Compound marine heatwaves and ocean acidity extremes over the satellite period

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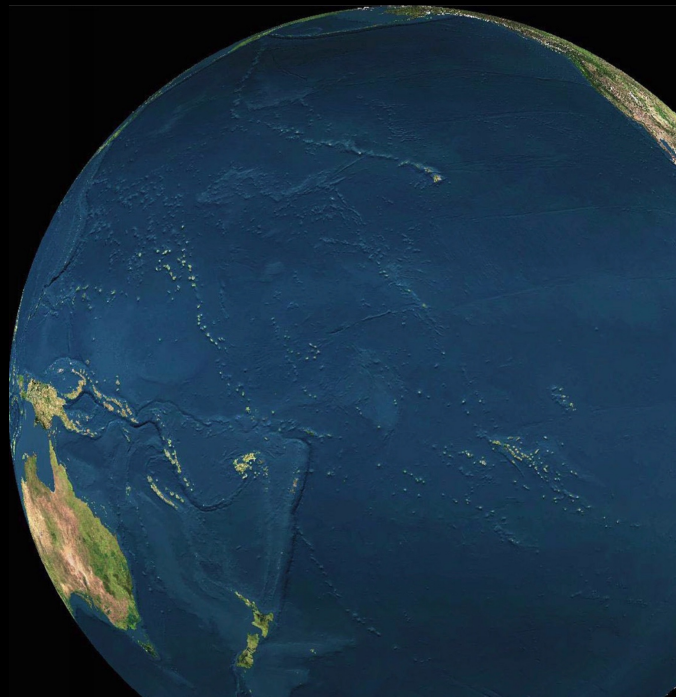
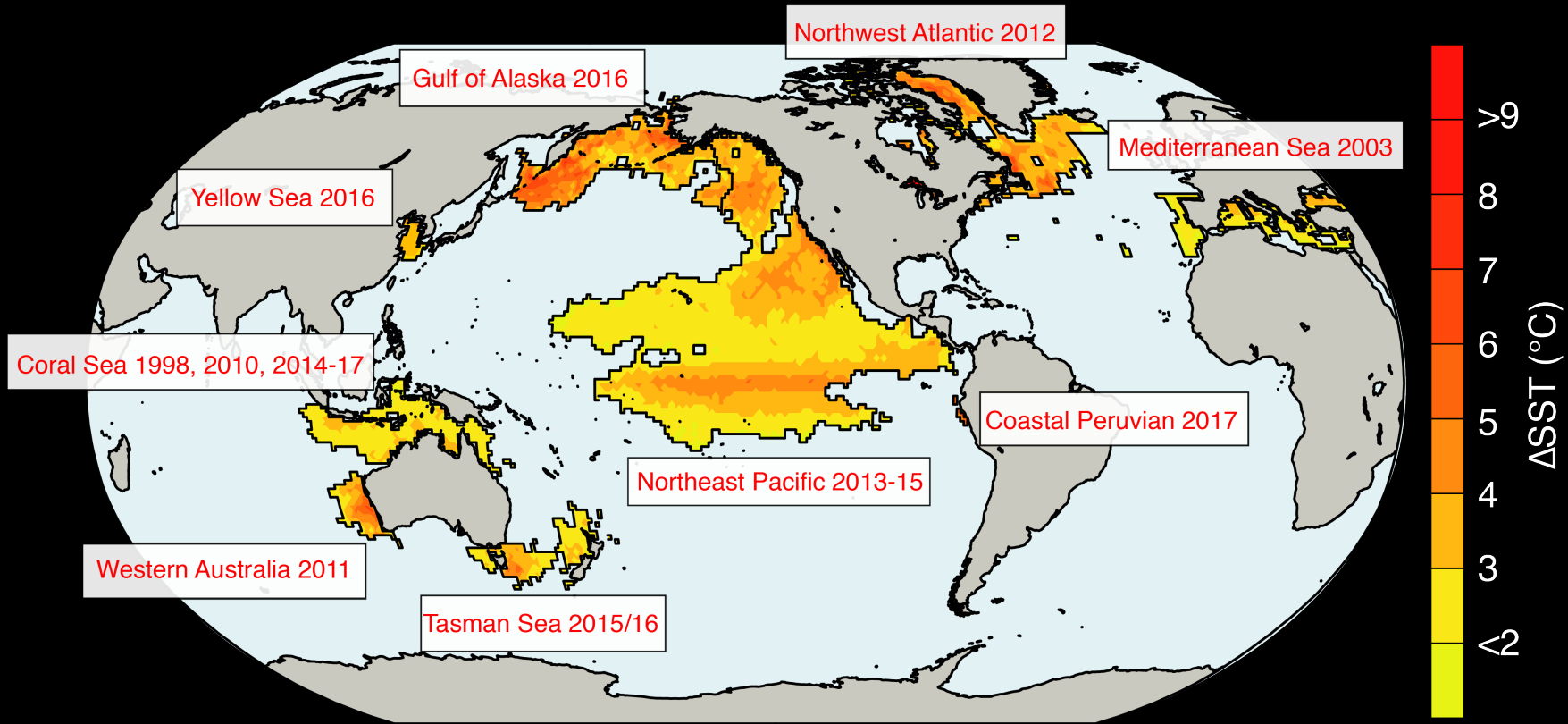
Thanks to:
Friedrich Burger, Jens Terhaar, Charlotte Laufkötter, Nicolas Gruber, William Cheung



