Zooplankton diapause in a warmer world: modelling the future impacts of climate change on *Calanus finmarchicus* dormancy duration

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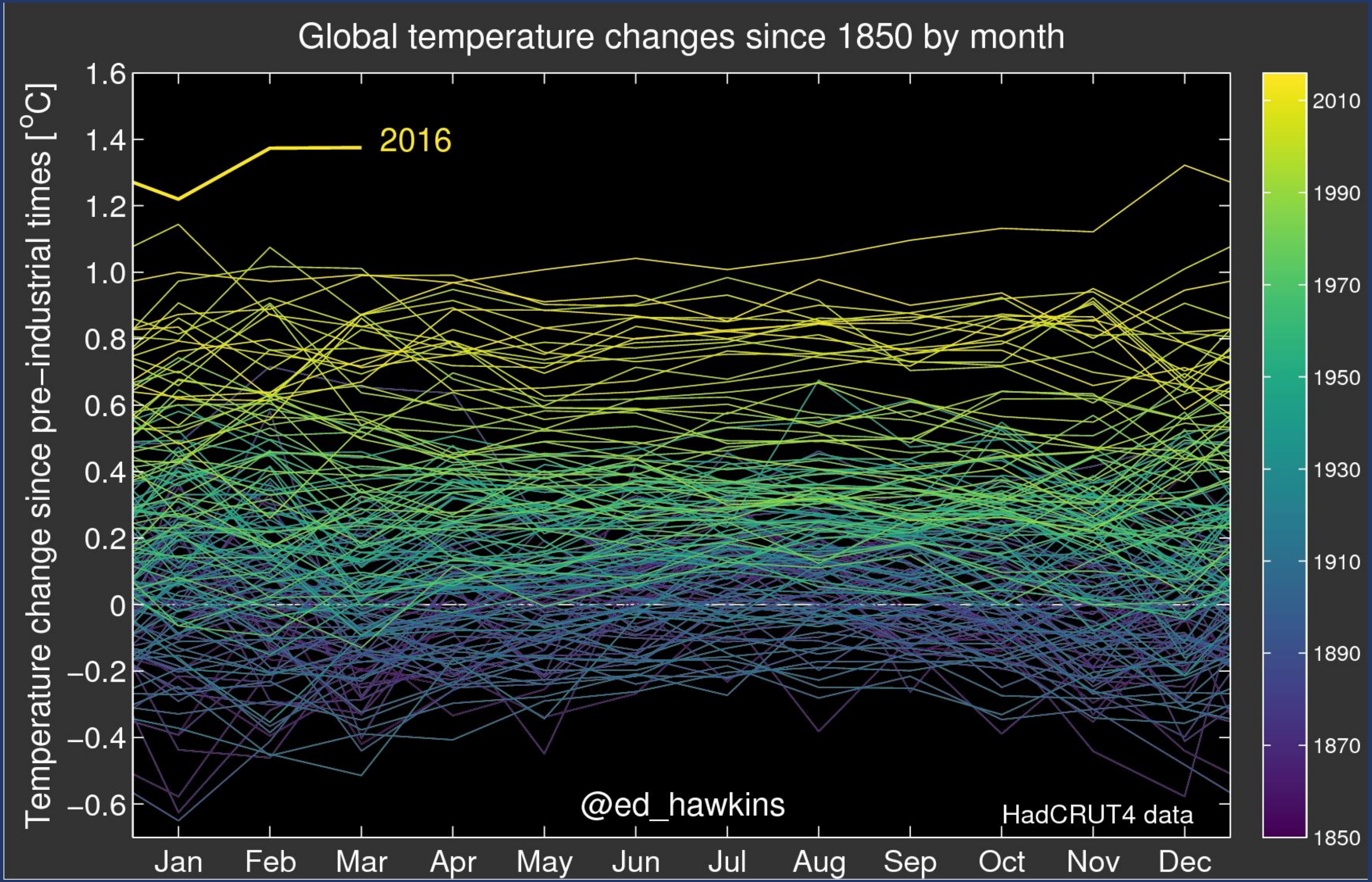
The world has already warmed by about 1 °C



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We probably have at least 1 °C of warming to come

A simple thought experiment

- Imagine that a decade from now we stop building new fossil fuel infrastucture
- Until then the world keeps emitting greenhouse gases at current levels
- …….. In the next decade we discover how to *fly hundreds of scientists* to Bergen without burning jet fuel

What would happen?

