Mapping the safe operating space of marine ecosystems under contrasting emission pathways

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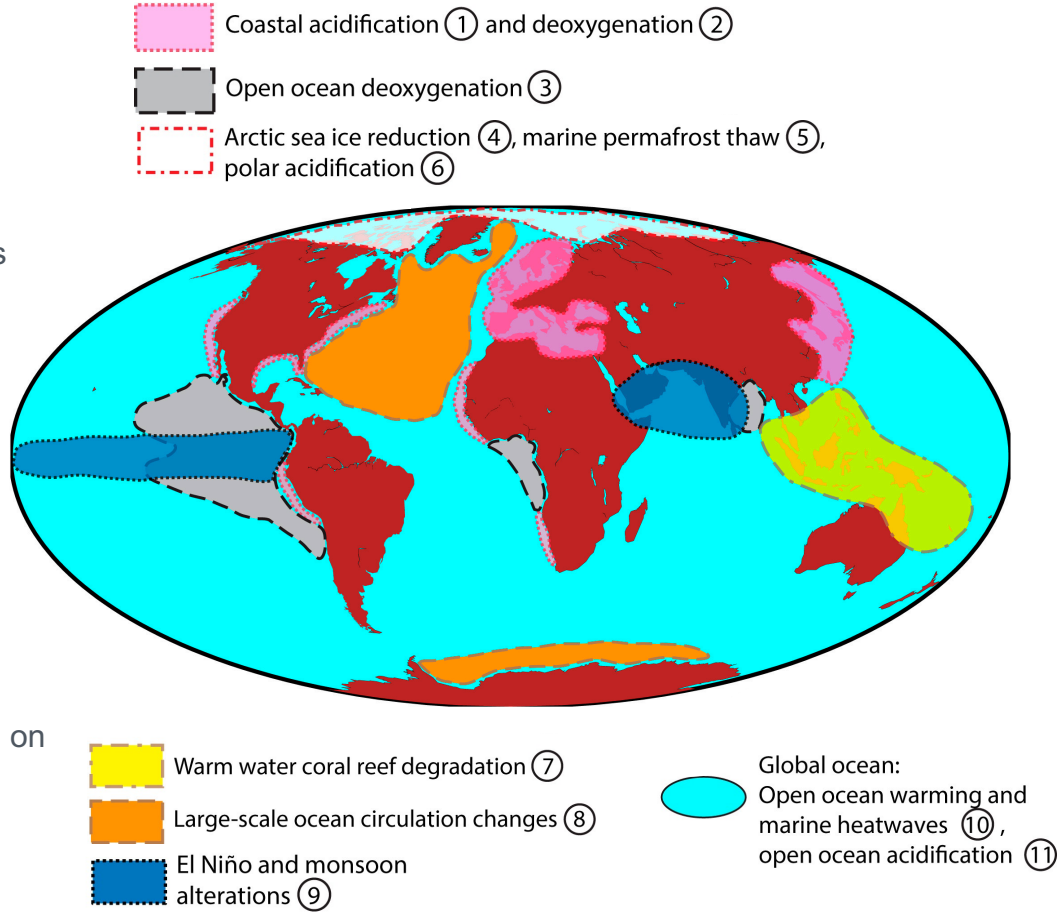
The need for a safe operating space for the Ocean

Slow onset events, extreme events, tipping point risks

- What are the best metrics to describe large scale changes?
- From which levels are they damaging marine ecosystems?
- How robust are our modelling tools in projecting exceedance of these thresholds?
- What is the likelihood of triggering them depending on climate scenarios?



Heinze et al. (2021)

Impact metrics and mitigation targets

Table 1 | Target variables and limits

Target variable (annual mean)		Target set number				Units
		1	2	3	4	
ΔSAT	Global mean SAT increase since 1800	1.5	2	3	4	°C
SSLR	Steric sea level rise since 1800	20	40	60	80	cm
A_{SO}	Aragonite undersaturation of Southern Ocean surface	5	10	25	50	Percentage of area south of 50 °S
$A_{\Omega>3}$	Global loss of surface waters with $\Omega_{arag}>3$	60	75	90	100	Percentage of area in 1800
$C_{NPP>10\%}$	Cropland area with NPP losses >10%	5	10	20	30	Percentage of crop area in 2005
$C_{carbon\ loss}$	Global soil carbon loss on croplands	5	10	20	30	Percentage of soil carbon in 2005

Steinacher et al. (2013)

