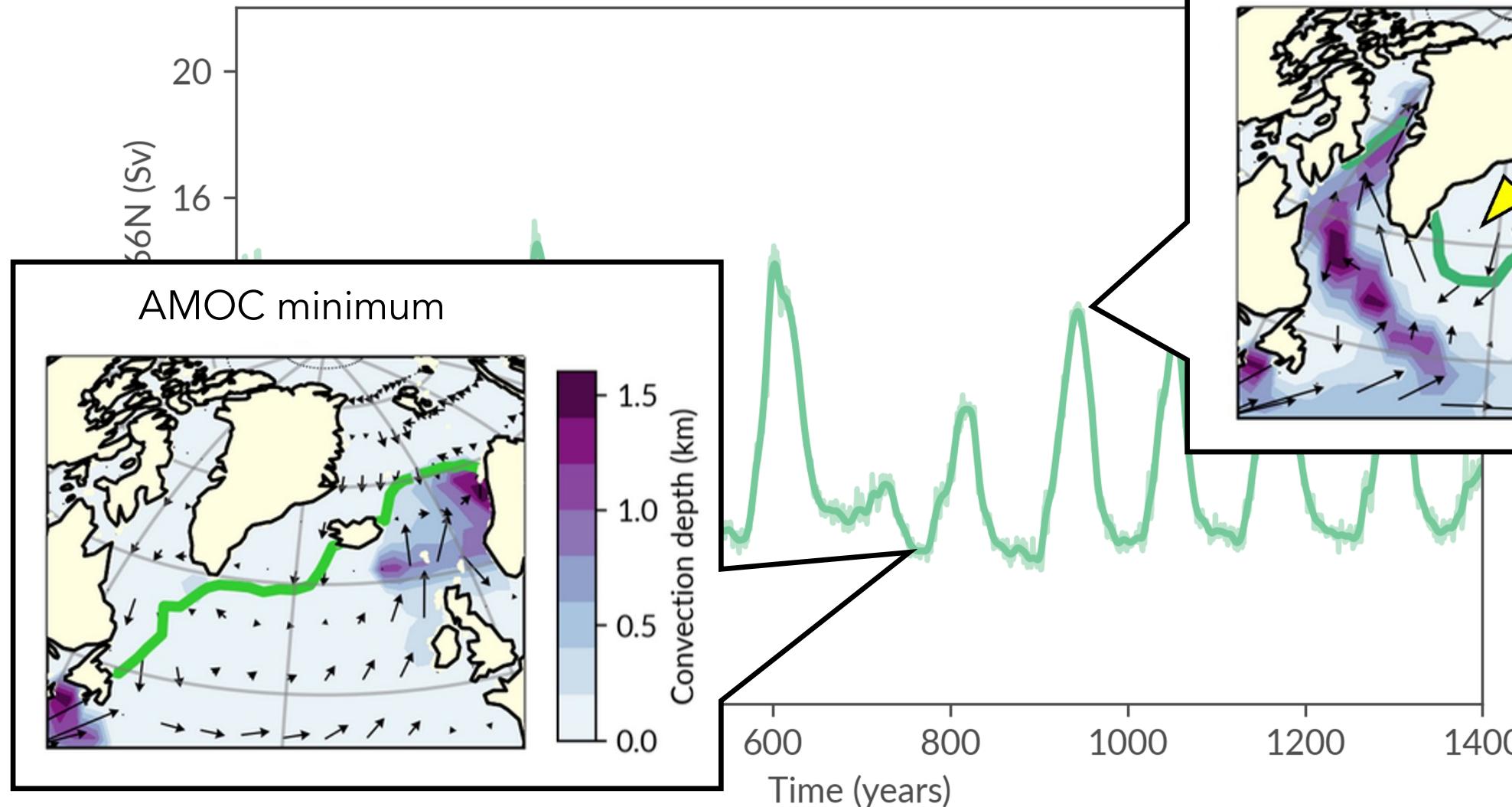
# AMOC oscillations on the edge state



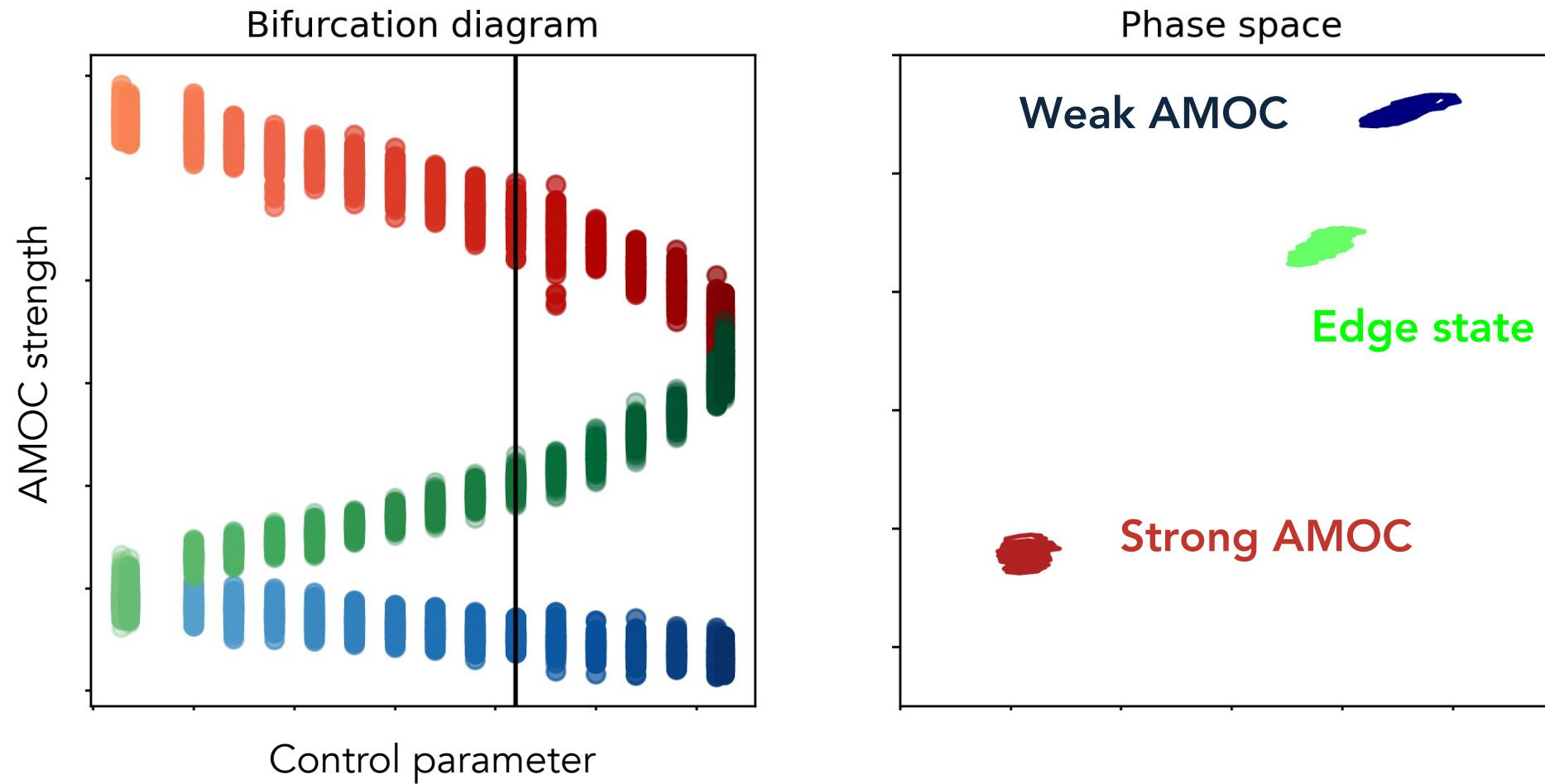
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