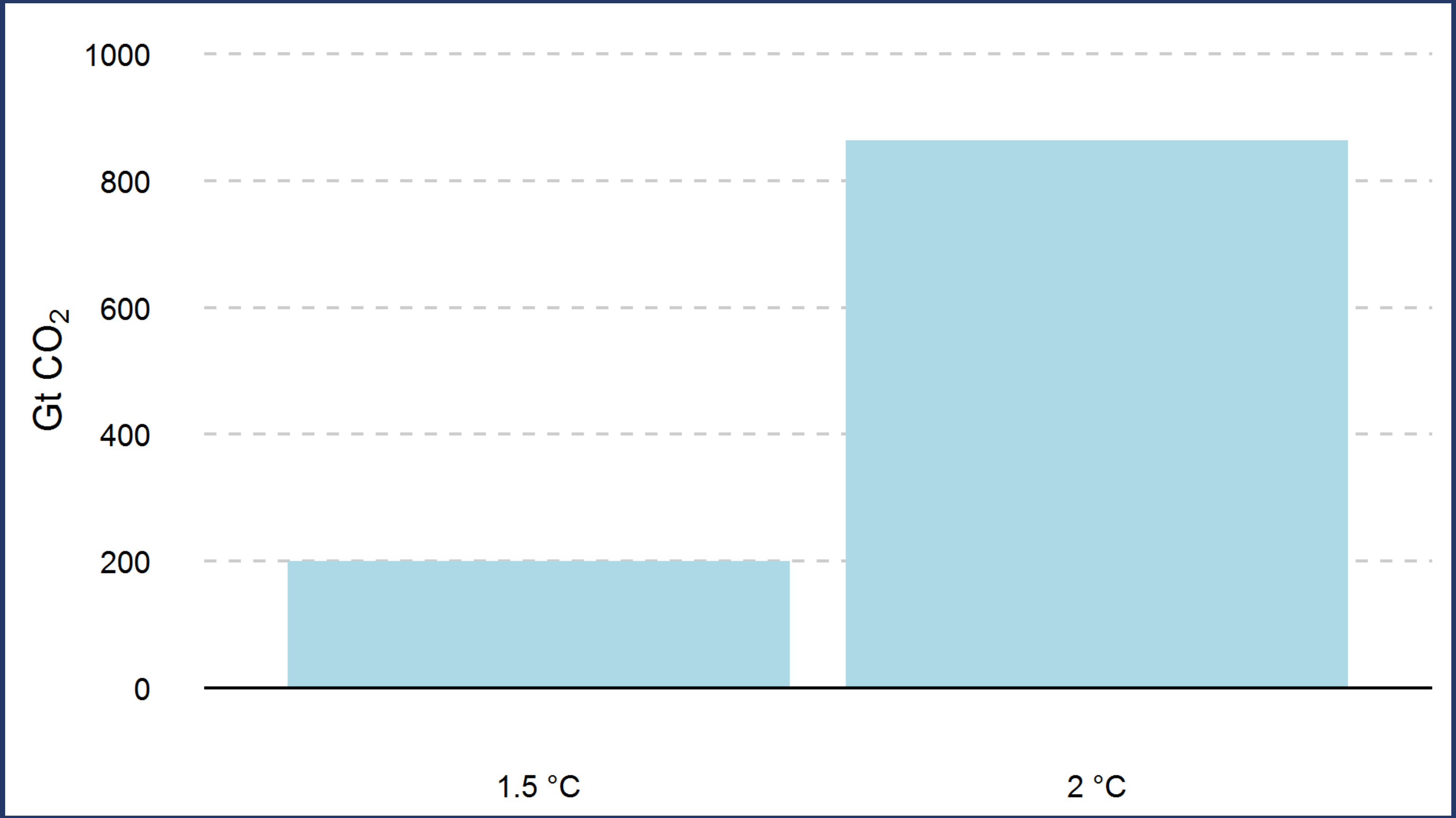
The arithmetic of this hopelessly optimistic scenario

- We emit the equivalent of 40 billion tonnes of CO_2 each year (*Global Carbon Project*)
- We will therefore emit 400 billion tonnes in the next decade
- Existing fossil fuel infrastructure is expected to emit at least 500 billion tonnes of CO_2 over its remaining lifespan (Davis et al. 2010 *Science*).

400 + 500 = 900 billion tonnes of CO_2

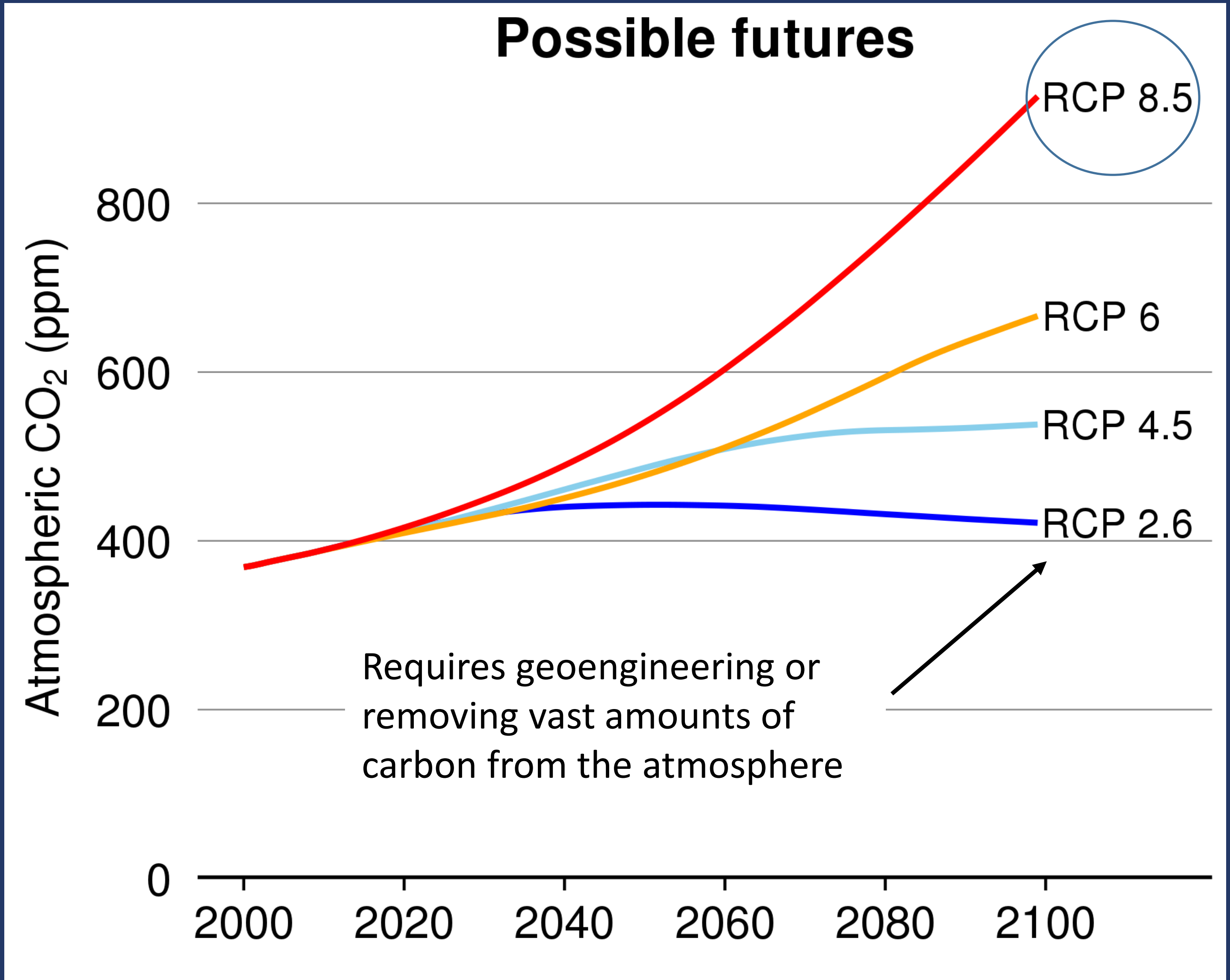
At least 1 °C of future warming now seems probable