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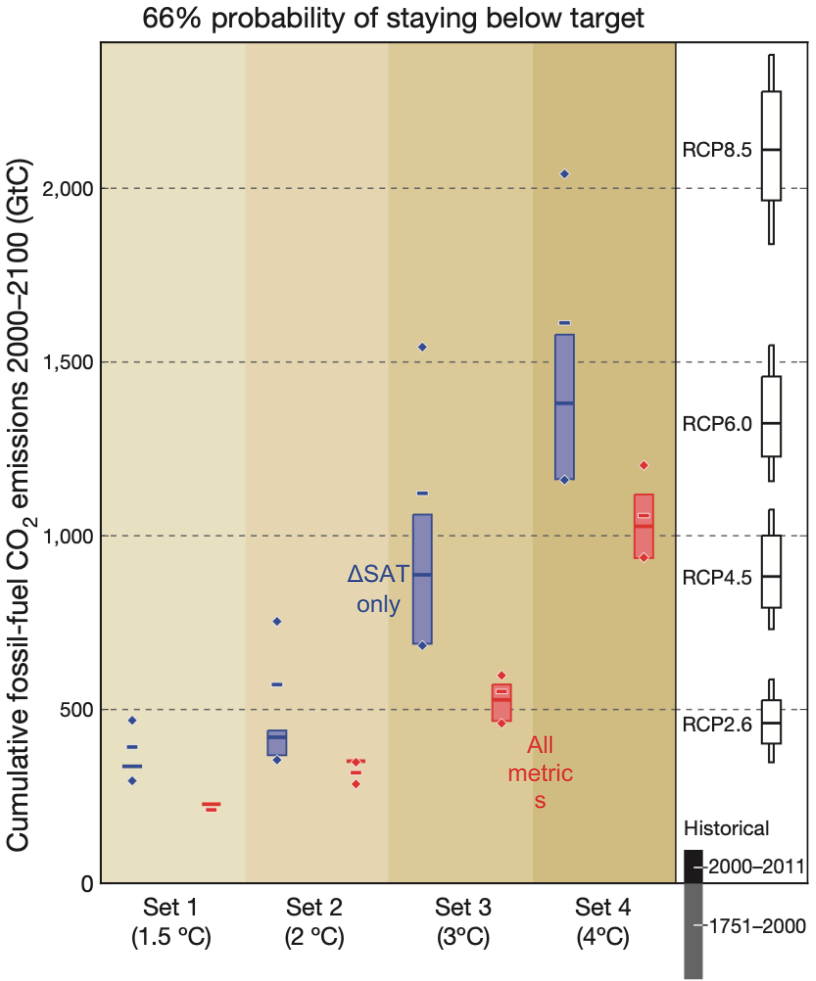
The assessment of multiple metrics is needed



Steinacher et al. (2013)

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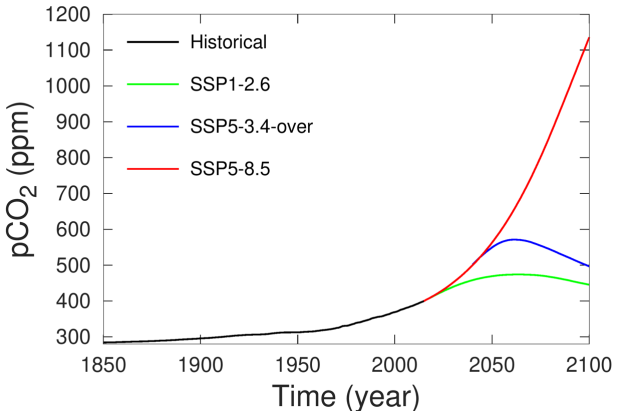
15 impact metrics associated to 4 mitigation limits

- Global warming
- Marine heatwaves duration
- Steric sea level rise
- Arctic summer sea ice extent
- Strength of Atlantic meridional overturning circulation
- Ocean acidification (Ω_{arag})
- Ocean deoxygenation
- Ocean net primary production
- Plankton biomass
- Fish metabolic index
- Particulate organic export

9 Earth system models

- ACCESS-ESM1-5
- CanESM5
- CESM2-WACCM
- CMCC-ESM2
- CNRM-ESM2-1
- IPSL-CM6A-LR
- MIROC-ES2L
- NorESM2-LM
- UKESM1-0-LL

3 emissions scenarios



Bourgeois et al. (in review)

