Effects of climate change and ocean acidification on the marine environment

Jon. Havenhand

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University of Gothenburg

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Science

Antarctic sea-ice at 'mind-blowing' low alarms experts

1 day ago

Climate change

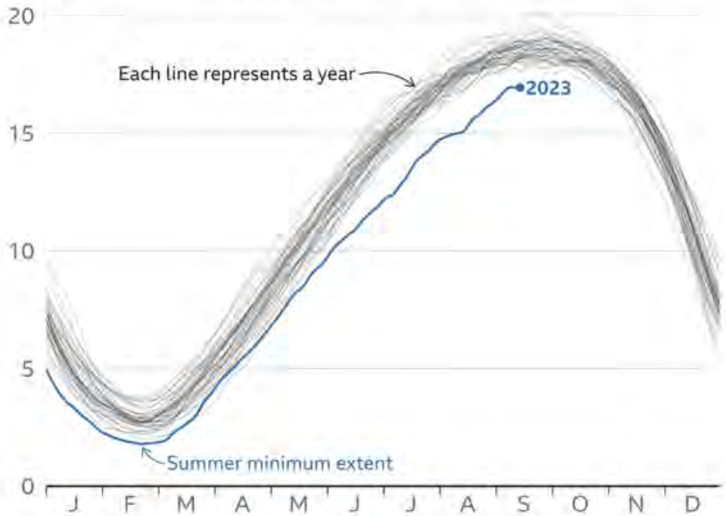
A scientist on the ice in Antarctica

By Georgina Rannard, Becky Dale and Erwan Rivault
BBC News Climate & Science and Data Journalism Team

The sea-ice surrounding Antarctica is well below any previous recorded winter level, satellite data shows, a worrying new benchmark for a region that once seemed resistant to global warming.

Antarctica sea-ice far lower than usual

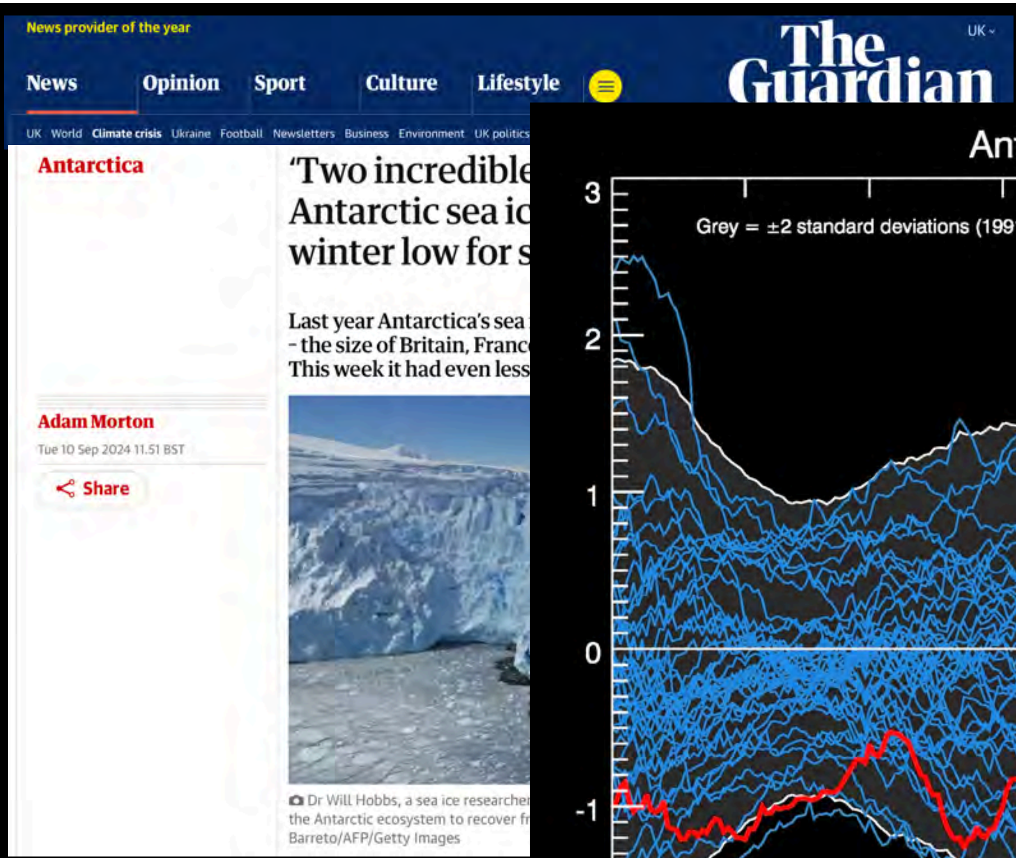
Daily sea-ice extent in million sq km, 1979-2023



Five-day rolling average of sea-ice extent

Source: National Snow and Ice Data Center (NSIDC), data to 14 Sep 2023 BBC

Dr Meier is not optimistic that the sea-ice will recover to a significant degree.



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Antarctica

'Two incredible
Antarctic sea ic
winter low for s

Last year Antarctica's sea
- the size of Britain, Franc
This week it had even less