The remaining carbon budgets to prevent global warming



Peters et al. 2015 *Environ. Res Lett.*; Rogelj et al., 2015, Nat. Clim. Ch.

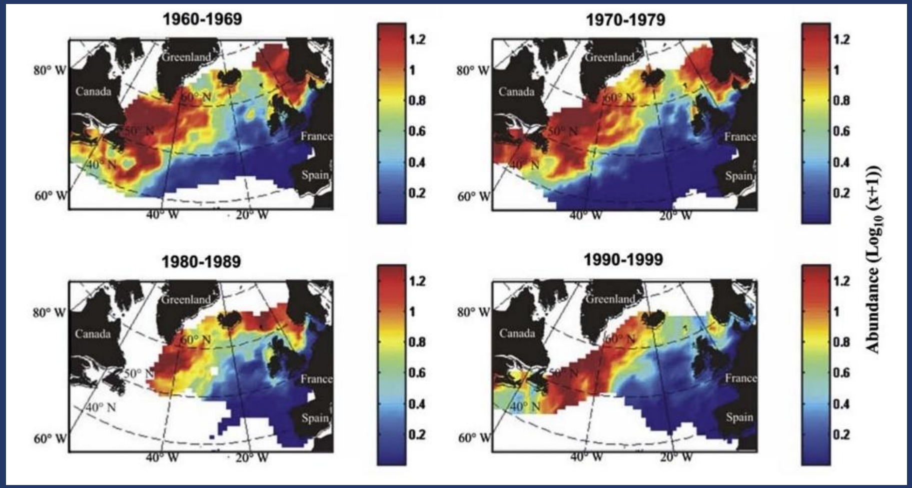
IPCC Reference Concentration Pathway 8.5: a bracketing scenario



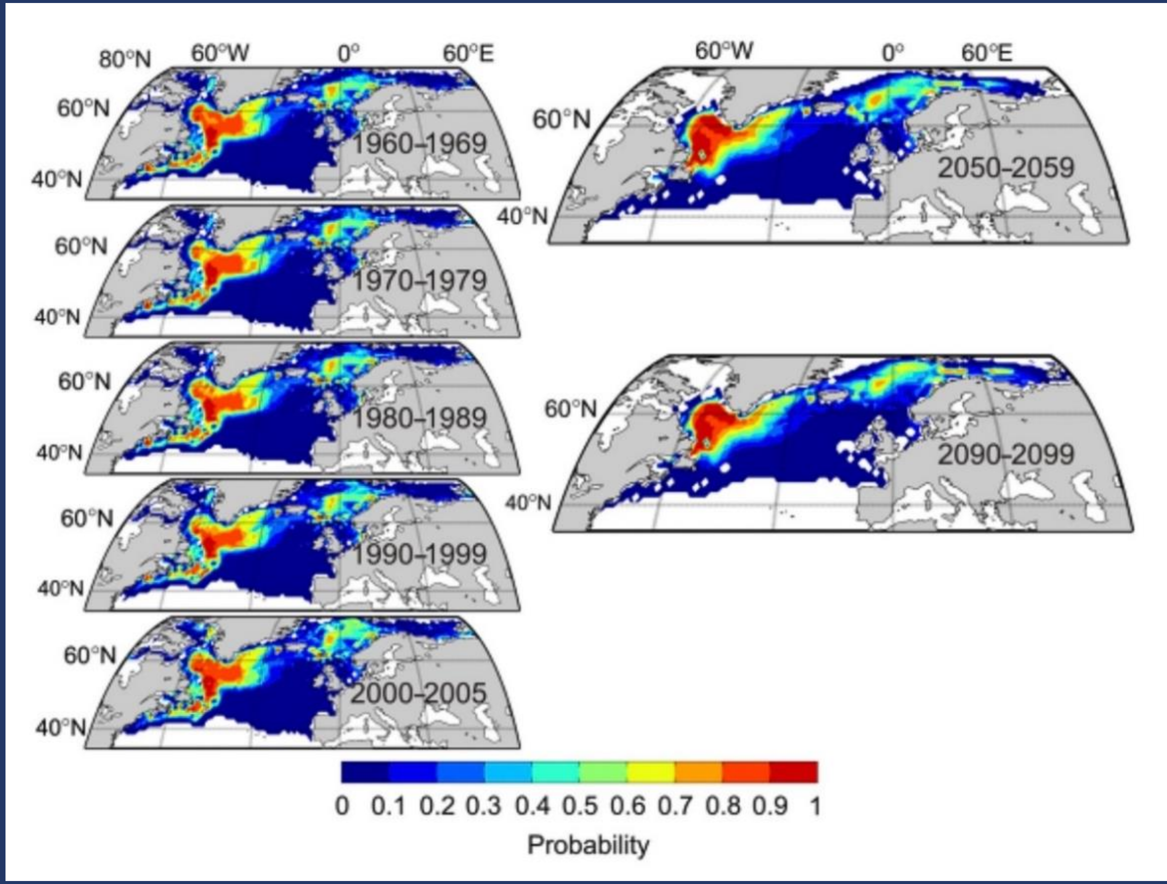
Context: warmer waters have and will continue to force *C. finmarchicus* north