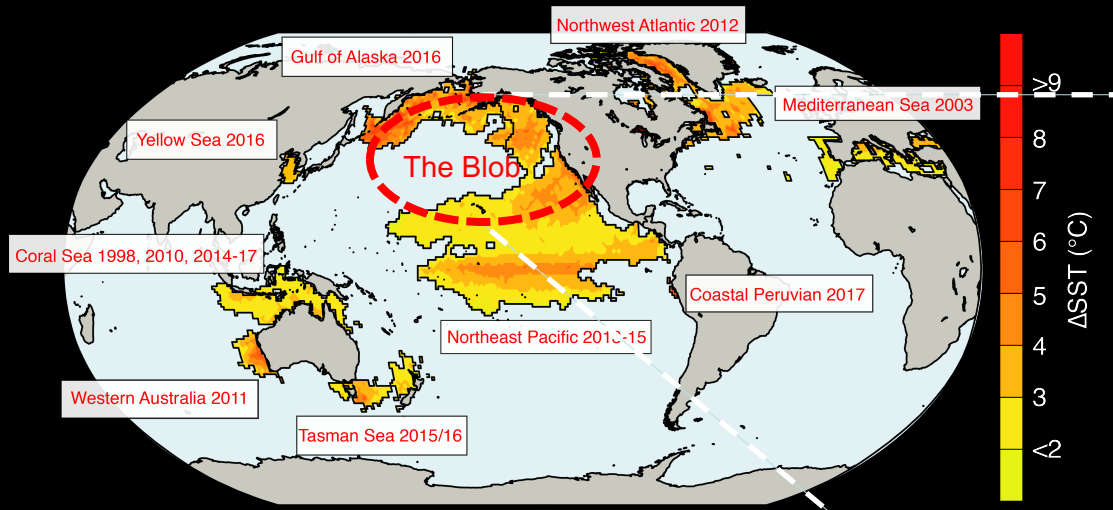
FNSNF Swiss National Science Foundation · COMFORT · 4C Climate-Carbon Interactions in the Current Century · AtlantECO Atlantic Ecosystems Assessment, Forecasting & Sustainability · PROVIDE

High-impact marine heatwaves over the last two decades

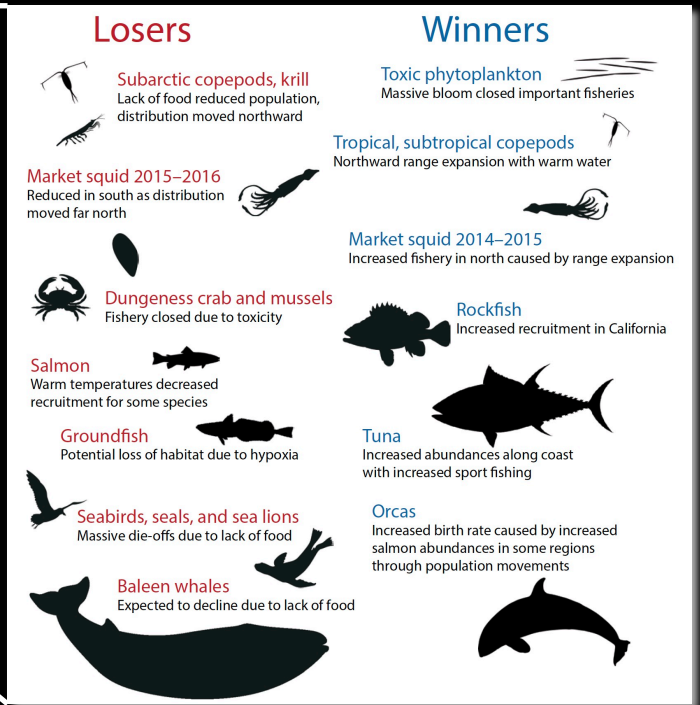


Frölicher and Laufkötter (2018, *Nature Communications*)