Adam Morton

Tue 10 Sep 2024 11.51 BST

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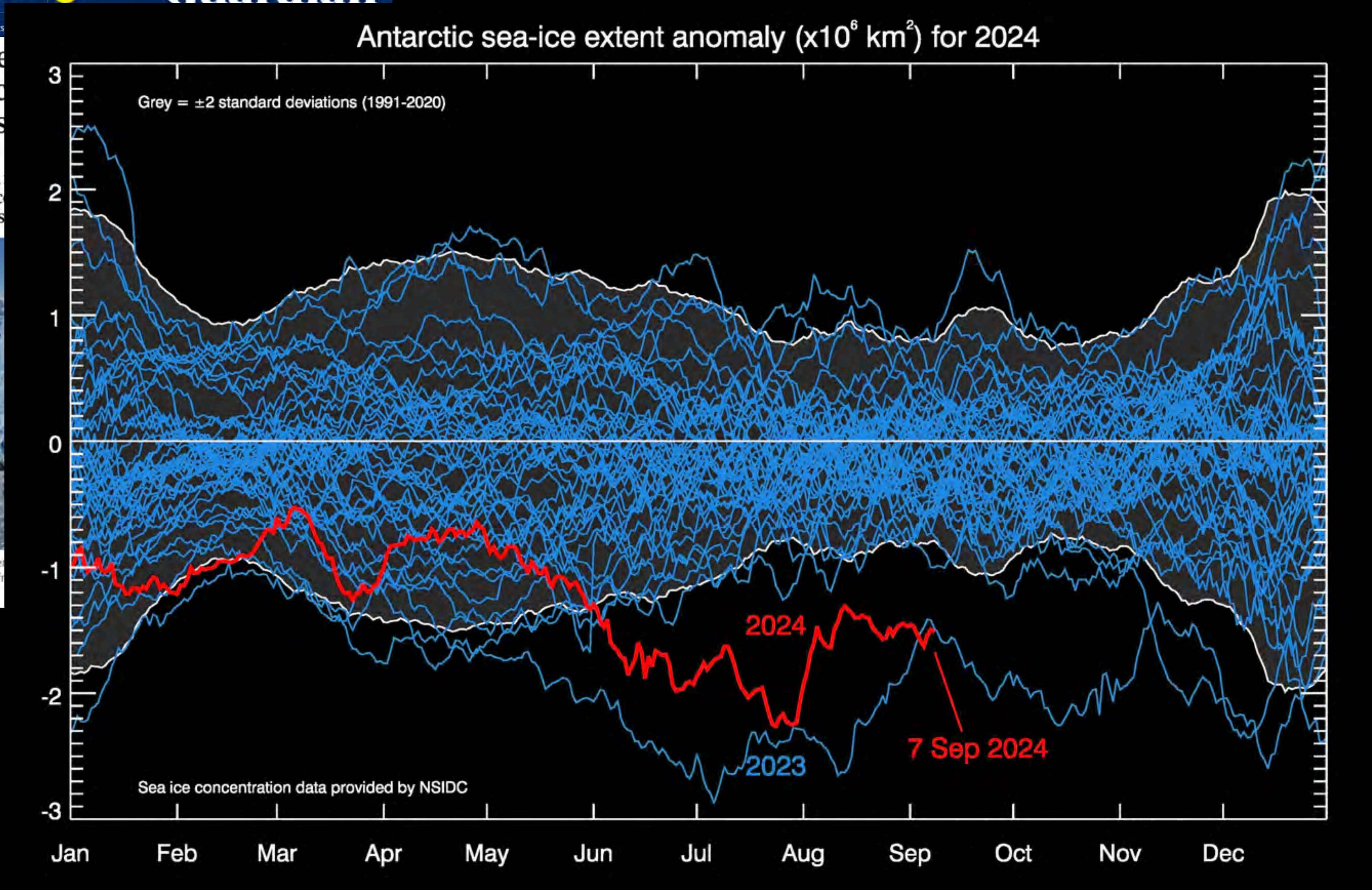
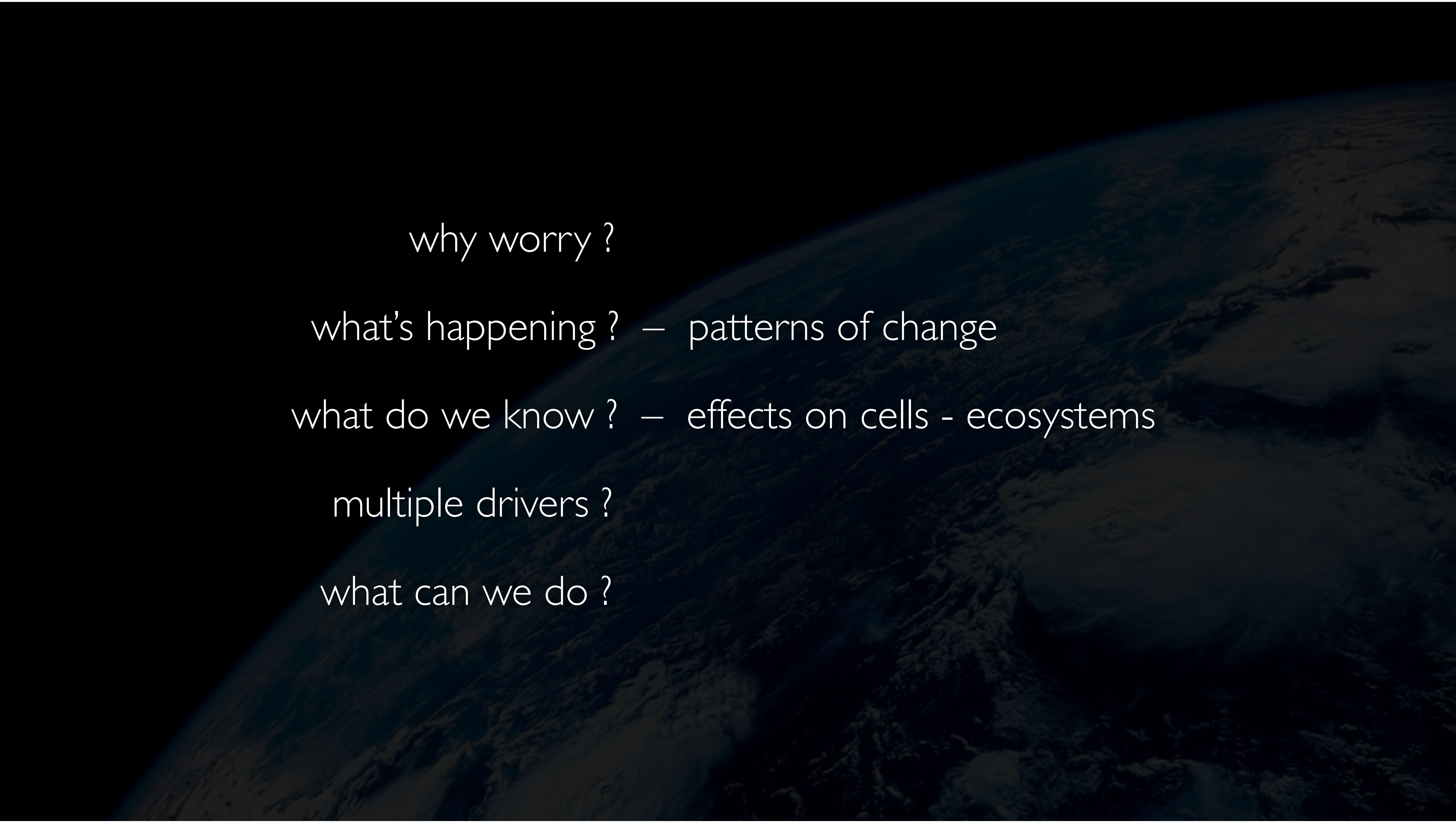
Dr Will Hobbs, a sea ice researcher
the Antarctic ecosystem to recover fr
Barreto/AFP/Getty Images