Future projection

Historical reconstruction



Bonnet et al, 2005



Reygondeau and Beaugrand, 2011

Diapause: a simple summary

Surface

Animals acquire lipid reserves in spring/summer

Descent as C5

200-250 days living with lowered metabolic rates, burning lipids.
Avoids starving during winter.

Ascent
Lipids used for molting and gonad formation

… on to the next generation

Deep

Diapause: *Calanus* as a carbon sequester

Carbon flux

Surface

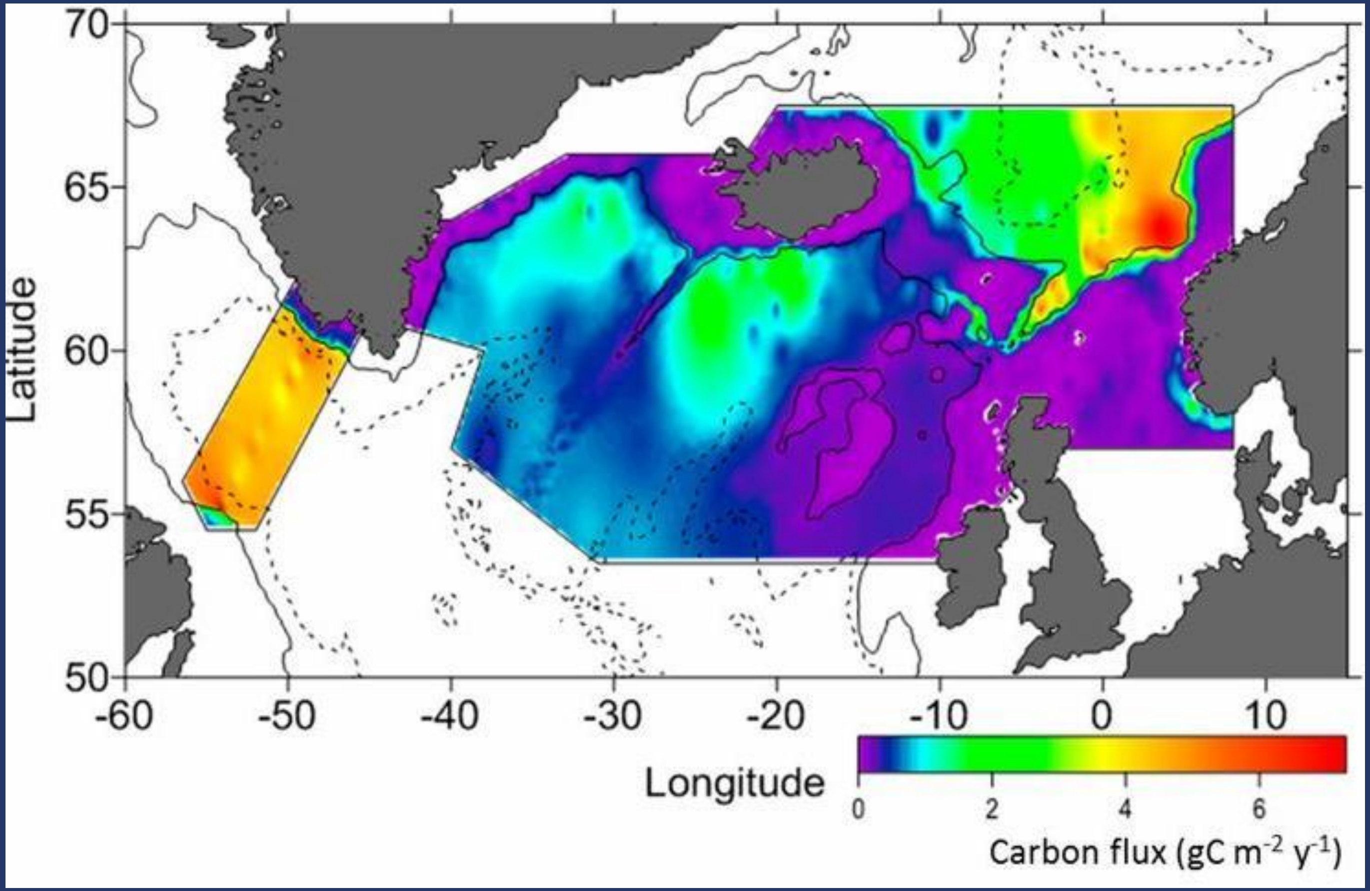
Animals acquire carbon reserves in spring/summer

Descent

200-250 burning carbon and releasing CO_2 in deep waters, where it stays

Deep

This almost doubles previous estimates of biological carbon sequestration in North Atlantic deep water



PNAS: Jónasdóttir et al., 2015

Modelling potential diapause duration from first principles using empirical data

Modelling how long an animal can diapause for, not necessarily how long they do diapause for