Marine heatwaves cause widespread impacts on marine species

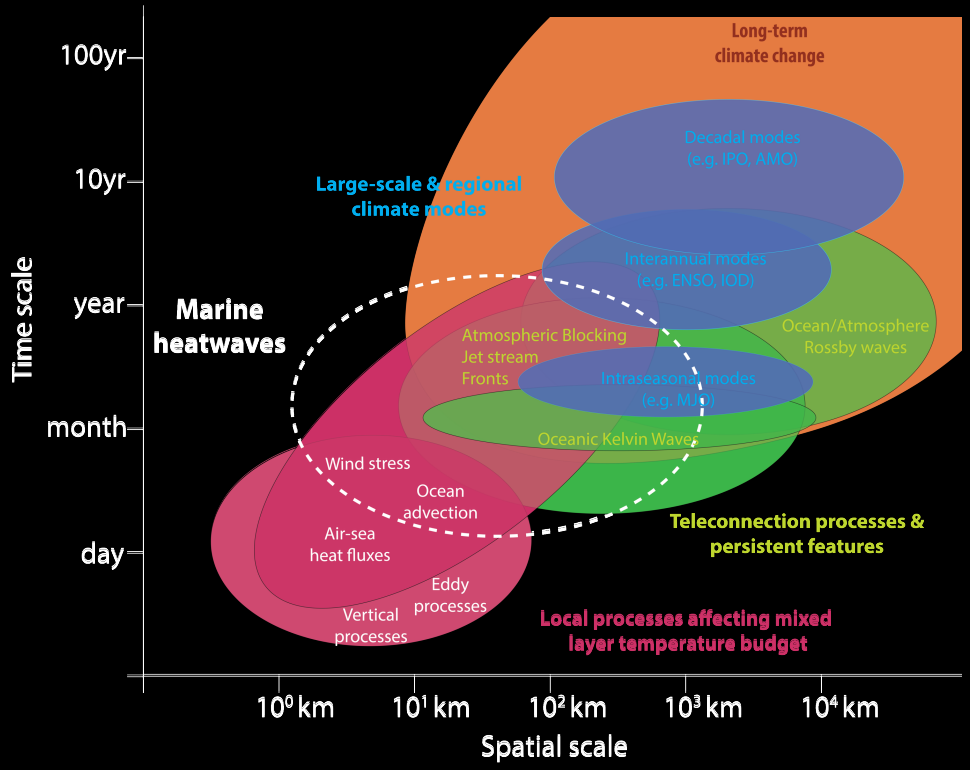


Frölicher and Laufkötter (2018, *Nature Communications*)



Cavole et al. (2016, *Oceanography*)

Space and time scales of characteristic marine heatwave drivers

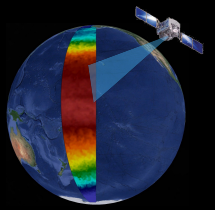


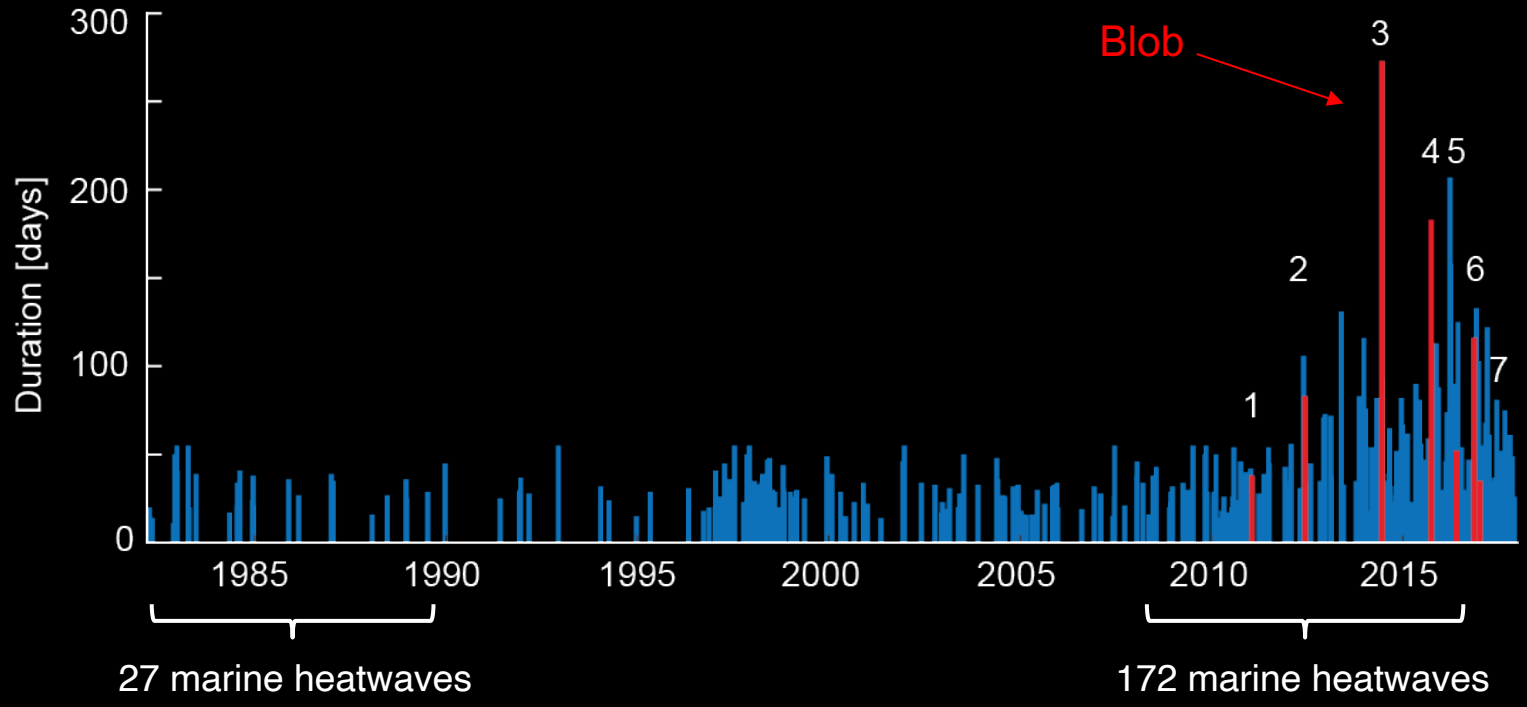
$$\underbrace{\frac{\partial \overline{T}}{\partial t}}_{\text{Temperature tendency}} = \underbrace{-\,\overline{\mathbf{u}}\cdot\nabla\overline{T}}_{\text{Horizontal advection}} + \underbrace{\overline{\nabla\cdot(\kappa_h\nabla T)}}_{\text{Horizontal mixing}} \underbrace{-\frac{1}{h}\kappa_z\left.\frac{\partial T}{\partial z}\right|_{-h}}_{\text{Vertical mixing}} + \underbrace{\frac{Q_{SW}-Q_{SW(-h)}+Q_{LW}+Q_{sens}+Q_{lat}}{\rho c_p h}}_{\text{Air–sea heat flux}}, + \text{Entrainment}$$

modified from Hollbrook et al. (2019, *Nature Communications*)