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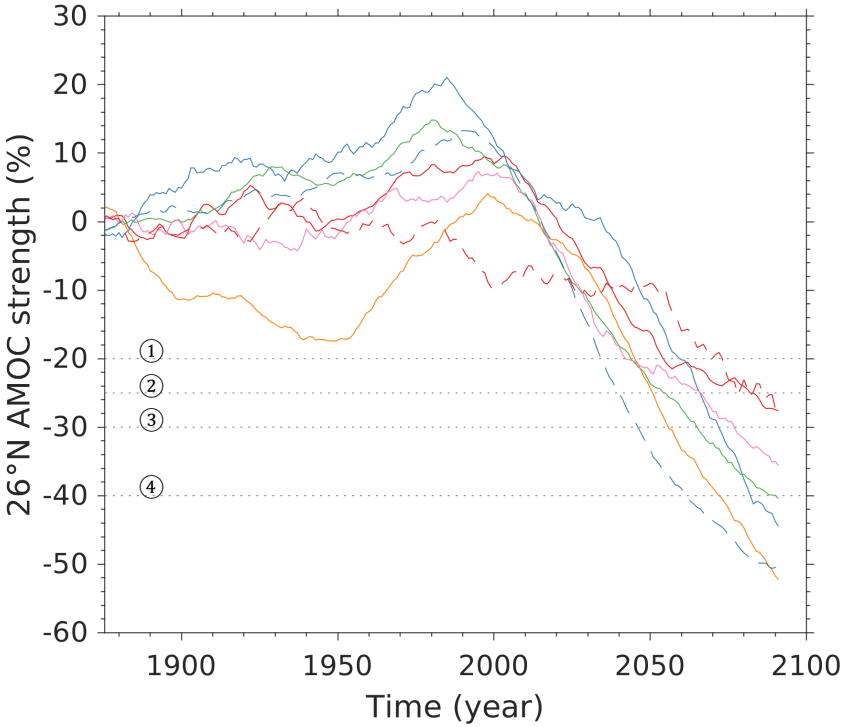
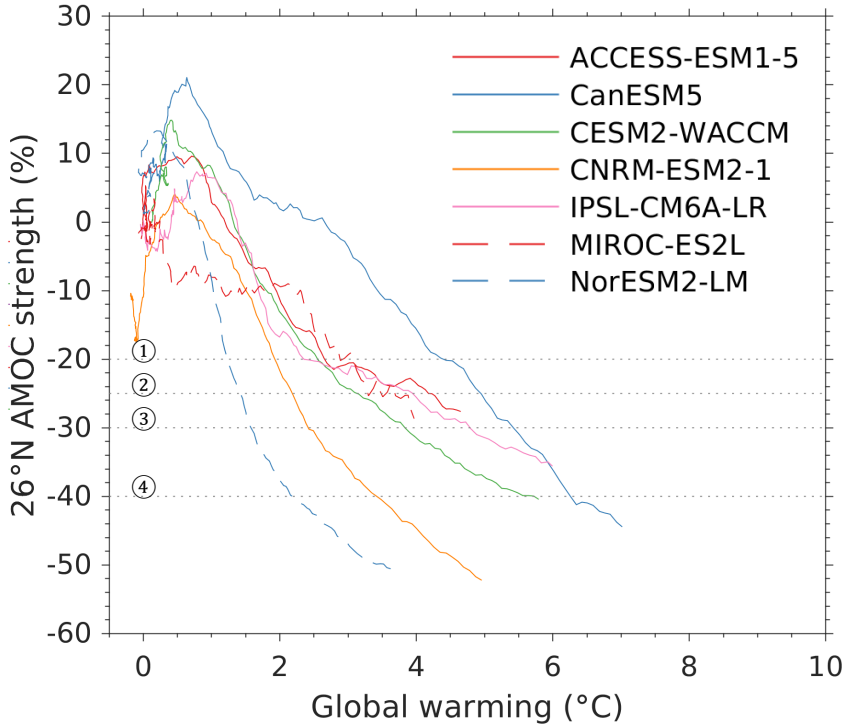
Identifying exceedances: Example with the AMOC under high emissions scenario SSP5-8.5