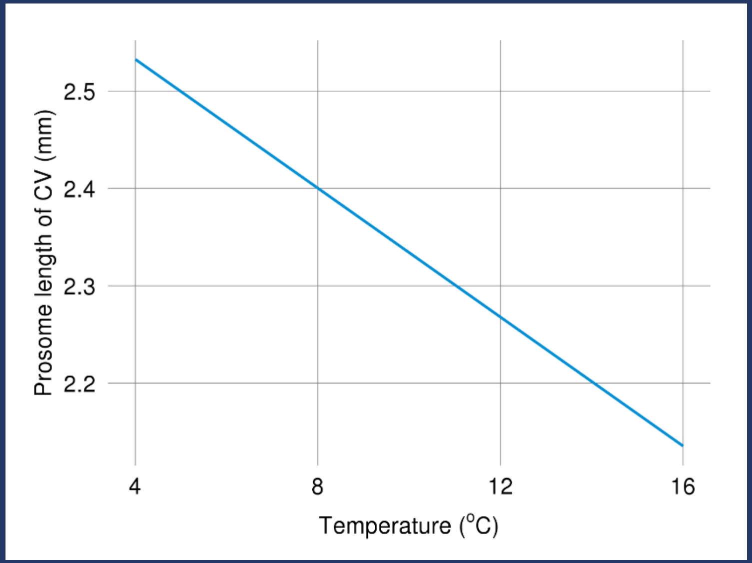
Potential diapause duration = maximum time animals of a given prosome length can diapause for

Model assumptions and simplifications

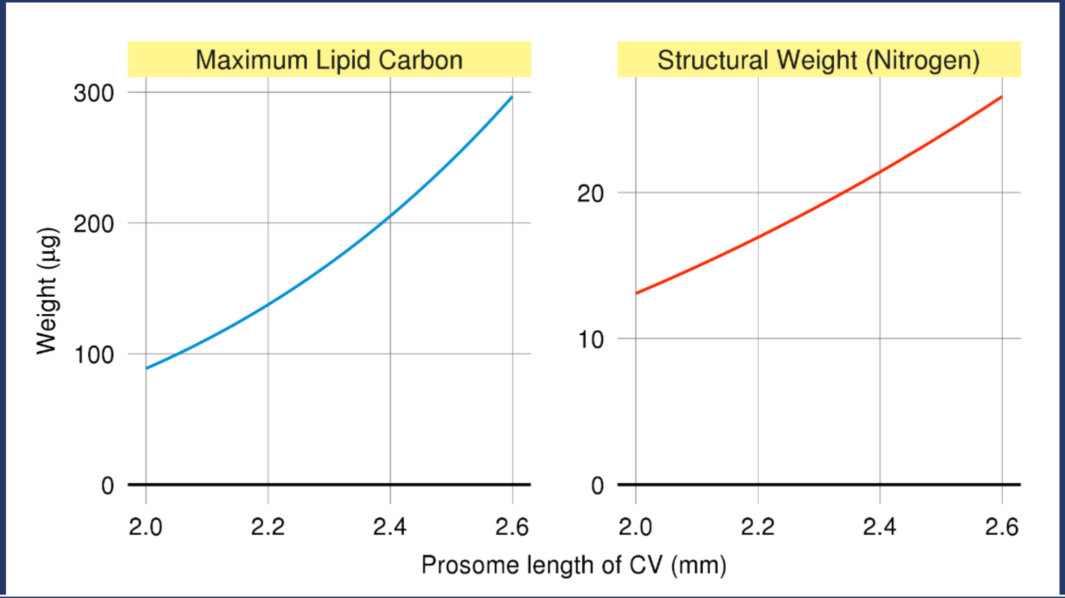
- Temperature experienced during development determines prosome length
- Animals of a given prosome length enter diapause with the maximum level of lipid implied by field studies
- Animals exit diapause when lipid levels have reduced to the levels required for gonad formation and post-diapause molting
- Caveat: we are forced to ignore the influence of food

The key: size scaling and the influence of temperature

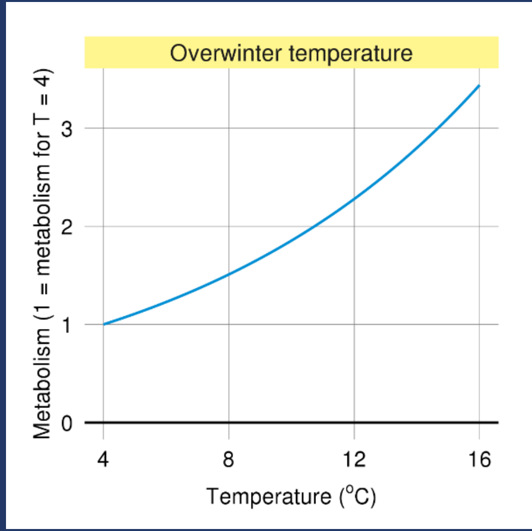
Temperature determines length

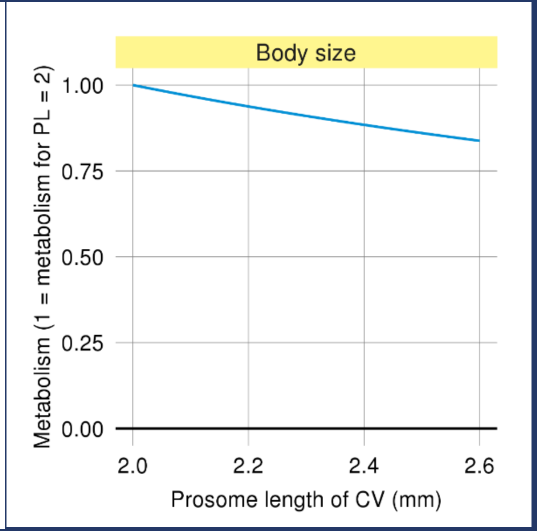


Energy reserves are much larger for bigger animals



Body size and temperature determine overwinter metabolism





Diapause duration as a function of summer and diapause temperature

Potential diapause duration (days)