why worry ?
what's happening ? – patterns of change
what do we know ? – effects on cells - ecosystems
multiple drivers ?
what can we do ?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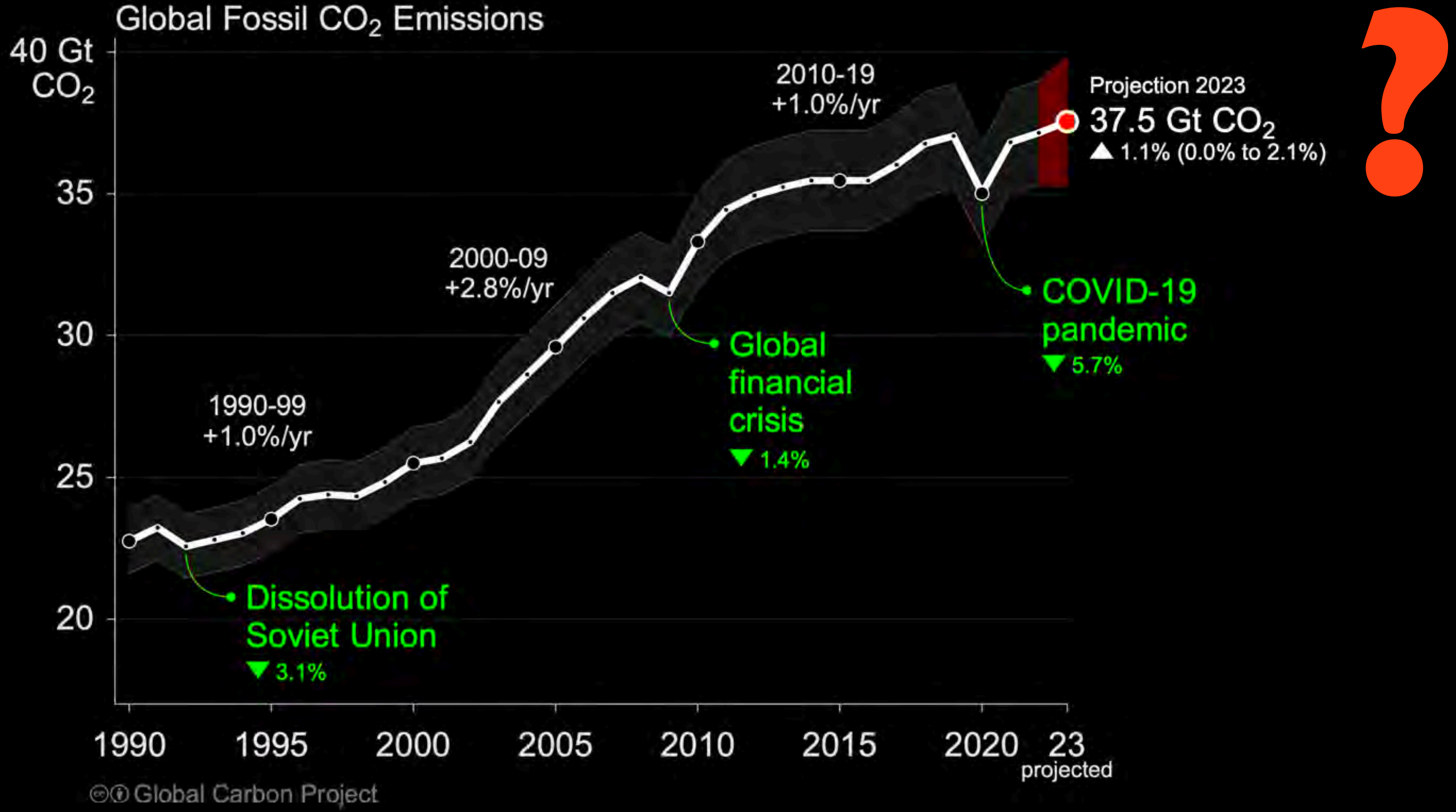
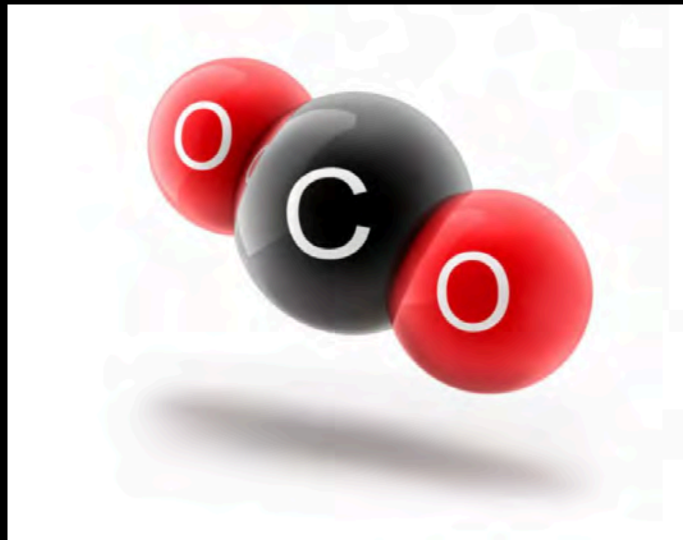
Global emissions from fossil fuels and industry



Carbon is not Carbon dioxide



Carbon atomic weight = 12
Oxygen atomic weight = 16
Carbon dioxide molecular weight = 44

So weight of Carbon is 12/44
= 27.3% of weight of CO_2

$CO_2 = 3.67 \times C$

1 Gt = 1 Gigatonne = 1 billion tonnes

Each wagon is ~ 18m long, and contains 100 tonnes coal, which is equivalent to 80 tonnes C

Q: How long does the train have to be to contain 10.2 Gt C (≈ 37.5 Gt CO_2) ?