Oliver et al. (2021, *Annual Review of Marine Sciences*)

Comparison of 300 largest marine heatwaves





Laufkötter, Zscheischler, Frölicher (2020, *Science*)

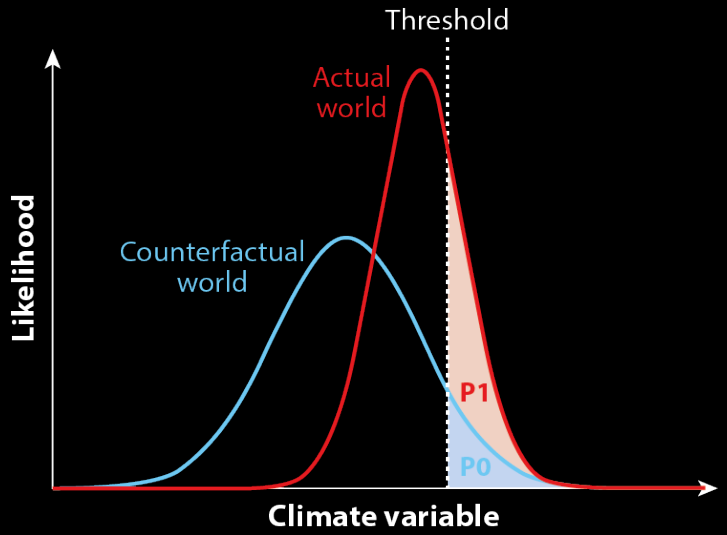
Average duration: 32 days; Average intensity: 4.8°C

Average duration: 48 days; Average intensity: 5.5°C

How did human-induced climate change modify the likelihood of past single events?

Single event attribution using Fraction of Attributable Risk framework (FAR; Stott et al. 2003; Otto 2017, Oldenborgh et al. 2021)

1. Model evaluation
2. Calculate likelihood of marine heatwaves in preindustrial and present-day simulations
3. Calculate fraction of attributable risk



$$FAR = 1 - \frac{P_{(\text{heatwave occurs in preindustrial climate})}}{P_{(\text{heatwave occurs in present-day climate})}}$$

Most impactful heatwaves became more than 20-fold more likely due to human-induced global warming

Heatwave number	Time and location	Intensity (°C)	FAR intensity	Duration (days)	FAR duration
1	Western Australian 2011	2.26	–	101	0.79 [−0.55, 0.97]
2	Northwest Atlantic 2012	2.15	0.97 [0.92, 0.99]	57	0.96 [0.94, 0.97]
3	Northeast Pacific 2013 to 2015	1.56	1.0 [0.97, 1.0]	357	1.0 [0.99, 10]
4	Tasman Sea 2015 and 2016	1.49	0.98 [0.92, 0.99]	175	1.0 [0.49, 1.0]
5	Indo-Australian Basin 2016	1.67	1.0 [0.77, 1.0]	90	–
6	Southern Ocean 2016*	1.0	0.03 [−2.71, 0.74]	183	−0.6 [−2.6, 0.26]
7	Southwest Atlantic 2017	1.96	1.0 [0.74, 1.0]	82	1.0 [0.91, 1.0]

Laufkötter, Zscheischler, Frölicher (2020, *Science*)

Northwest Atlantic 2012 marine heatwave

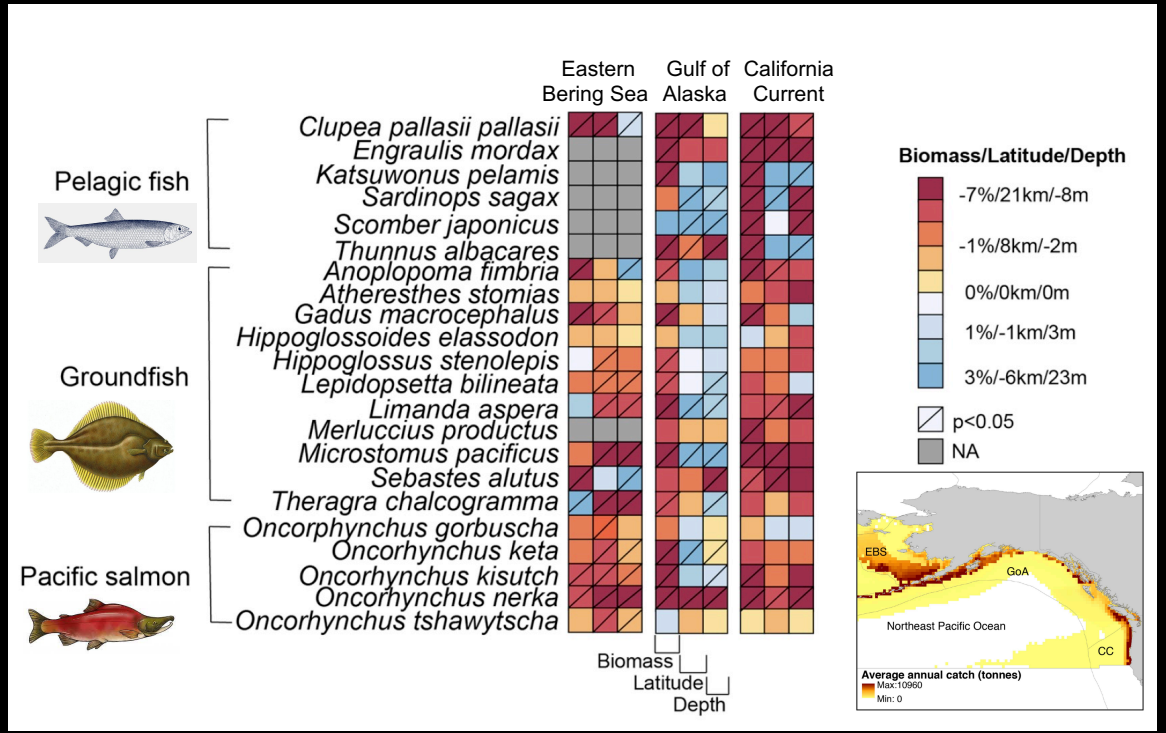
- 2.15°C → 33x more likely by 1982-2017 than preindustrial
- 57 days → 25x more likely by 1982-2017 than preindustrial