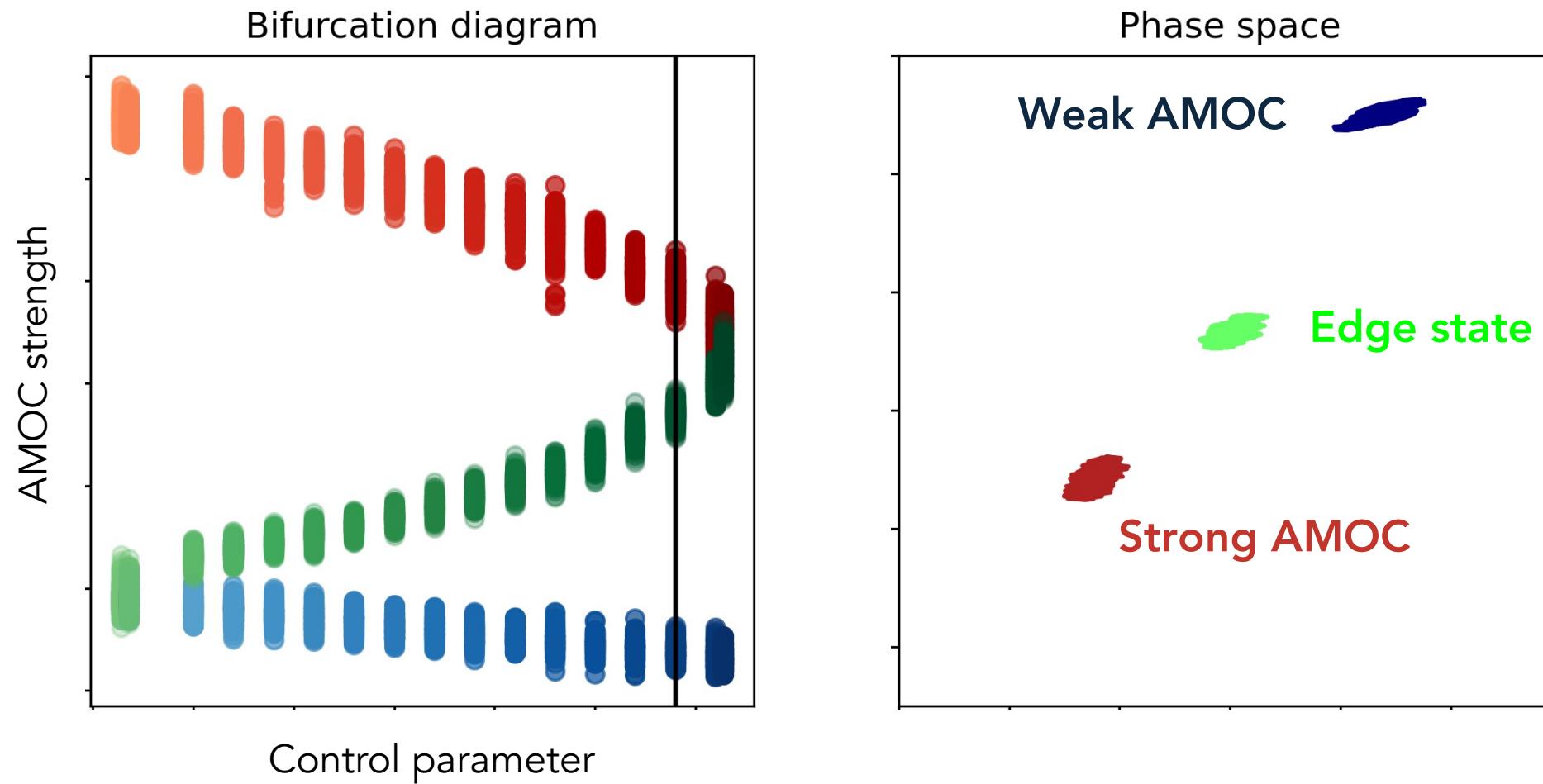
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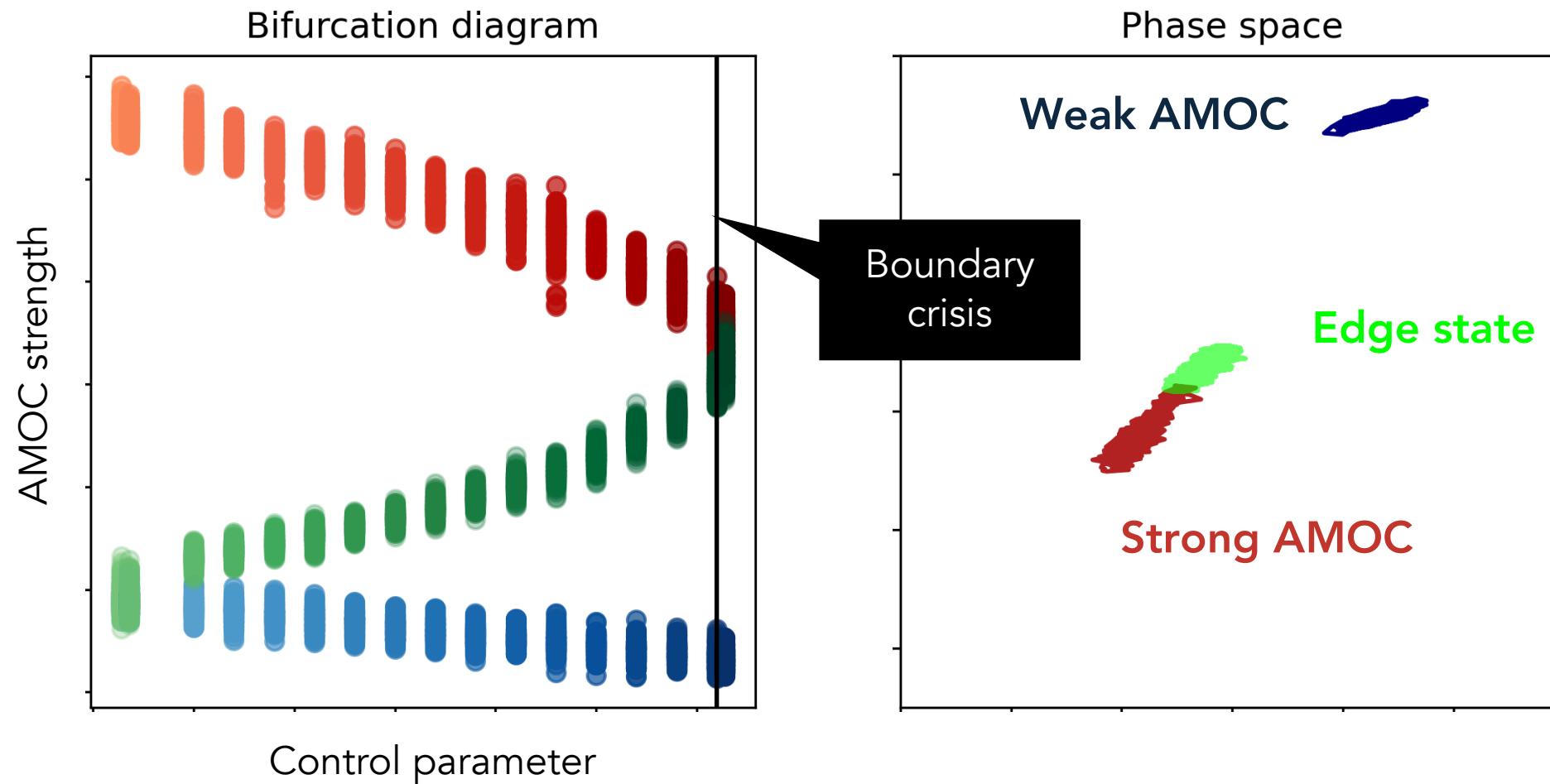
# Climate change morphs the stability landscape