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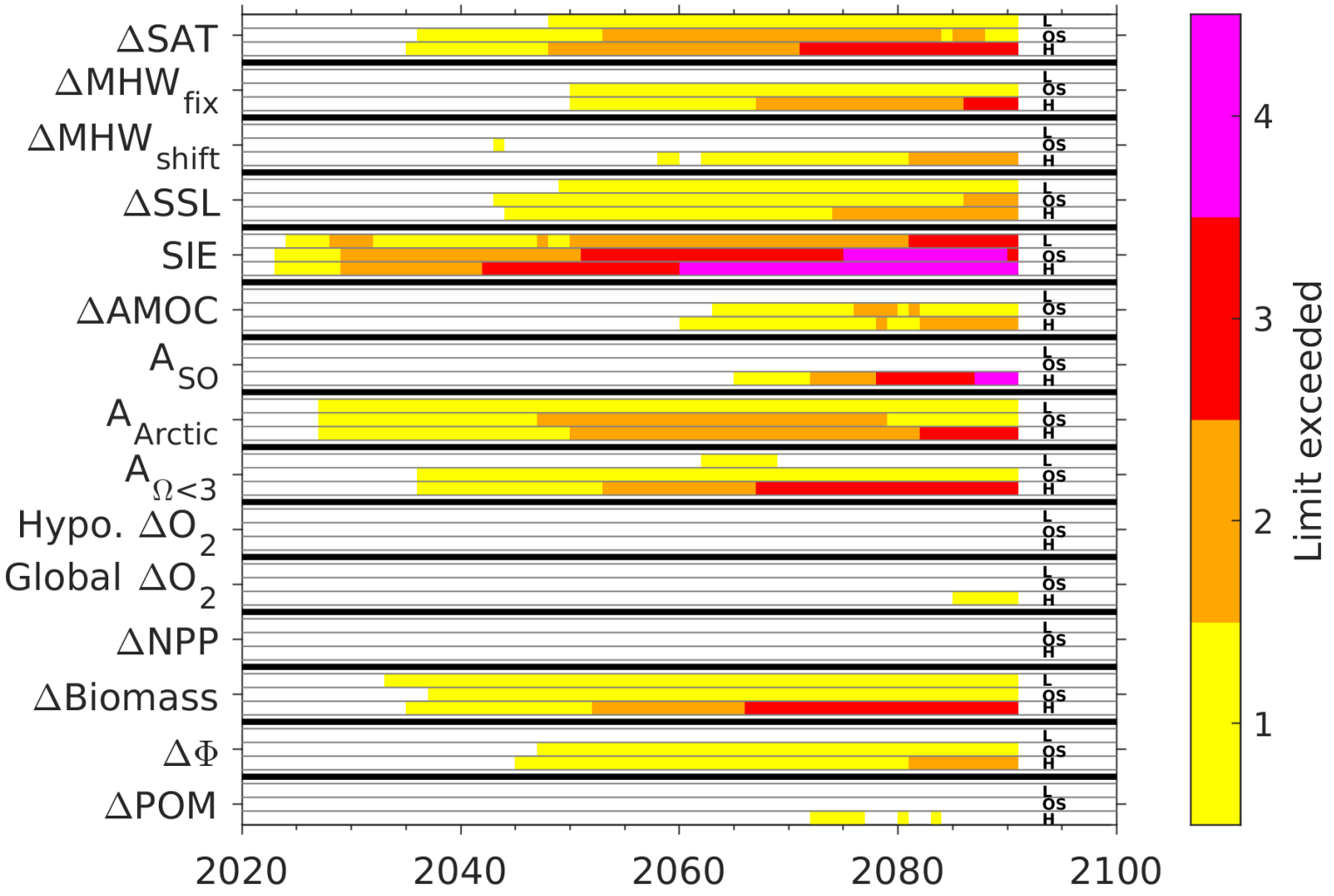
L: SSP1-2.6