1 Gt = 1 Gigatonne = 1 billion tonnes

45 454 000 km ≈ 1134 x around the Earth

from "*Life*" Magazine, 1962

(courtesy Jelle Bijma)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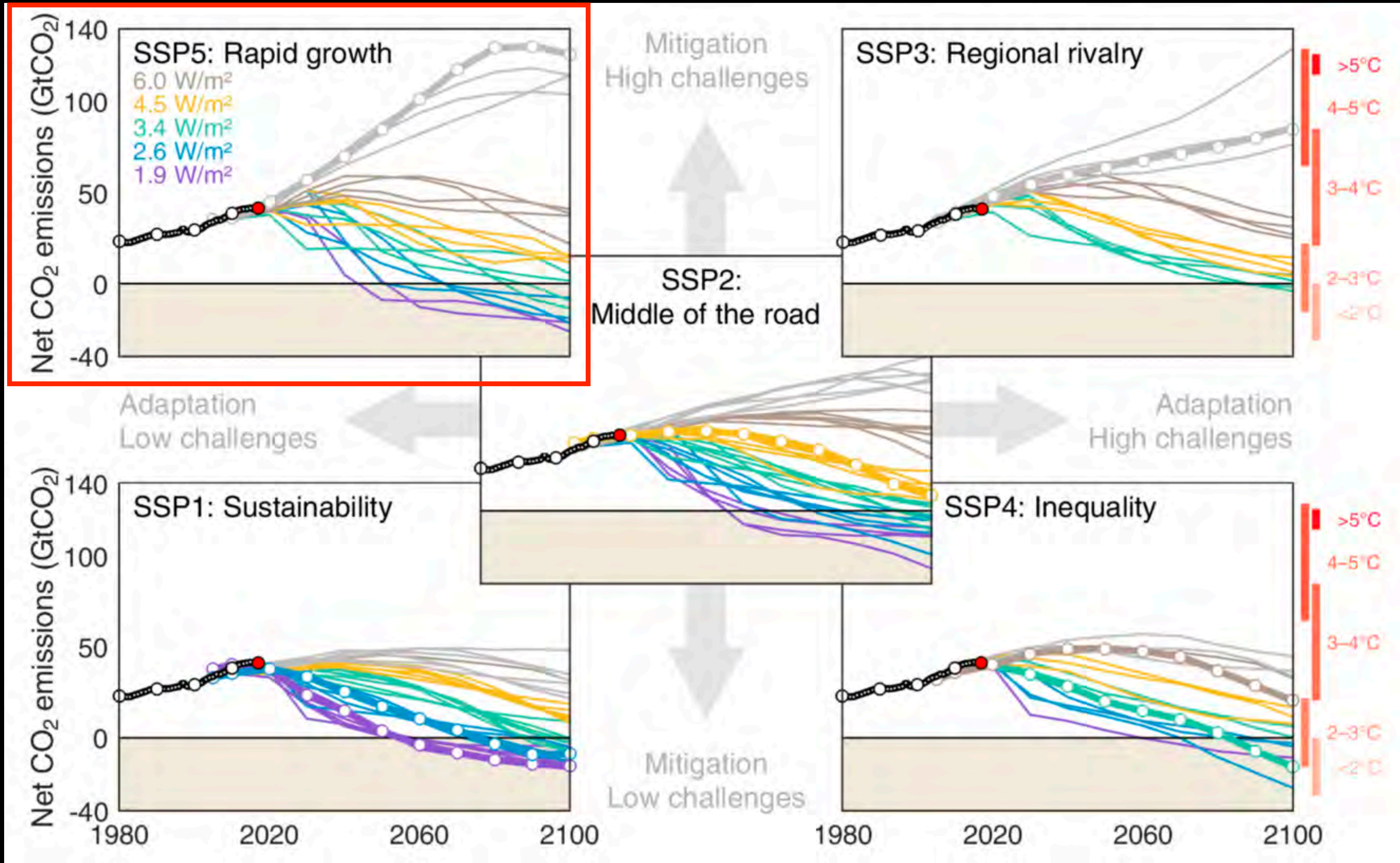
acidification

GLOBAL CARBON PROJECT

Shared Socioeconomic Pathways (SSPs)