Northeast Pacific 2013-2015 marine heatwave ('Blob')

- 1.56°C → only possible due to climate change
- 357 days → only possible due to climate change

Marine heatwaves amplify impacts of climate change on fish and fisheries: Northeast Pacific case study

Results from an integrated climate-biodiversity-fisheries impact model



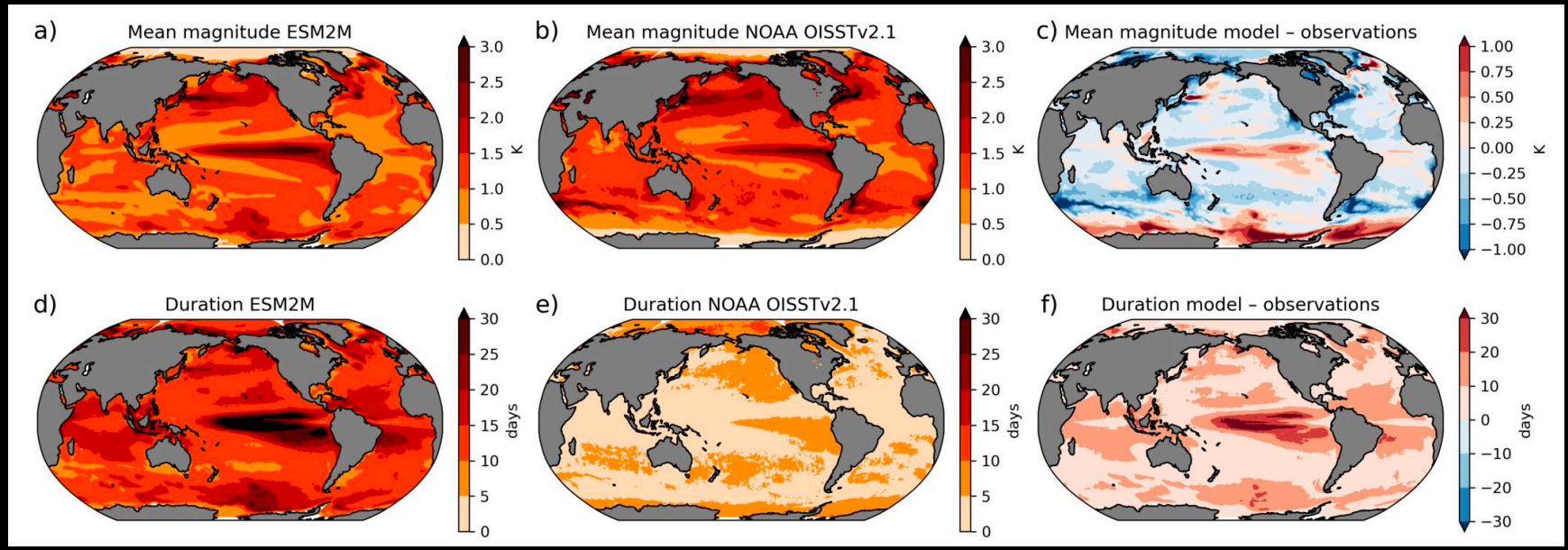
Marine heatwaves cause changes that are at least four times faster and bigger in magnitude than climate-change driven decadal-scale mean changes in the Northeast Pacific

Cheung and Frölicher (2020, *Scientific Reports*)