OS: SSP5-3.4-over

H: SSP5-8.5



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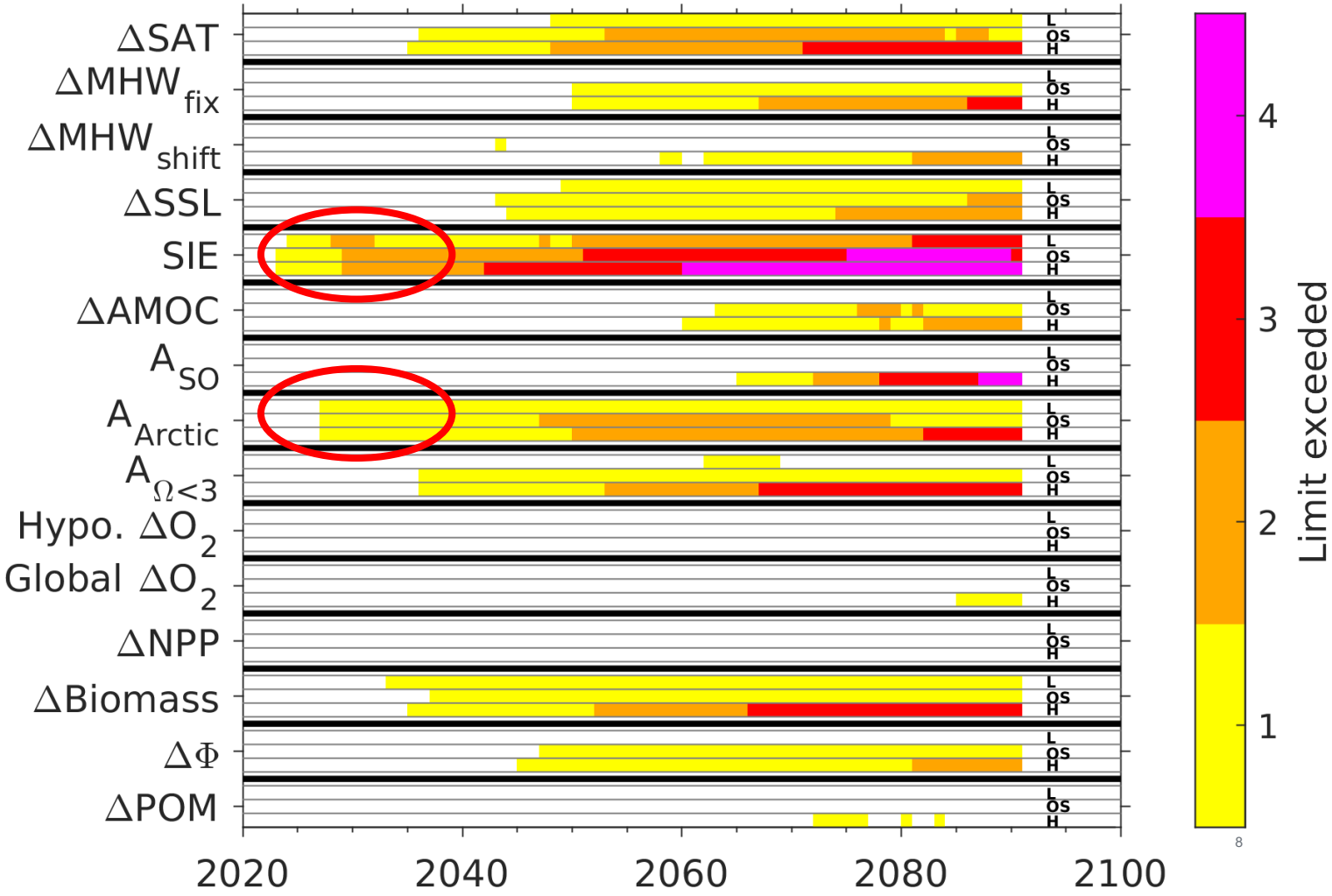