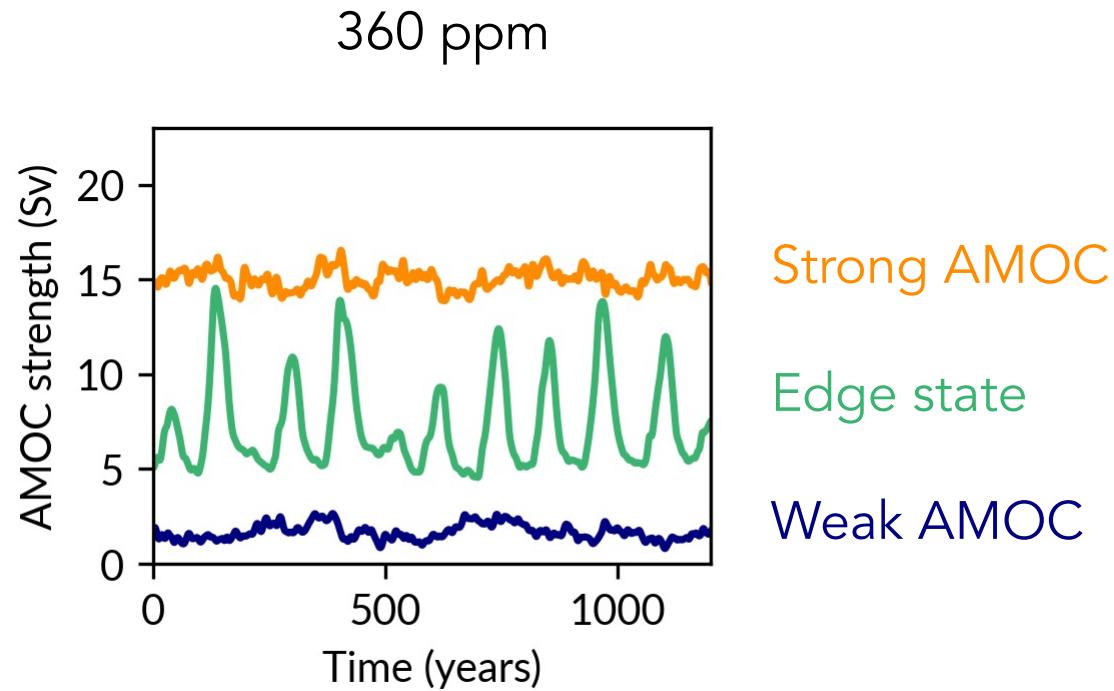
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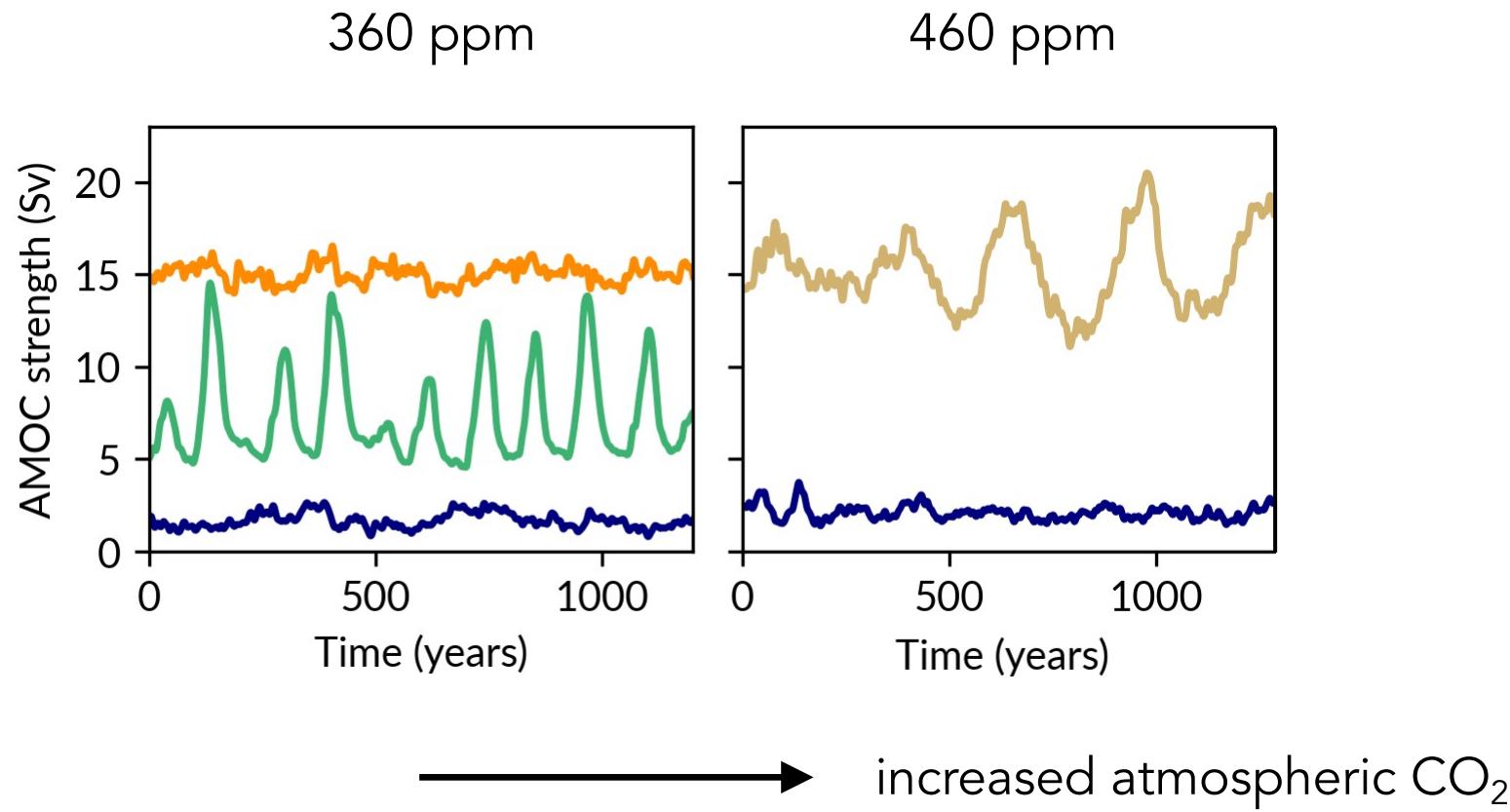
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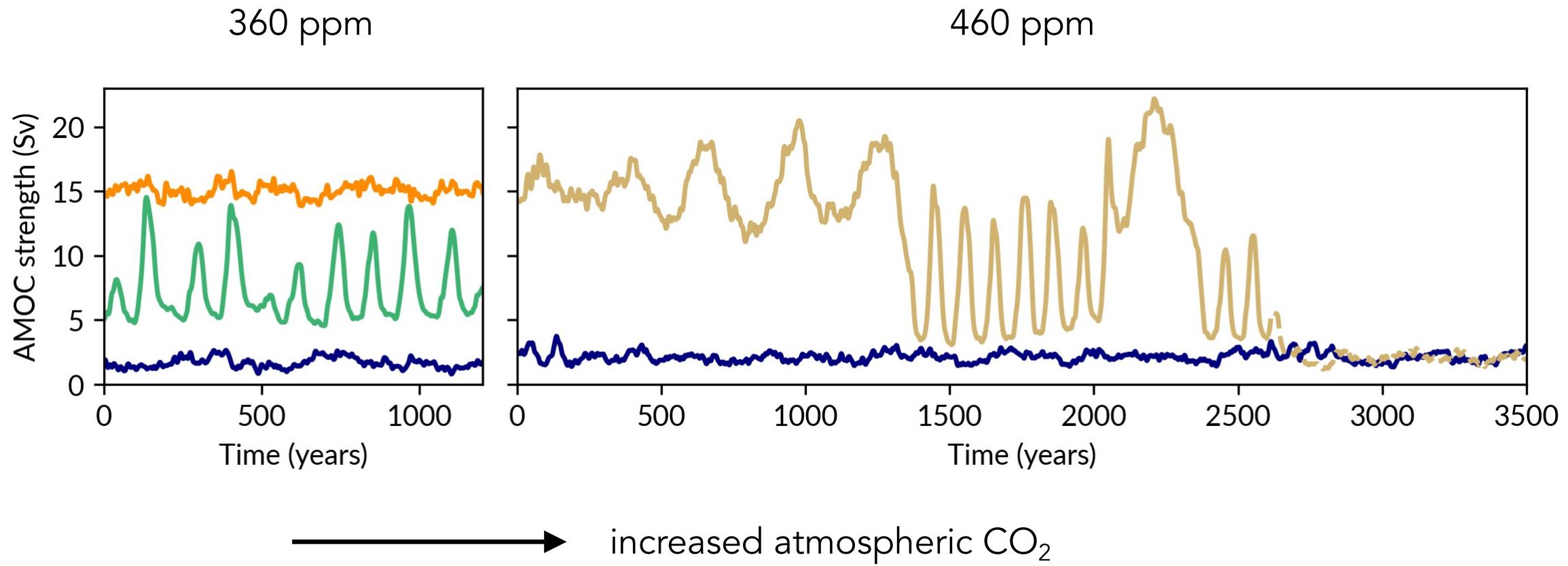
# AMOC stability landscape: from 360 to 460 ppm CO<sub>2</sub>