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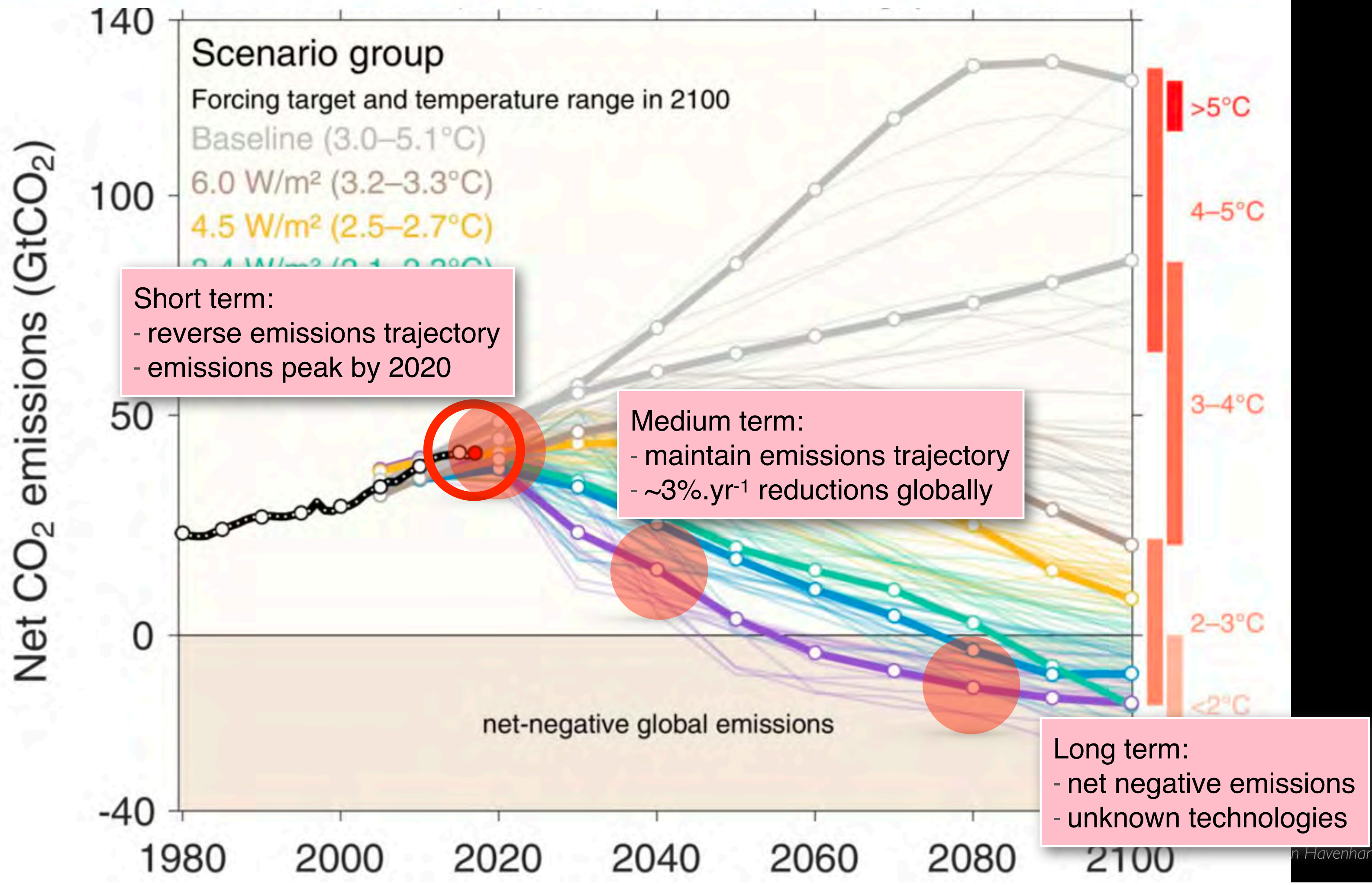
GLOBAL CARBON PROJECT

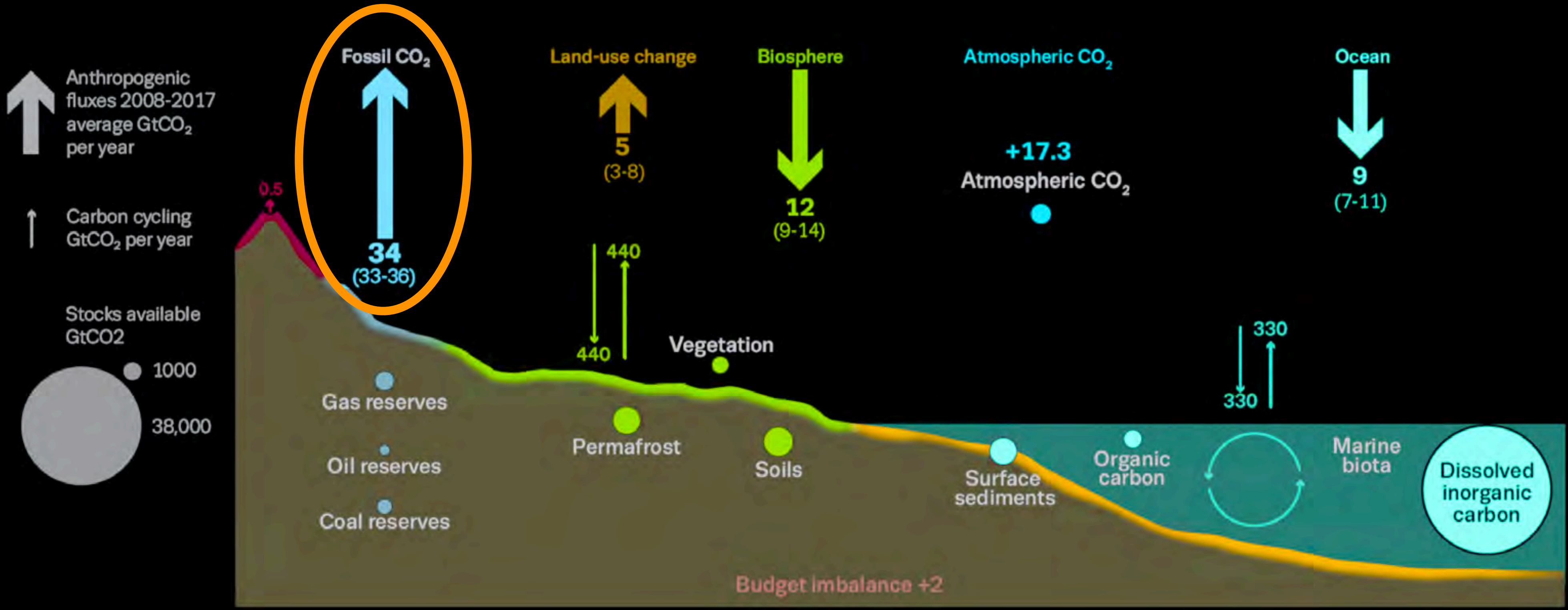
Shared Socioeconomic Pathways (SSPs)