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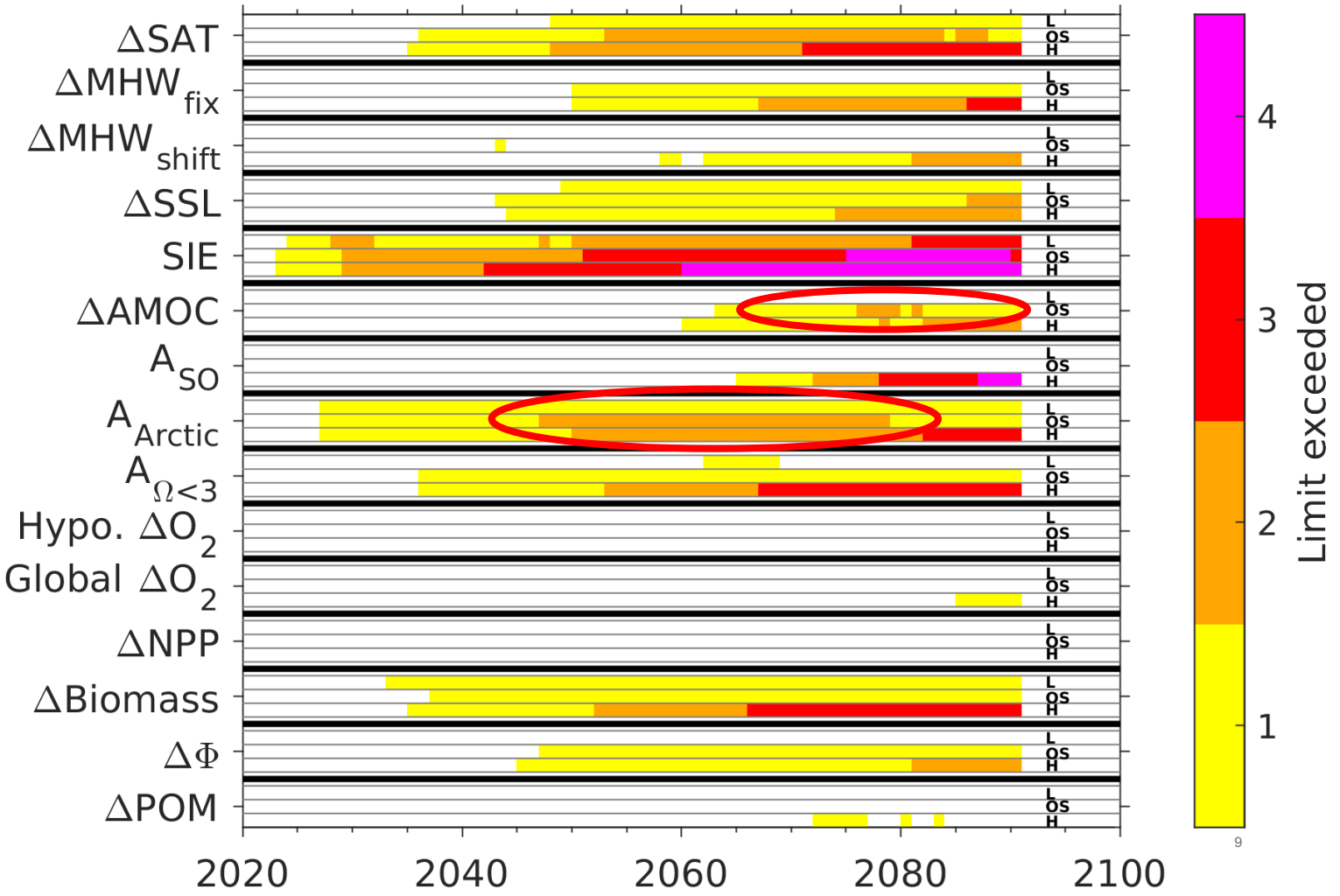

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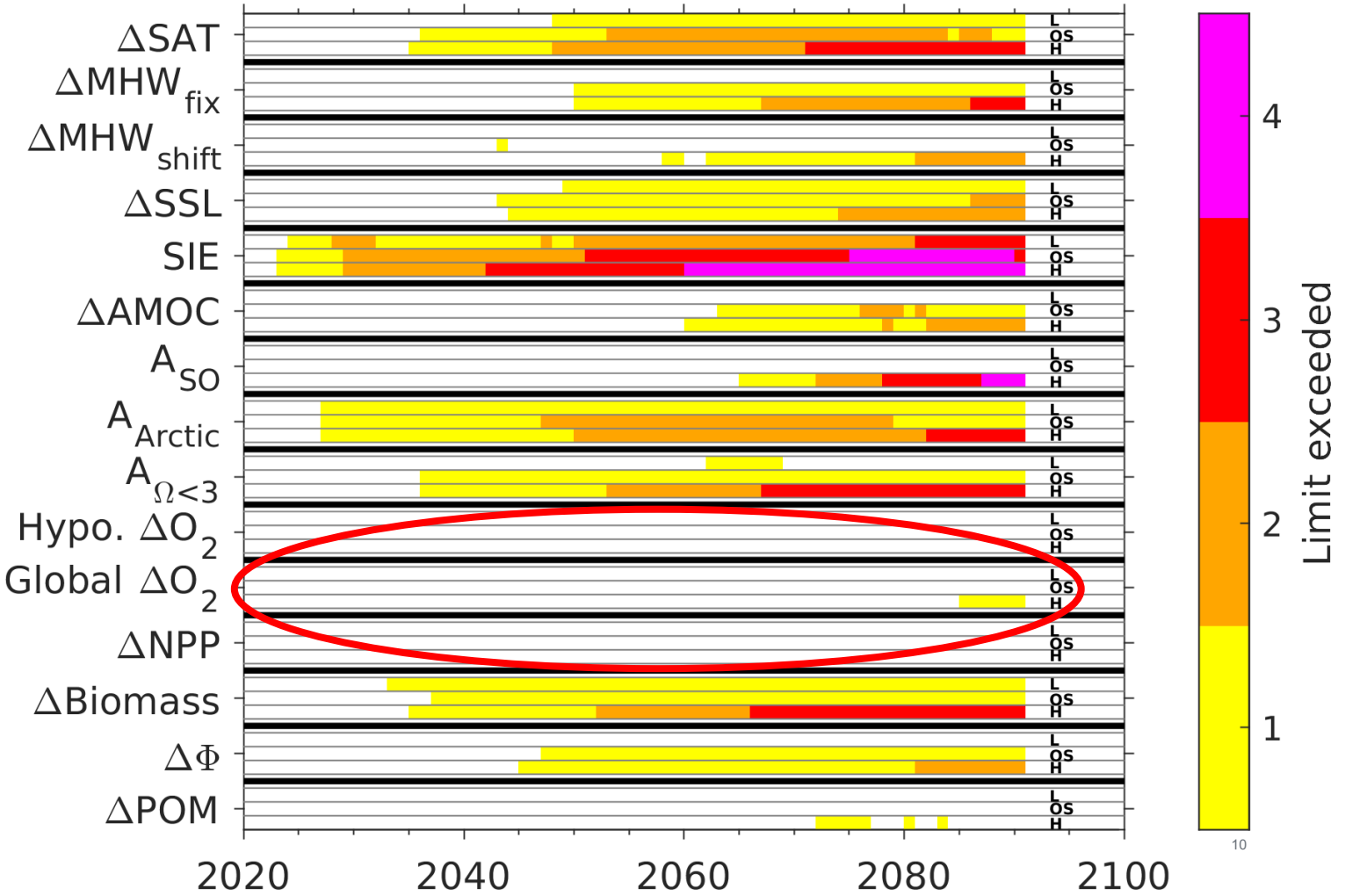