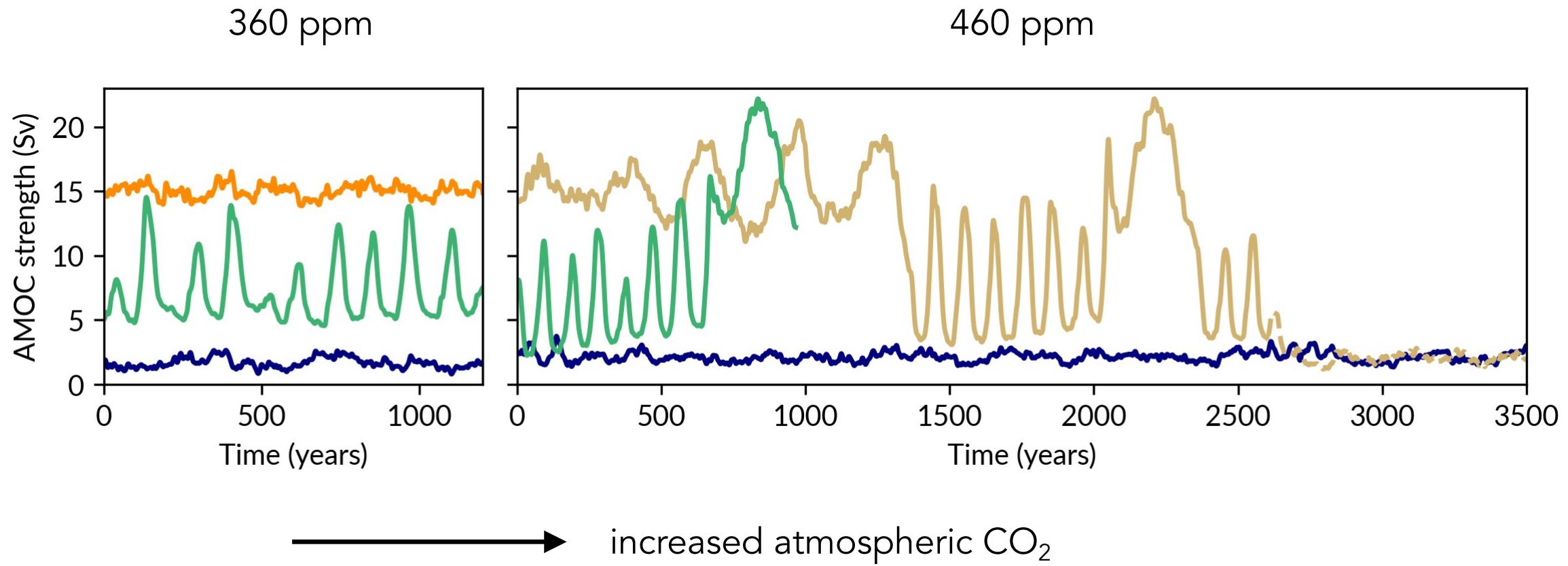
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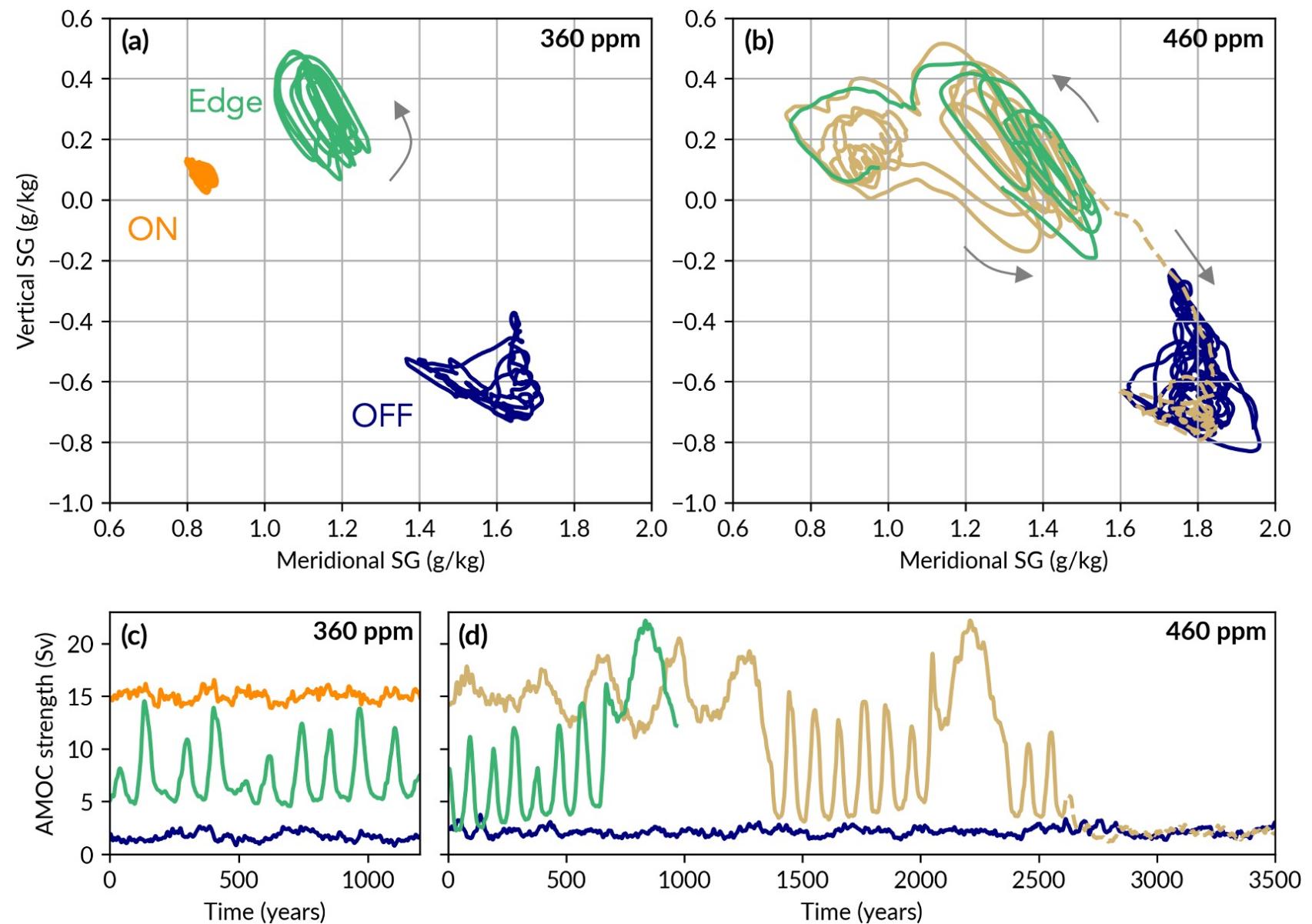
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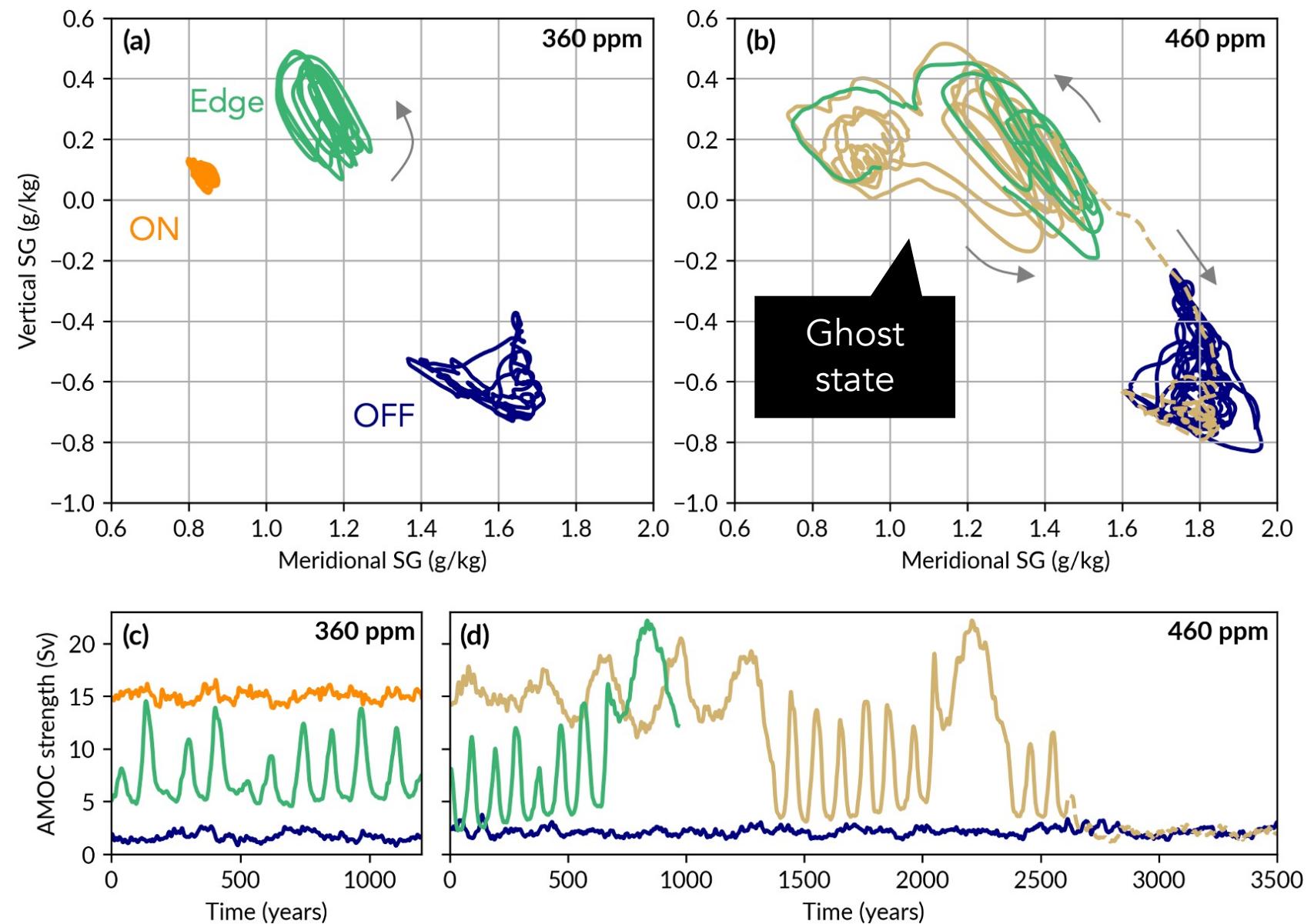
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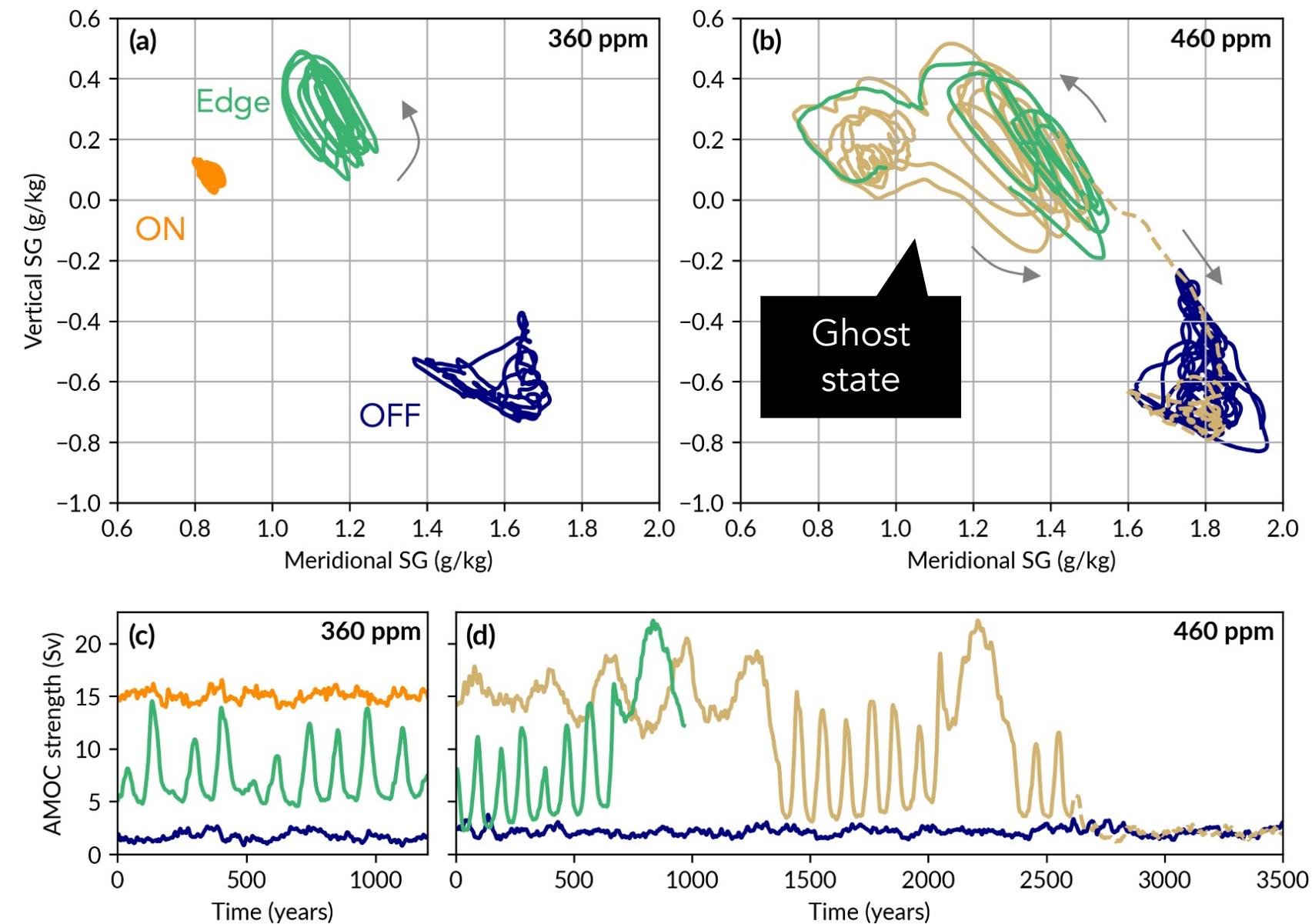
# Phase portrait as a function of CO<sub>2</sub>