Challenge: Duration of marine heatwaves is not well simulated in current ESMs

1.2°C

1.3°C

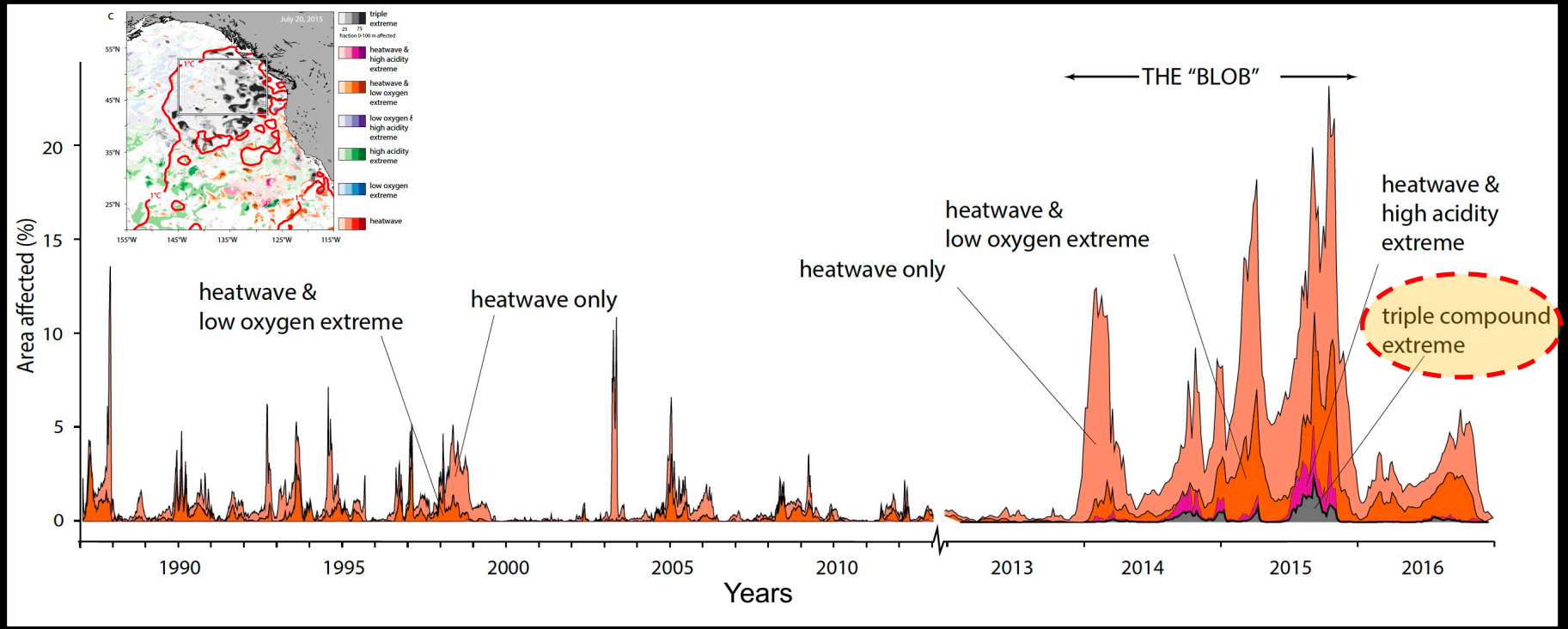


13.9 days

4.5 days

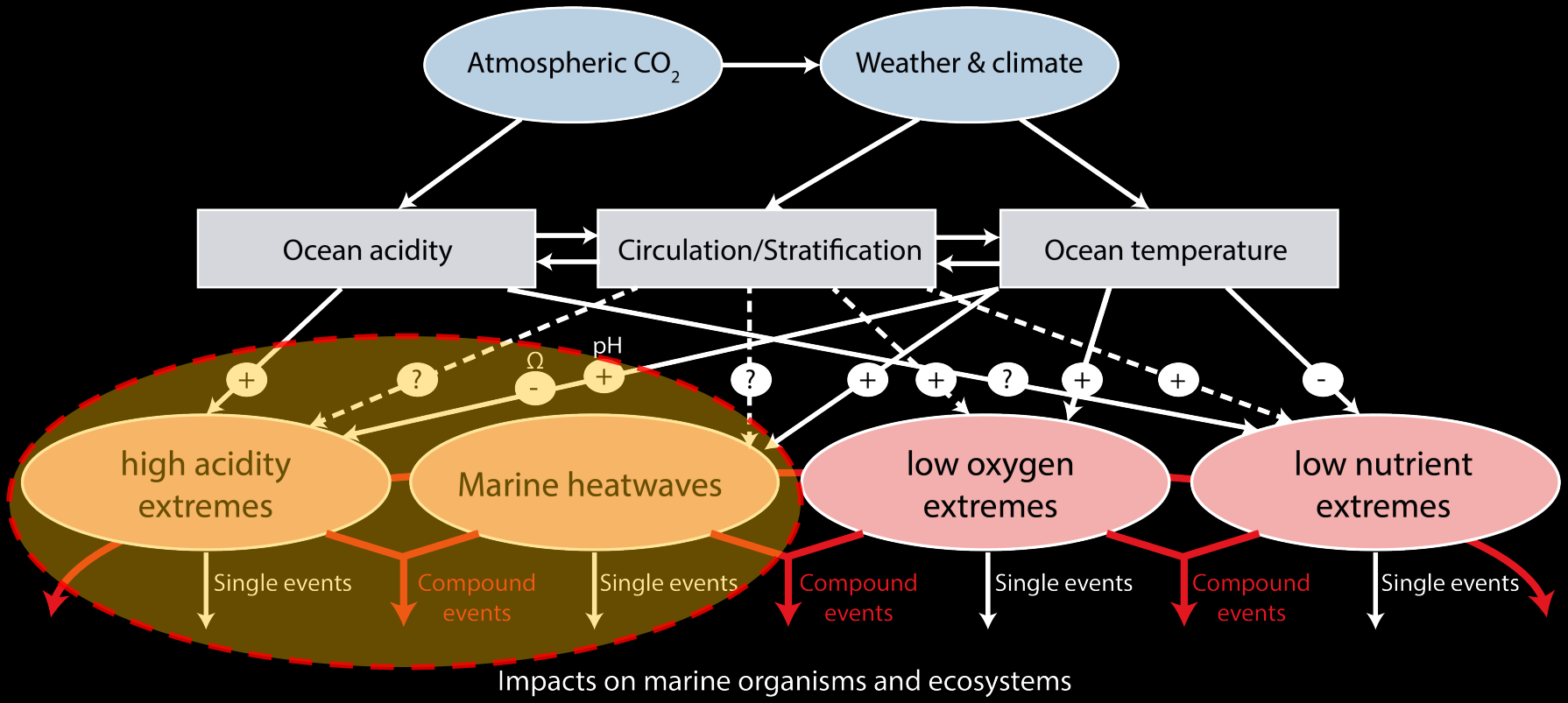
Vogt, Burger, Griffies, Frölicher (Frontiers in Climate,in press)