The Shared Socioeconomic Pathways (SSPs) lead to a broad range in baselines (grey), with more aggressive mitigation leading to lower temperature outcomes (grouped by colours)



effect of rising $CO_{2\,atm}$ on ocean climate and acidification

Global CO_2 budget: average $GtCO_2$ / yr (2008 - 2017)



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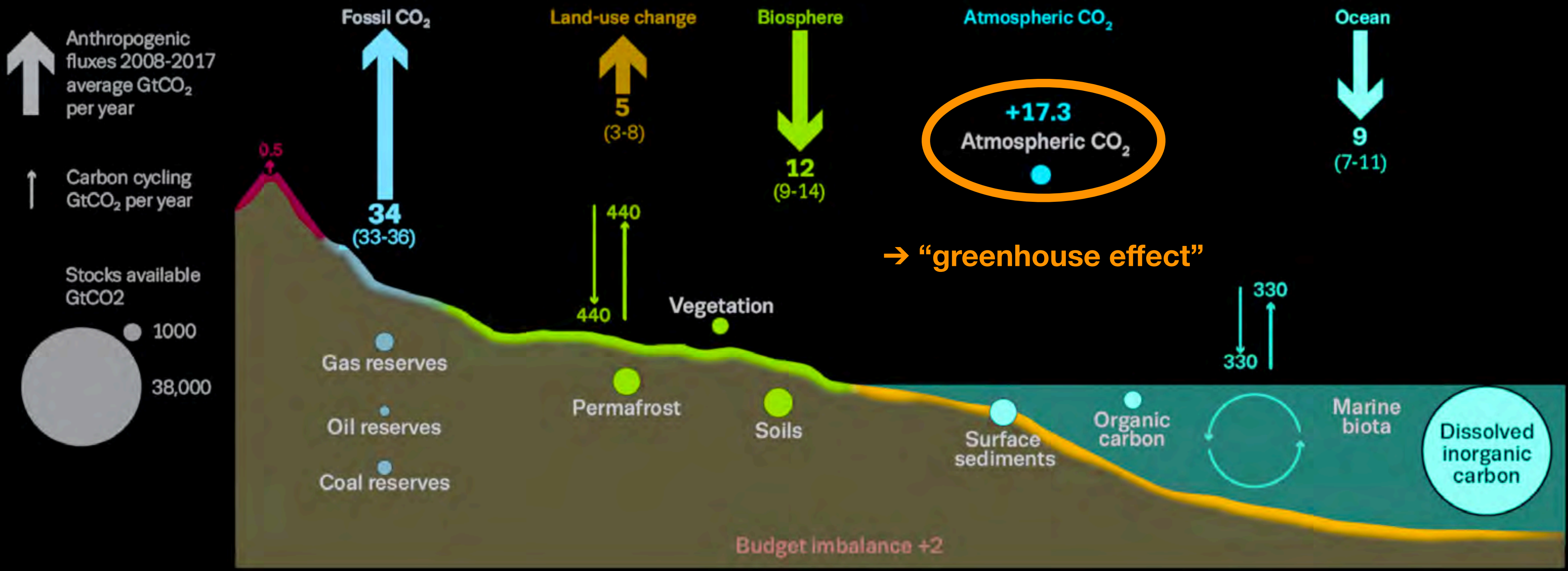