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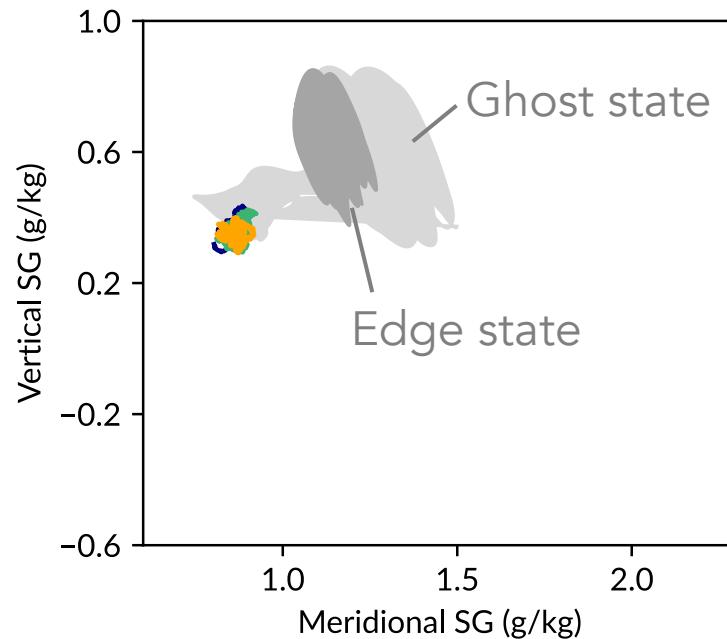
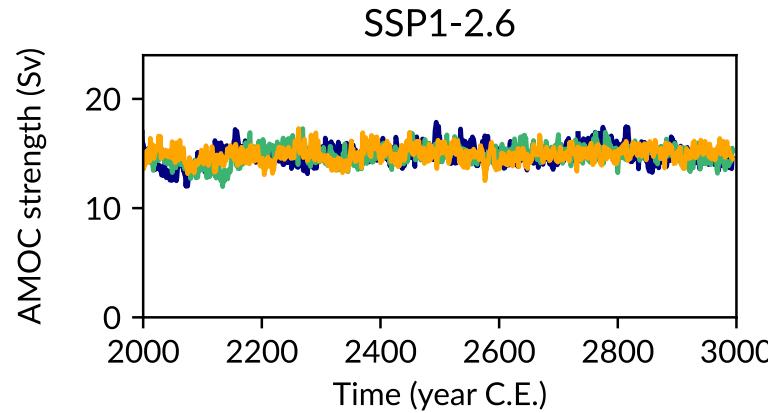