$$= aL^b Q_{10}{}^{-T/10}$$

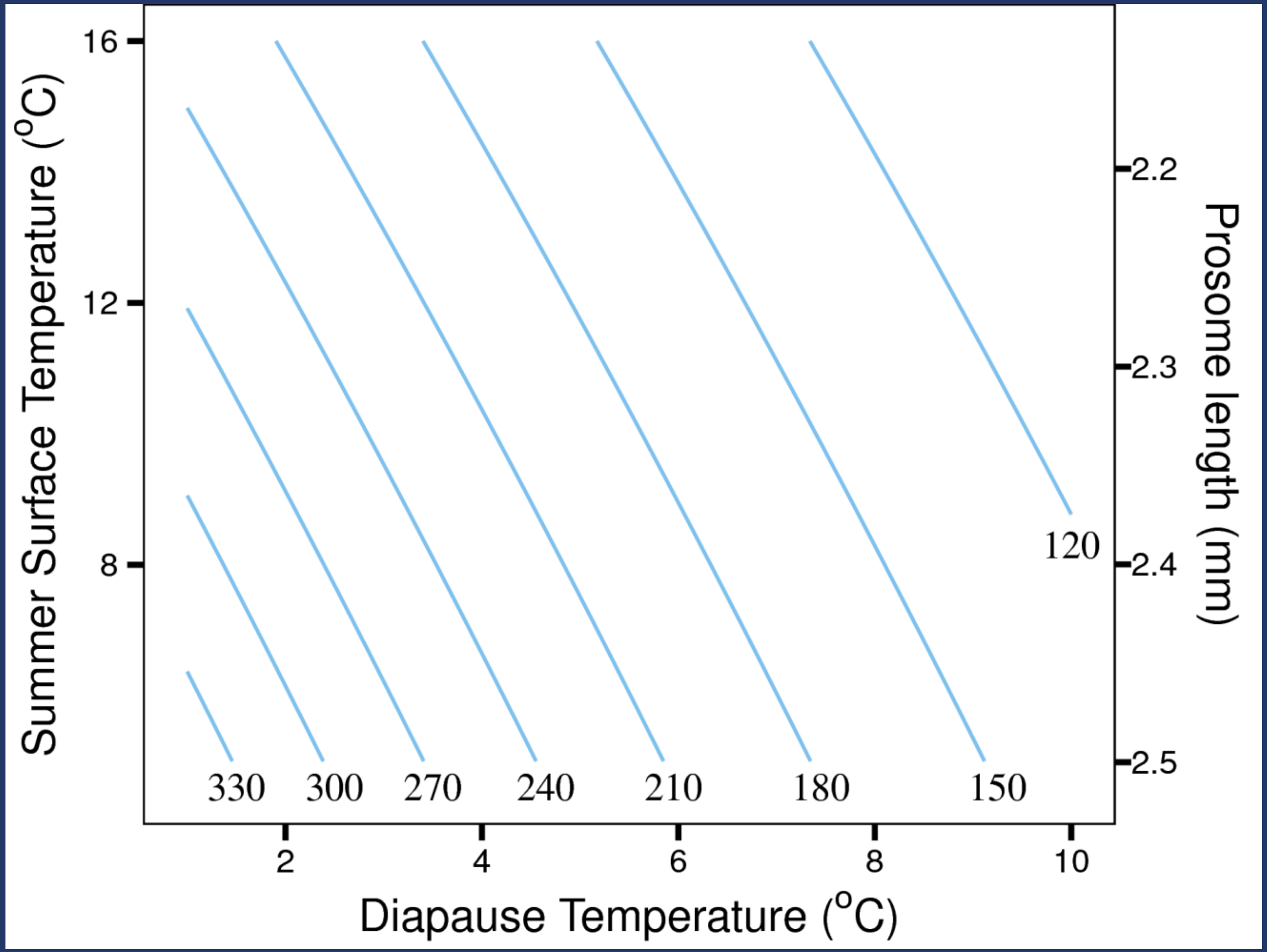
L = Prosome length

T = Diapause Temperature (°C)