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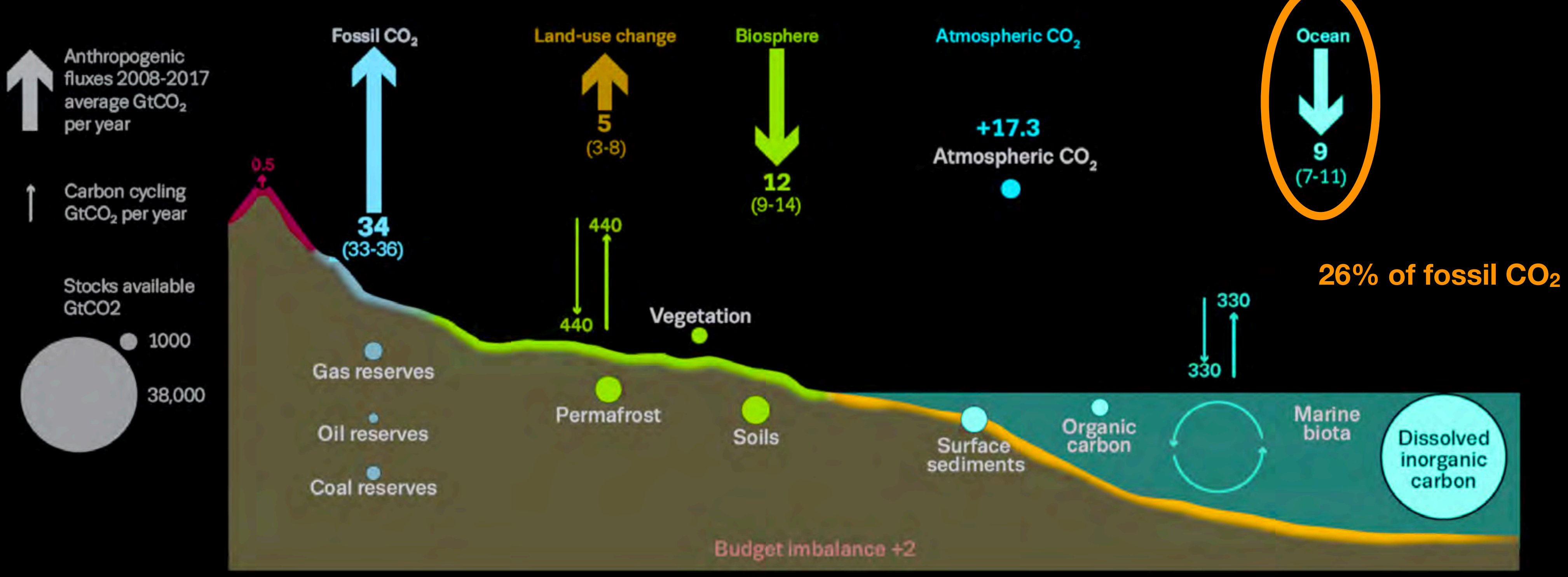
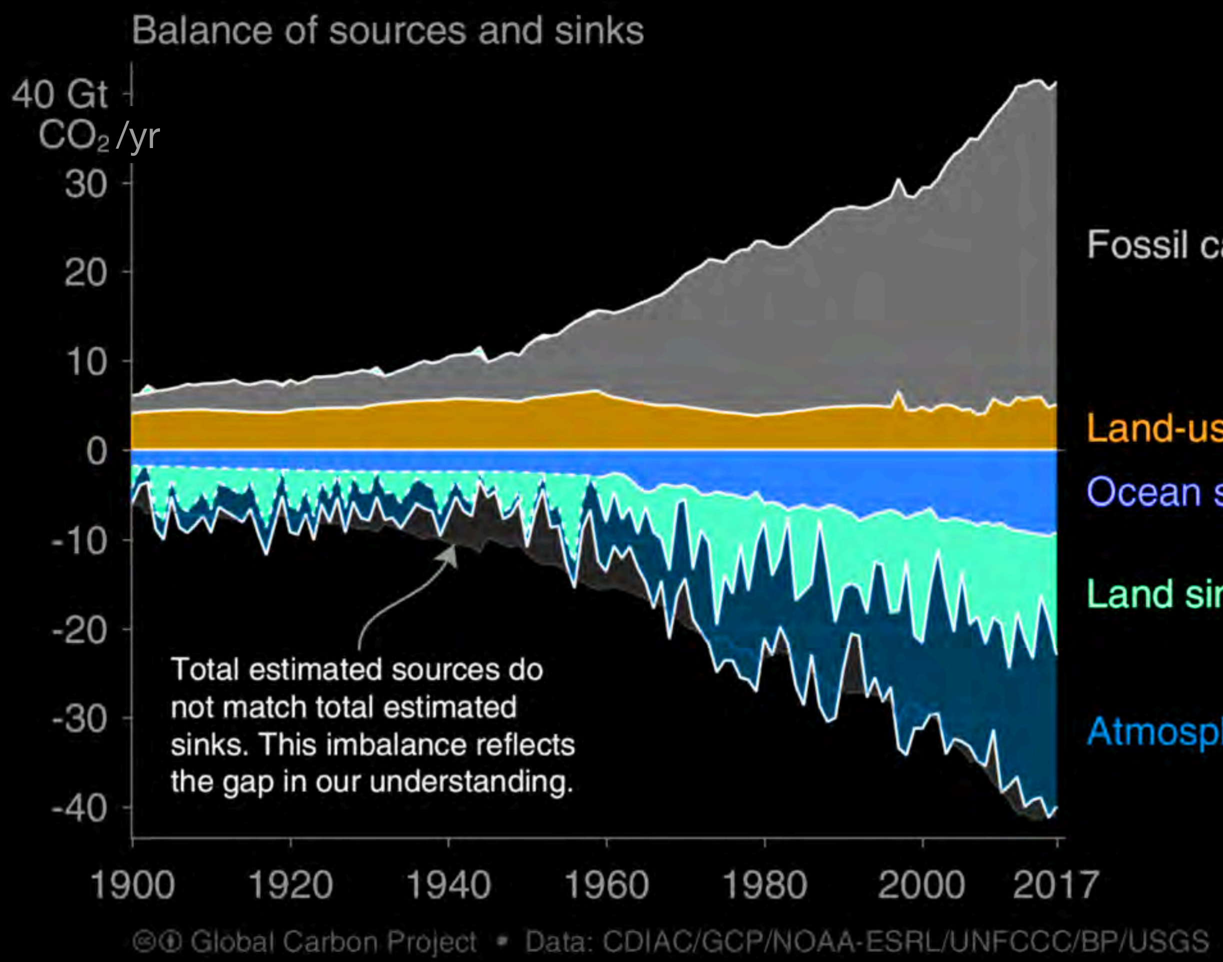