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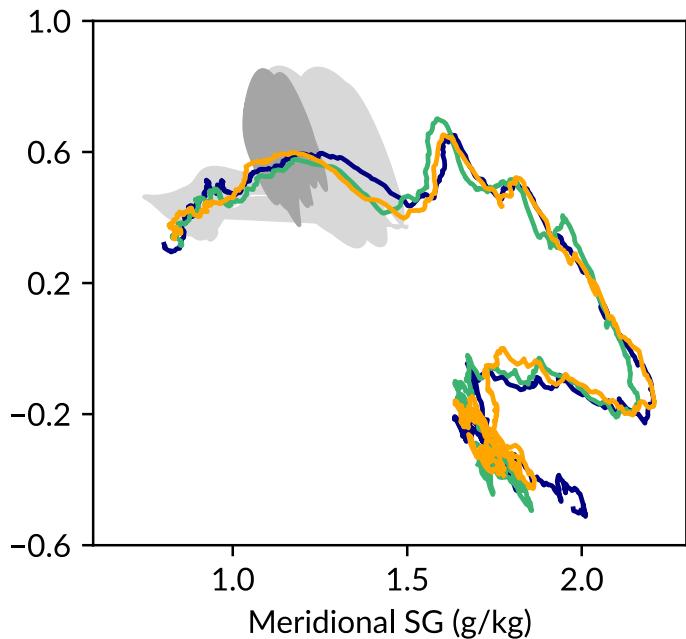
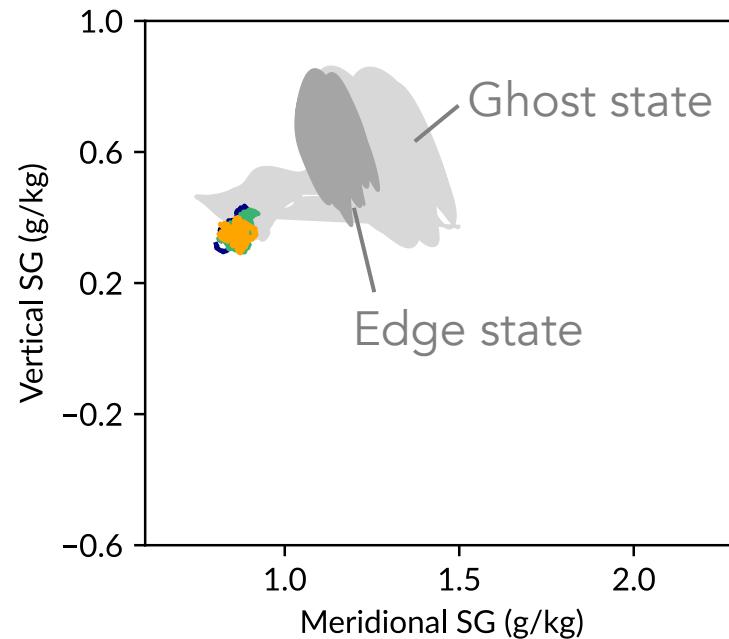
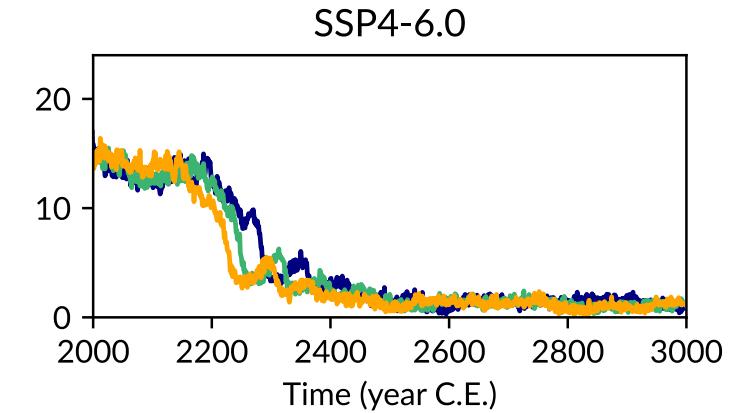
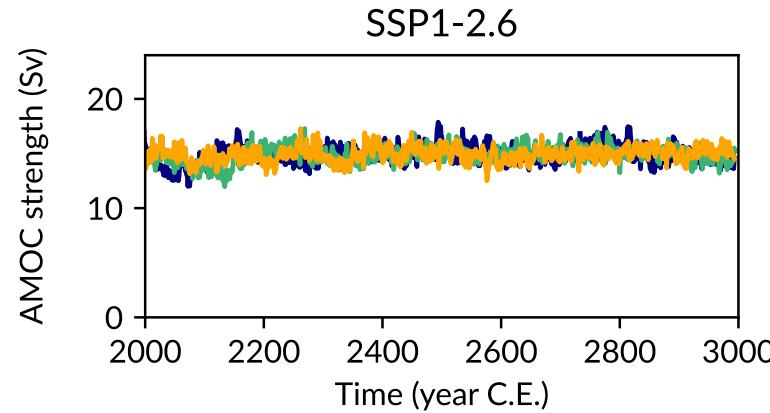