Compound events are a new phenomena (in ocean science)



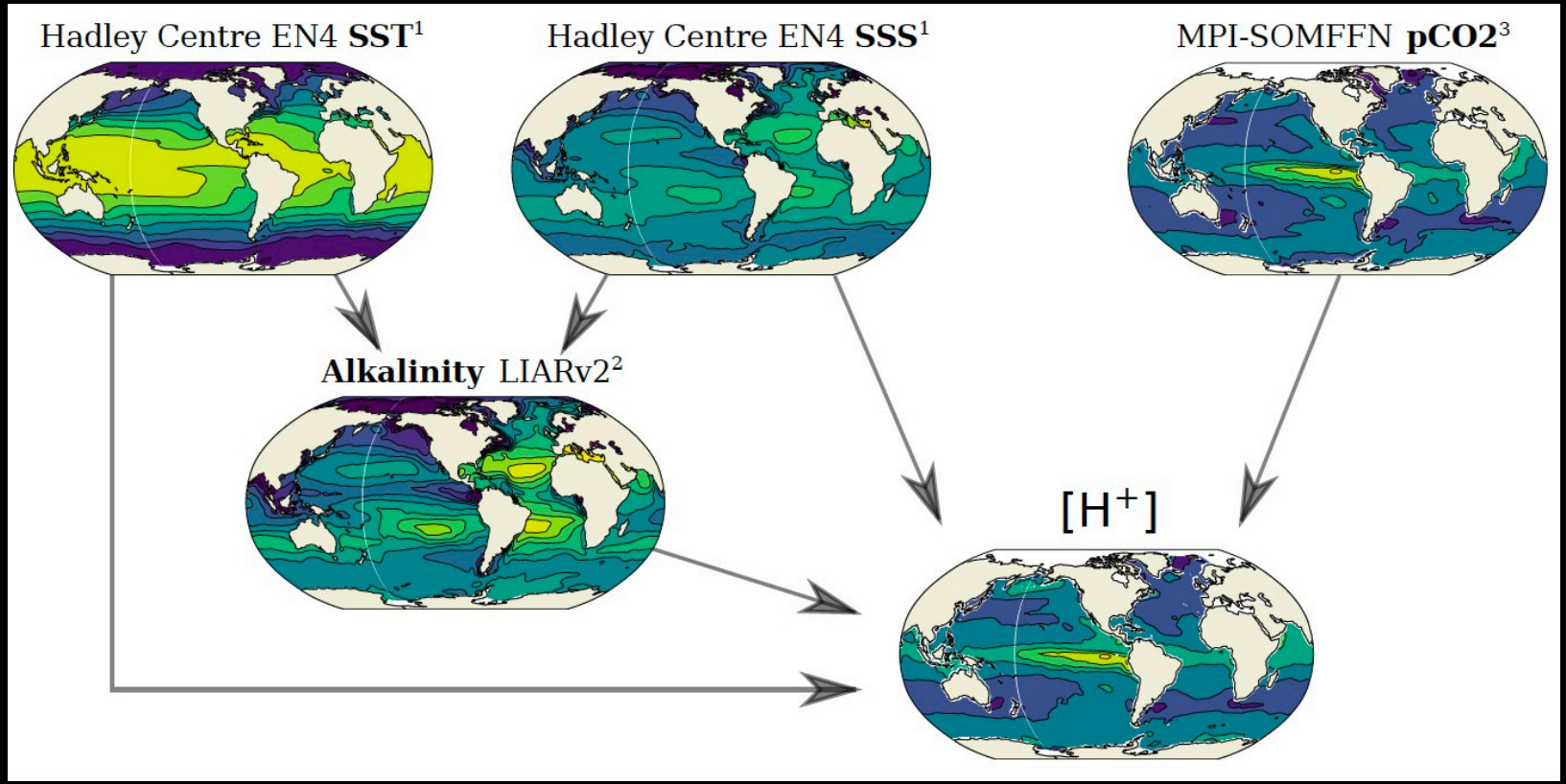
Gruber, Boyd, Frölicher, Vogt (*Nature*, 2021)