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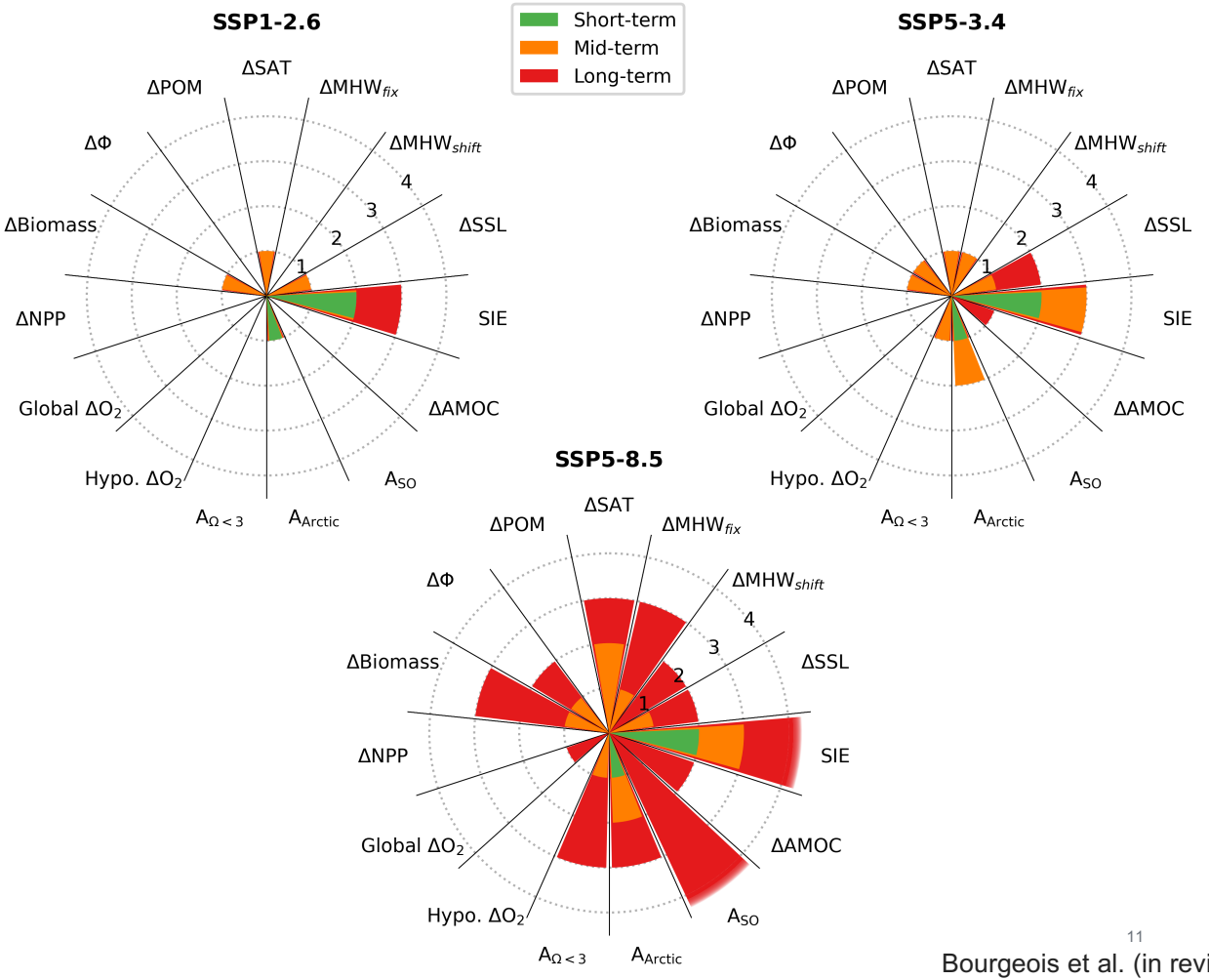
Near, mid and far future