Conclusion:  
**Boundary crisis** has  
occurred just before  
460 ppm

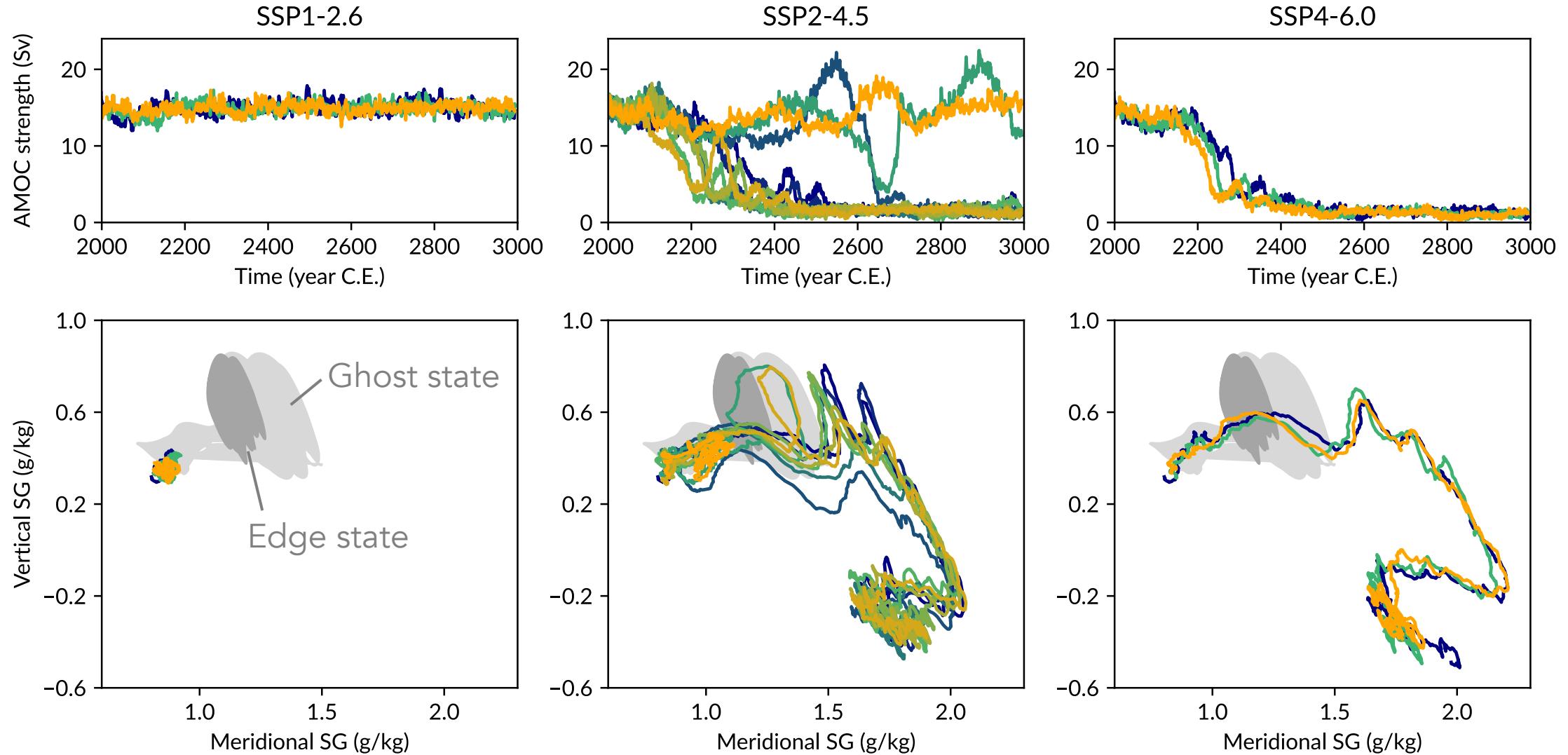
# Trajectories under future climate change: PlaSim-LSG