$a = 36.08$

$b = 2.58$

$Q_{10} = 2.8$



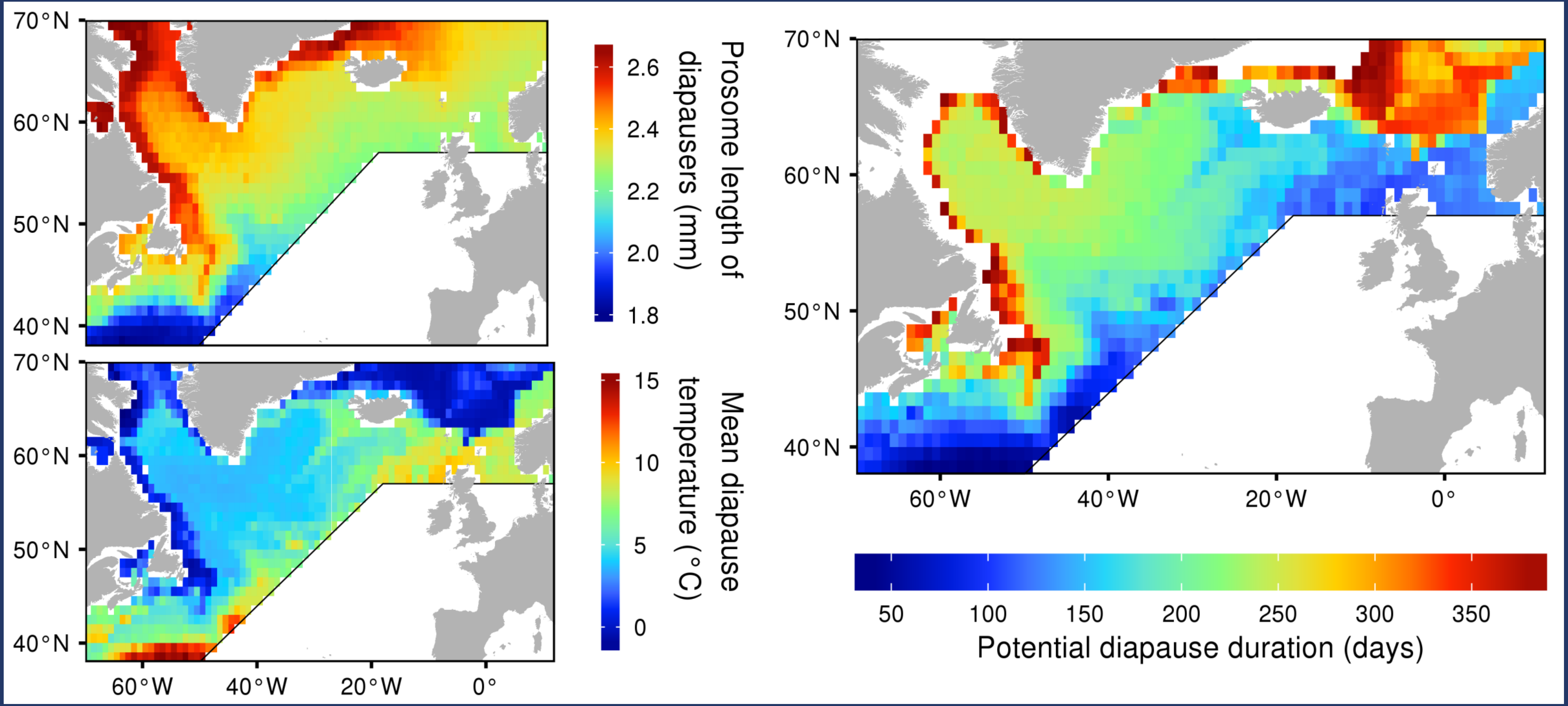
Model scenarios

	Present	Future
Period	2005-2012	2000-2009 to 2090-2099
Temperature	NOAA World Ocean Atlas	Nemo model driven by IPCC RCP 8.5

Ecological assumptions

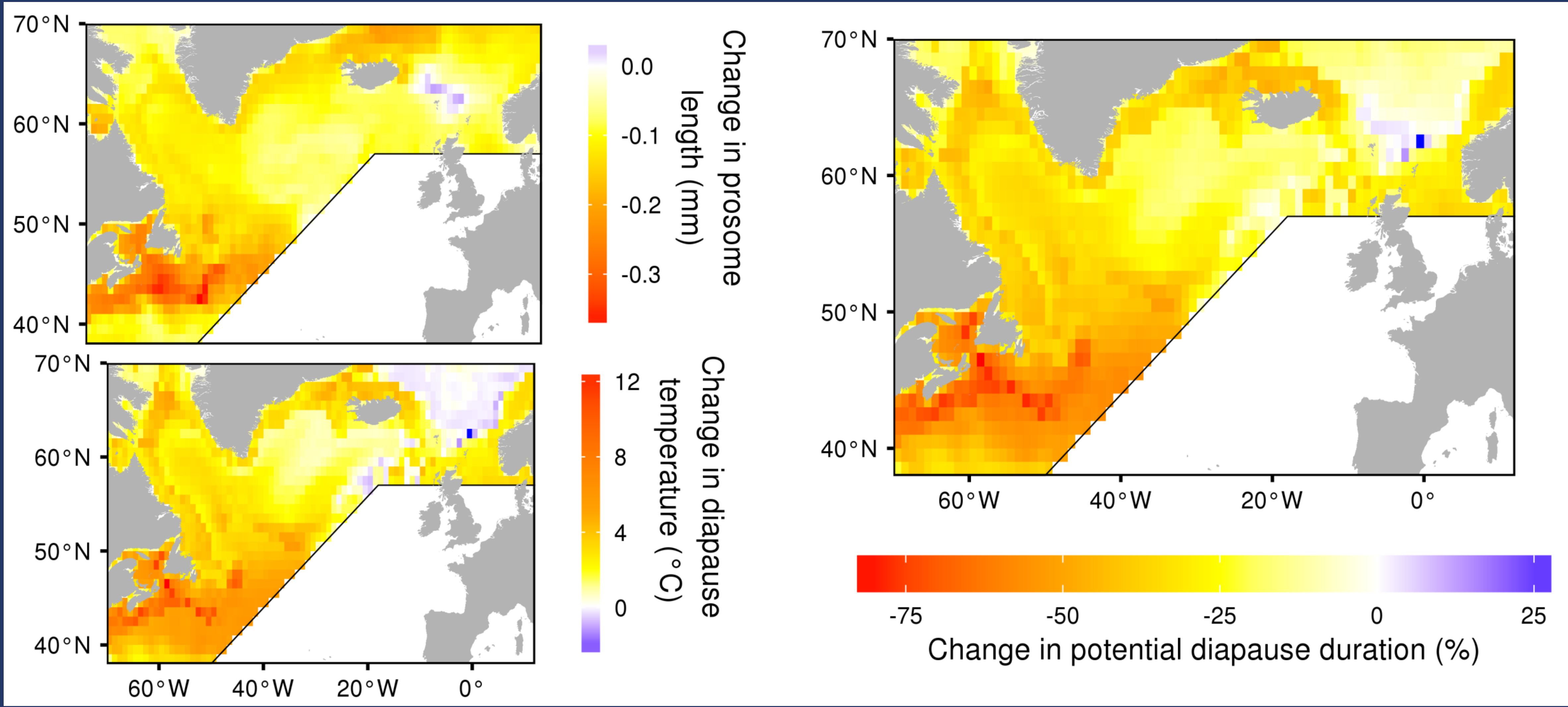
- Diapause depths in the North Atlantic were derived from field data (Heath et al. 2004)
- Body size of diapausing animals is determined by mean July/August surface temperature
- Diapause temperature assumed to be mean temperature at diapause depth between September and March