From marine heatwaves to compound events



modified from Gruber, Boyd, Frölicher, Vogt (*Nature*, 2021)

Monthly gridded observation-based [H$^+$] product (1982-2019)

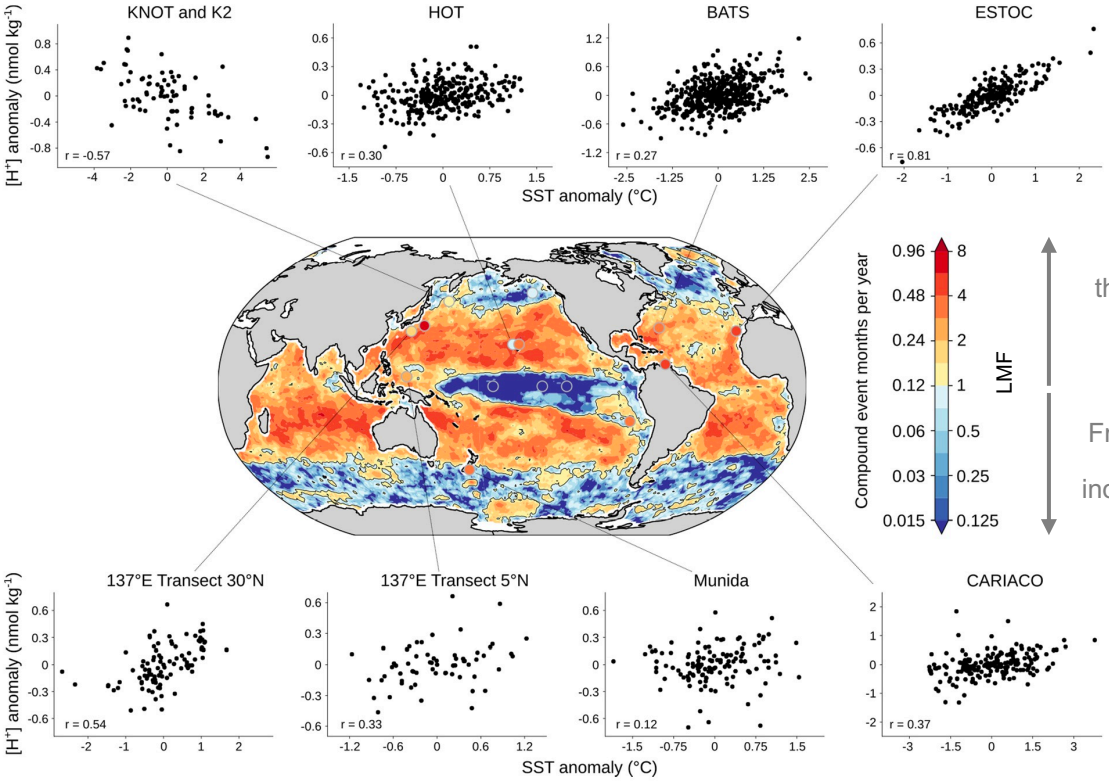


[1]Good et al. (*J. Geophys. Res. Ocean*, 2013), [2]Carter et al. (*Limno. Oceanogr. Methods,* 2018), [3]Landschützer et al. (*NCEI*, 2020)

Present-day pattern of compound marine heatwave-ocean acidity events

Results of monthly satellite-based SST and reconstructed [H⁺] data: 1982-2019

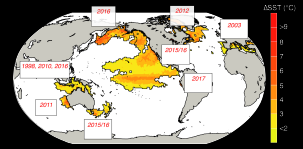
$$\mathrm{LMF} = \frac{P(\mathrm{SST} > \mathrm{t} \cap [\mathrm{H}^+] > \mathrm{h})}{P(\mathrm{SST} > \mathrm{t}) \cdot P([\mathrm{H}^+] > \mathrm{h})}$$



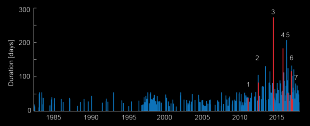
Burger, Terhaar, Frölicher (*Nature Communications, under review*)

Summary

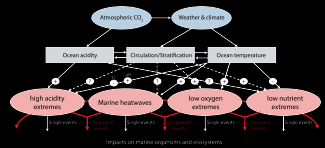
1. Recent MHWs demonstrated the high vulnerability of marine ecosystems, but also physical and socio-economic systems to such extreme climate events.



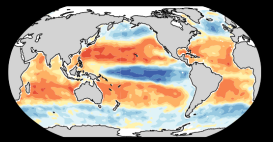
2. MHWs have doubled in frequency since 1982 and will further increase in intensity and duration. Most of the individual MHW events have a human-induced signal.



3. Biogeochemical extreme events, such as ocean acidity extremes, are also bound to strongly increase under climate change.



4. Compound marine heatwaves-ocean acidity extremes occur relatively frequently in the subtropical oceans, while they are much rare in the equatorial Pacific and the mid-to-high latitudes. The Blob was a compound event.



Key knowledge gaps and the way forward (incomplete list!)

Thanks!

How reliable are emerging novel observations to reveal and quantify (compound) ocean extreme events, especially at subsurface?

How do ocean compound ocean extreme events change under global warming and what are the physical and biogeochemical drivers?

What are the risks of compound ocean extreme events for marine organisms and ecosystems?

How do ocean extreme events affect ocean biogeochemical cycles and weather and climate?