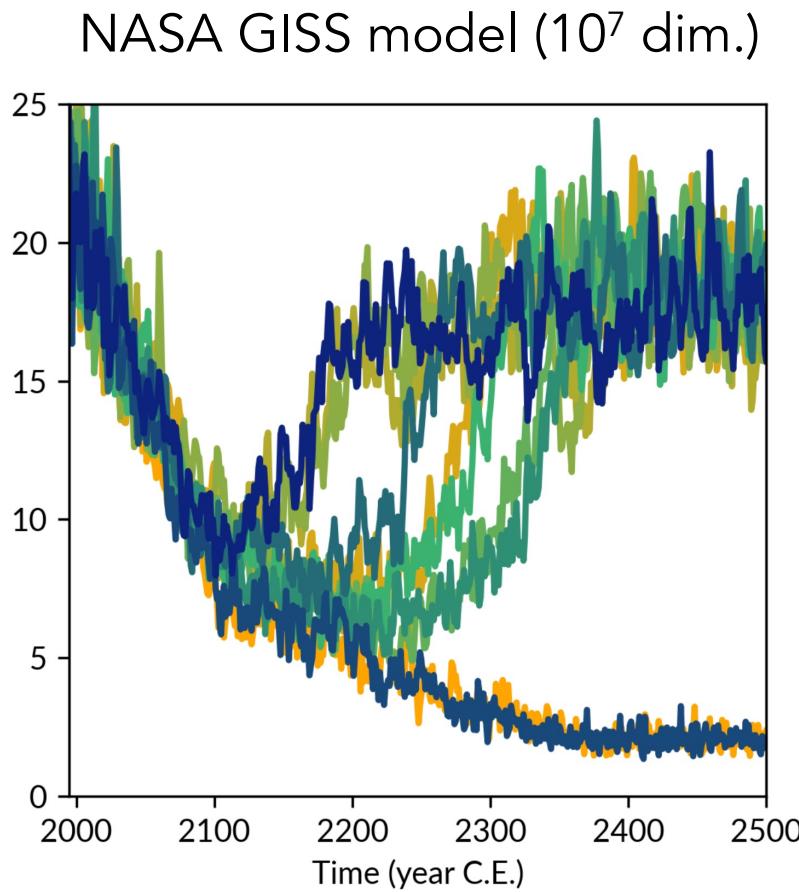
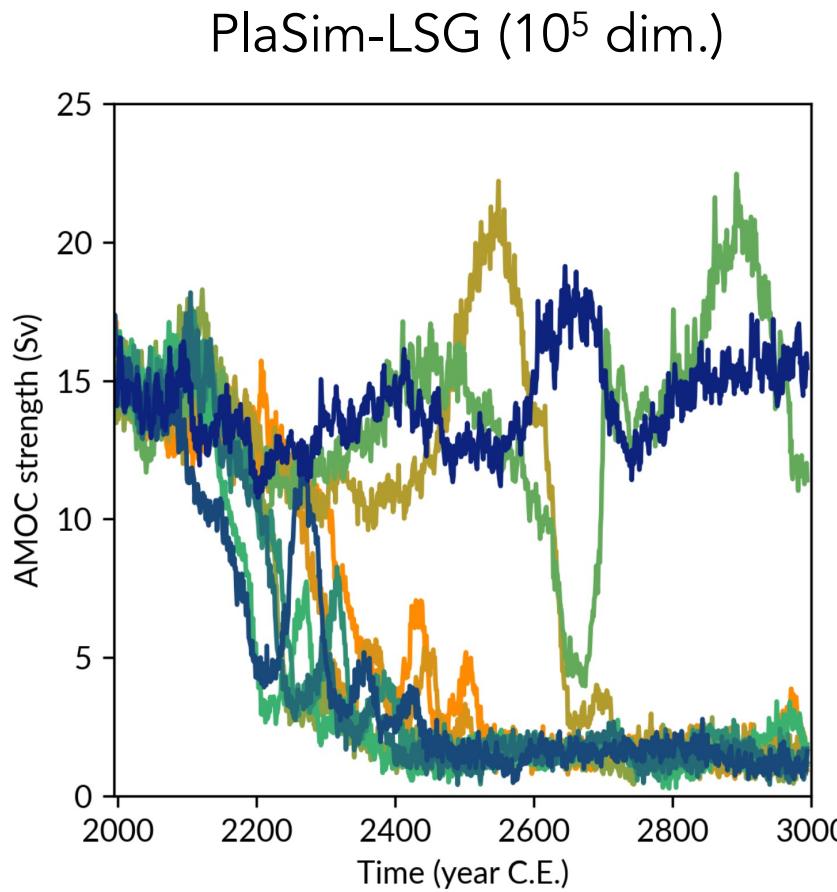
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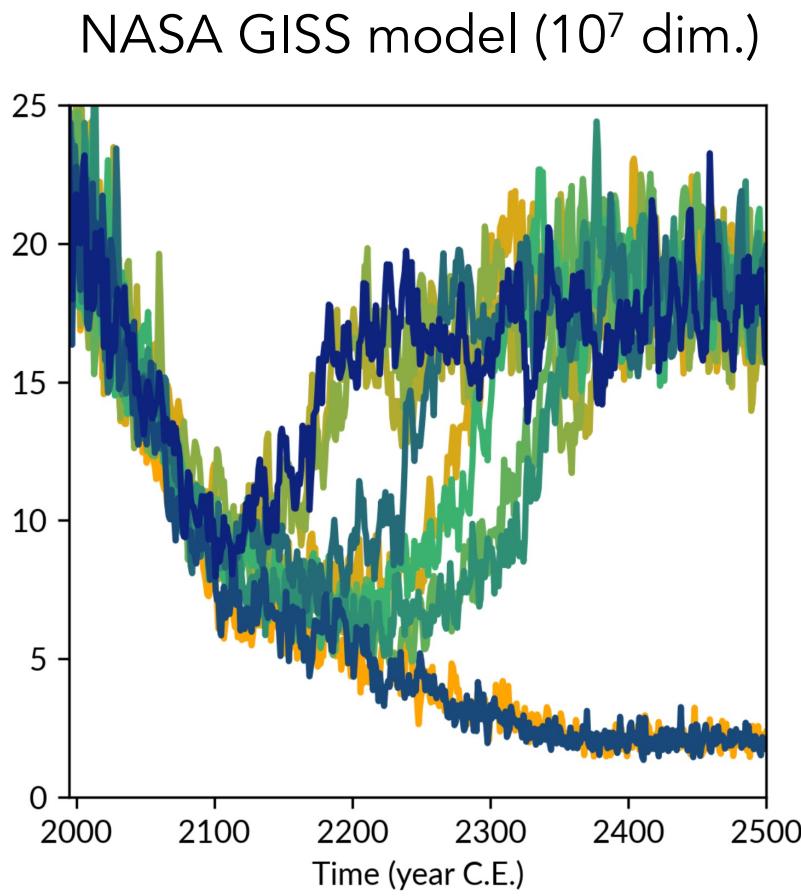
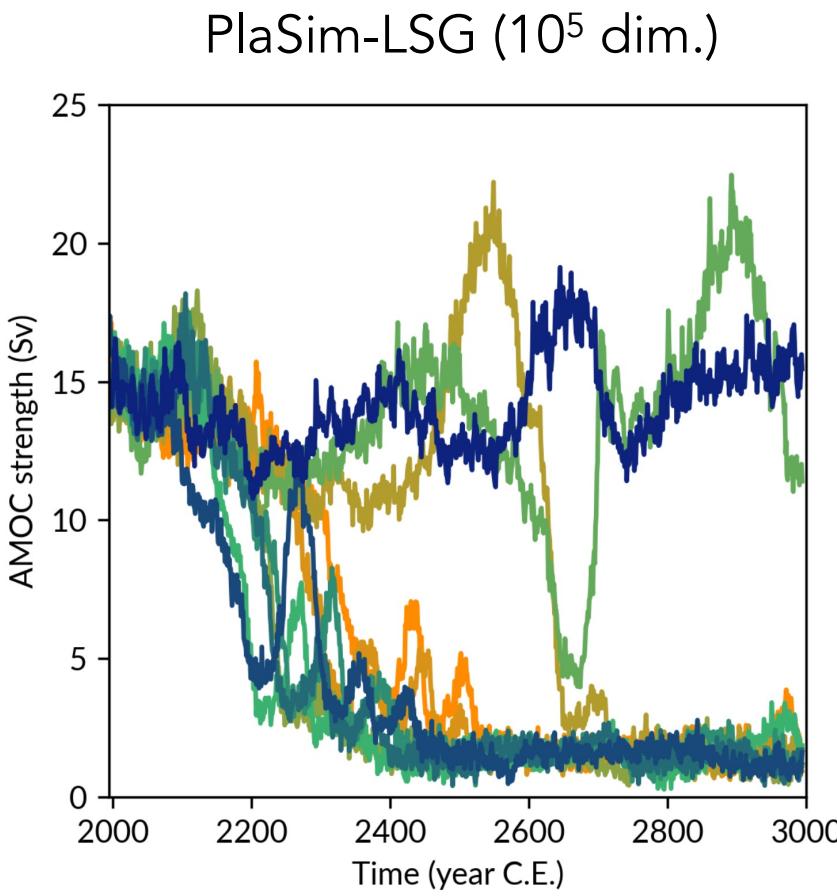


# Ensemble splitting also occurs in CMIP6

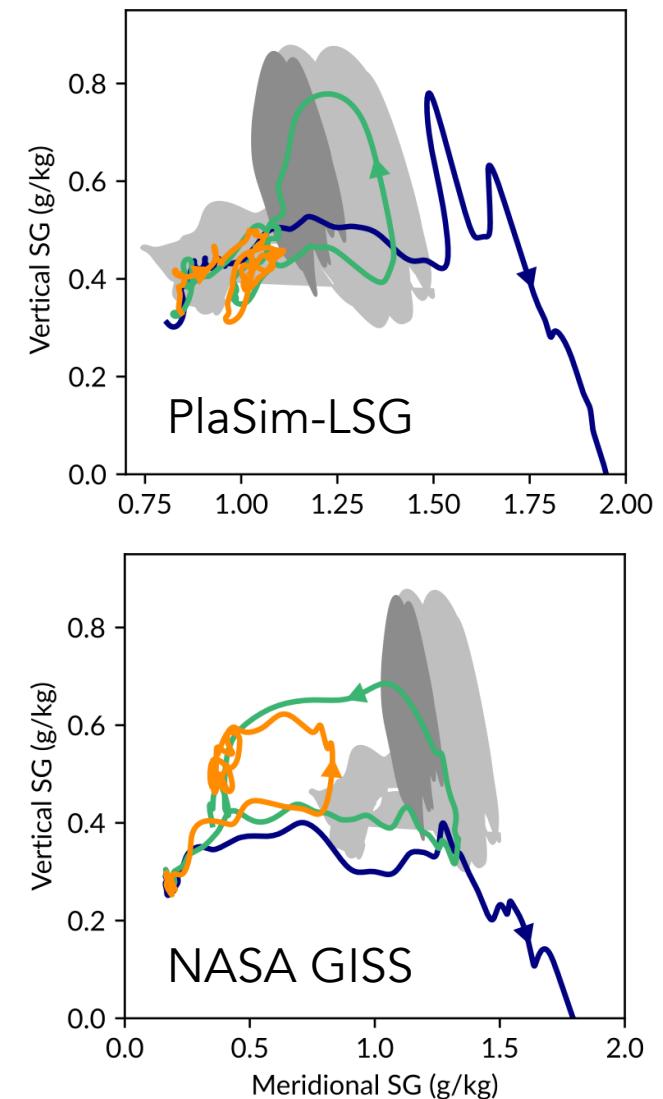


Romanou et al. (2023)

# Ensemble splitting also occurs in CMIP6



Romanou et al. (2023)



- **Boundary crisis of the AMOC** with respect to CO<sub>2</sub> demonstrated in an intermediate-complexity climate model
- The dynamics of an **AMOC edge state** mediate **long transients** and **ensemble splitting** under intermediate nonautonomous forcing scenarios



Work with Valerio Lucarini, Oliver Mehling, Jost v. Hardenberg

arXiv:2504.20002



Thank you!