Deep water temperature drives geographic variations in current potential diapause duration



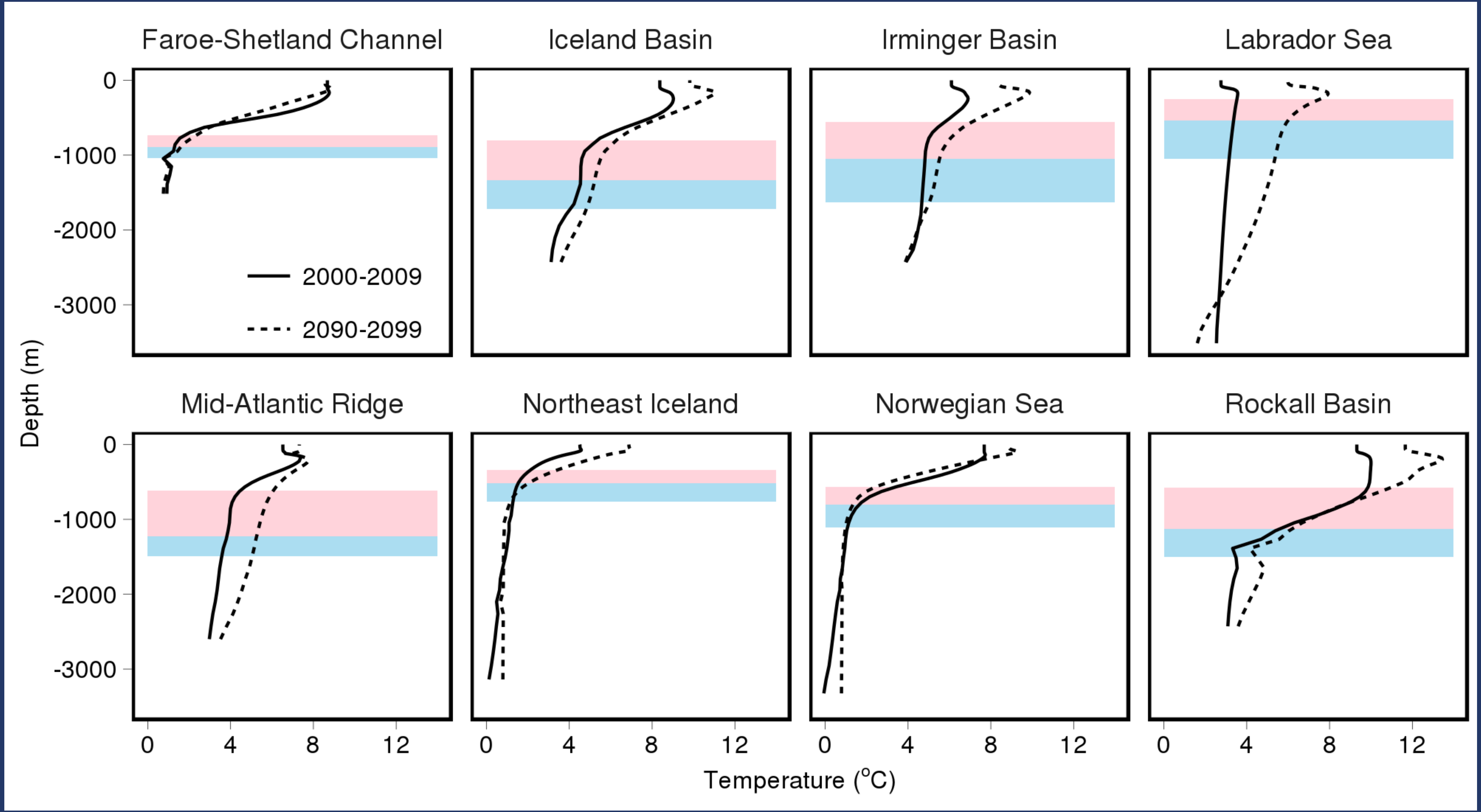
Wilson et al., 2016, *Global Change Biology*

21st century changes in the west Atlantic are the most severe



Wilson et al., 2016, *Global Change Biology*

Animals could reduce climate impacts by diapausing in deeper water



Current diapauser distribution

13-50%

50-83%

Temperature profiles for 1st week of January

Conclusions

- Good news for diapausers in the Norwegian Sea
- Potentially not so bad news for diapausers in the Labrador Sea.
- But, can *C. finmarchicus* actually control its diapause depth to adapt to climate change?

Thanks for listening

Funding

Marine Alliance for Science and Technology Scotland

University of Washington

National Science Foundation

Key field and experimental studies used in the model

Campbell *et al.* (2001) *Marine Ecology Progress Series*,

Heath *et al.* (2004). *ICES Journal of Marine Science*.

Pepin and Head (2009) *Deep-Sea Research*

Runge *et al.* (2006) *Deep-Sea Research Part II*

Saumweber and Durbin (2006) *Deep-Sea Research Part II*