20-year periods:

Short-term: 2020-2039

Mid-term: 2040-2059

Long-term: 2080-2099



Bourgeois et al. (in review)

Take home messages

Low emissions scenario:

Many stringent mitigation limits are exceeded with high probability in the near-term (~2030) or mid-term (~2050).

(Steric sea level rise, Arctic sea ice extent, Arctic ocean acidification, plankton biomass)

Overshoot scenario:

Efficient risk reduction of exceeding mitigation limits by 2100 in the long-term.

(marine heatwaves, Arctic sea ice extent, AMOC strength, ocean acidification, global deoxygenation, plankton biomass, fish metabolic index)

Disagreement in net primary production projections does not permit to conclude on any target exceedances.

15 impact metrics with 4 mitigation limits (1/2)

Impact metric	Description	Level 1	Level 2	Level 3	Level 4	Unit
ΔSAT	Increase in mean annual global surface atmospheric temperature relative to 1850-1900	1.5	2	3	4	°C
MHW_{fix}*	Global mean duration of marine heatwaves within a year, from a fixed baseline	90	180	270	360	day
MHW_{shift}*	Same as MHW_{fix} (line above), but from a shifting baseline	4	6	8	10	day
ΔSSL	Mean annual steric sea level rise relative to 1850-1900	0.1	0.2	0.3	0.4	m
SIE*	Arctic September sea-ice extent	4	3	2	1	10^6 km^2
ΔAMOC	Change in mean annual strength of the AMOC relative to 1850-1900	-20	-25	-30	-40	%
A_{SO}	Mean annual area proportion of Southern Ocean surface waters (south of 50°S) with aragonite undersaturation ($\Omega_{arag}<1$)	20	40	60	80	%
A_{Arctic}	Mean annual area proportion of Arctic Ocean surface waters (north of 70°N) with aragonite undersaturation ($\Omega_{arag}<1$)	20	40	60	80	%

15 impact metrics with 4 mitigation limits (2/2)

Impact metric	Description	Level 1	Level 2	Level 3	Level 4	Unit
$A_{\Omega<3}$	Mean annual area proportion of global ocean surface waters with $\Omega_{arag}<3$	50	70	90	100	%
Hypoxic ΔO_2	Change in mean annual volume of hypoxic waters (<63 umol L^{-1}) above 1000 m relative to 1850-1900	2	4	6	8	%
Global ΔO_2	Change in mean annual global O_2 content relative to 1850-1900	-1.8	-2.4	-2.6	-3.5	%
ΔNPP*	Change in mean annual depth-integrated net primary production relative to 1850-1900	-2	-3.5	-4	-8	%
ΔBiomass*	Change in mean annual depth-integrated plankton biomass relative to 1850-1900	-2	-3.5	-4	-8	%
ΔΦ	Change in mean annual upper-ocean (depth < 400 m) metabolic index relative to 1850-1900	-5	-10	-15	-20	%
ΔPOM	Change in mean annual particulate organic matter flux at 100 m depth (30°N-20°S) relative to 1850-1900	-4	-6	-8	-10	%