the oceans absorb increasing amounts of CO_2



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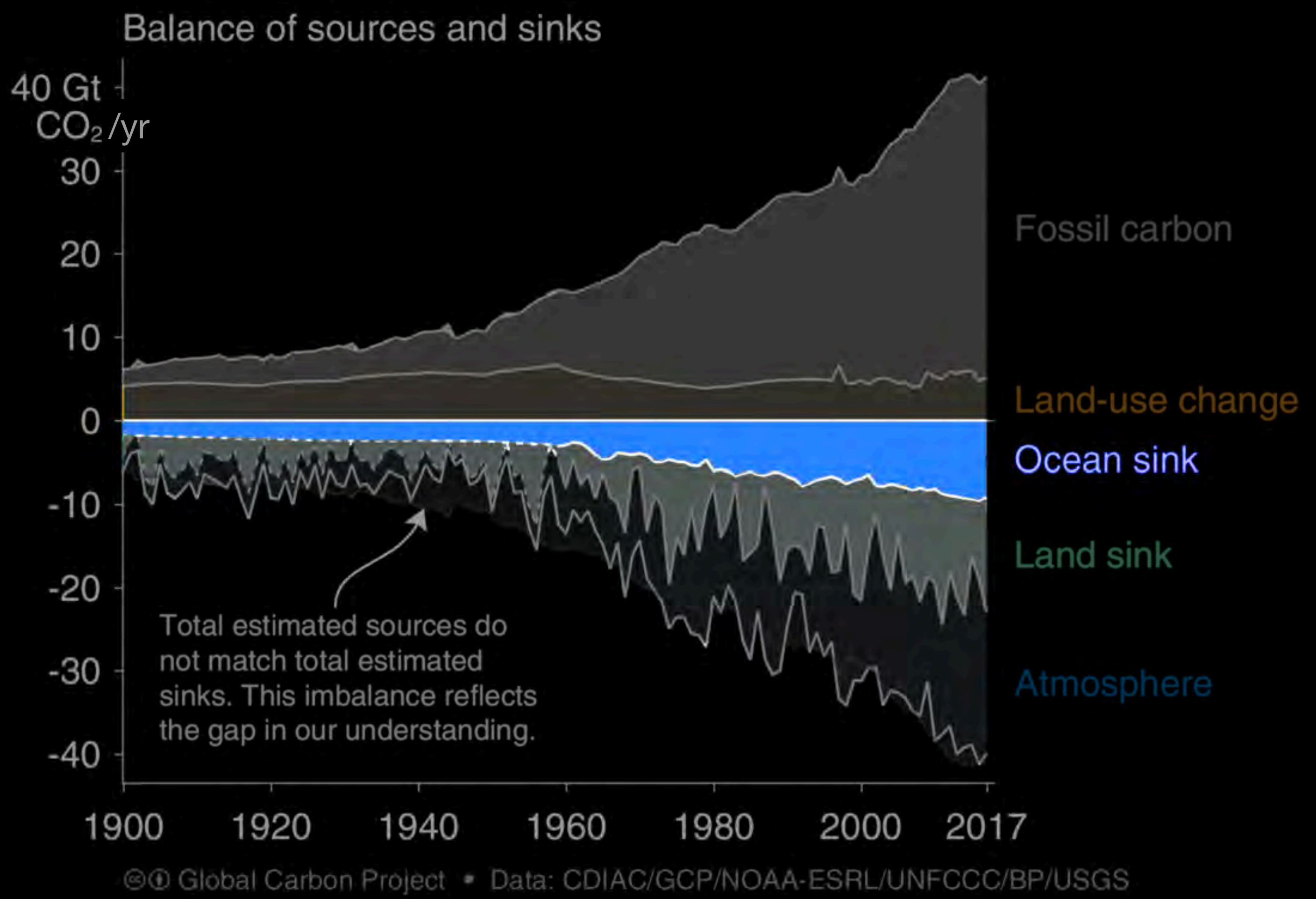

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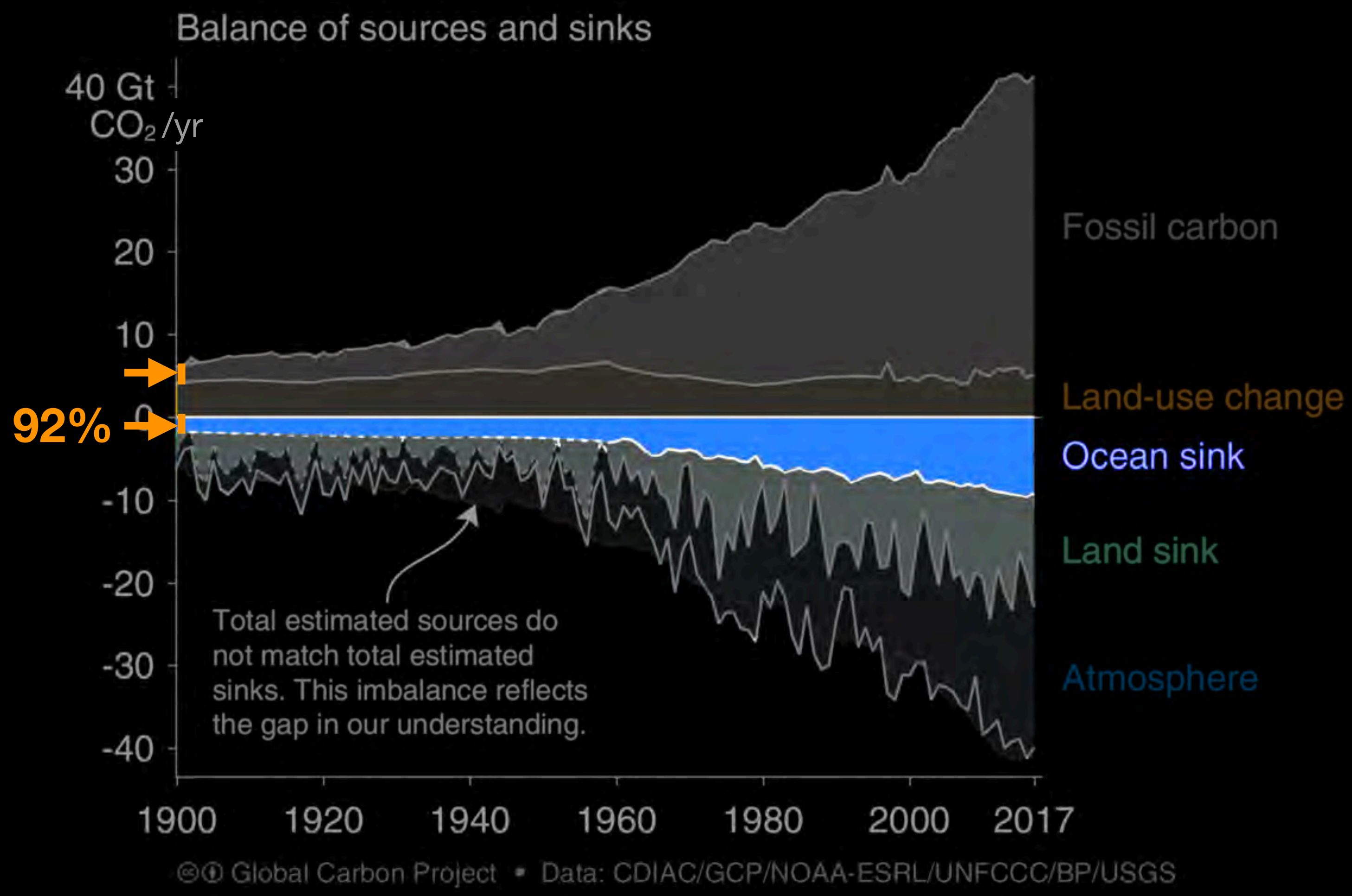

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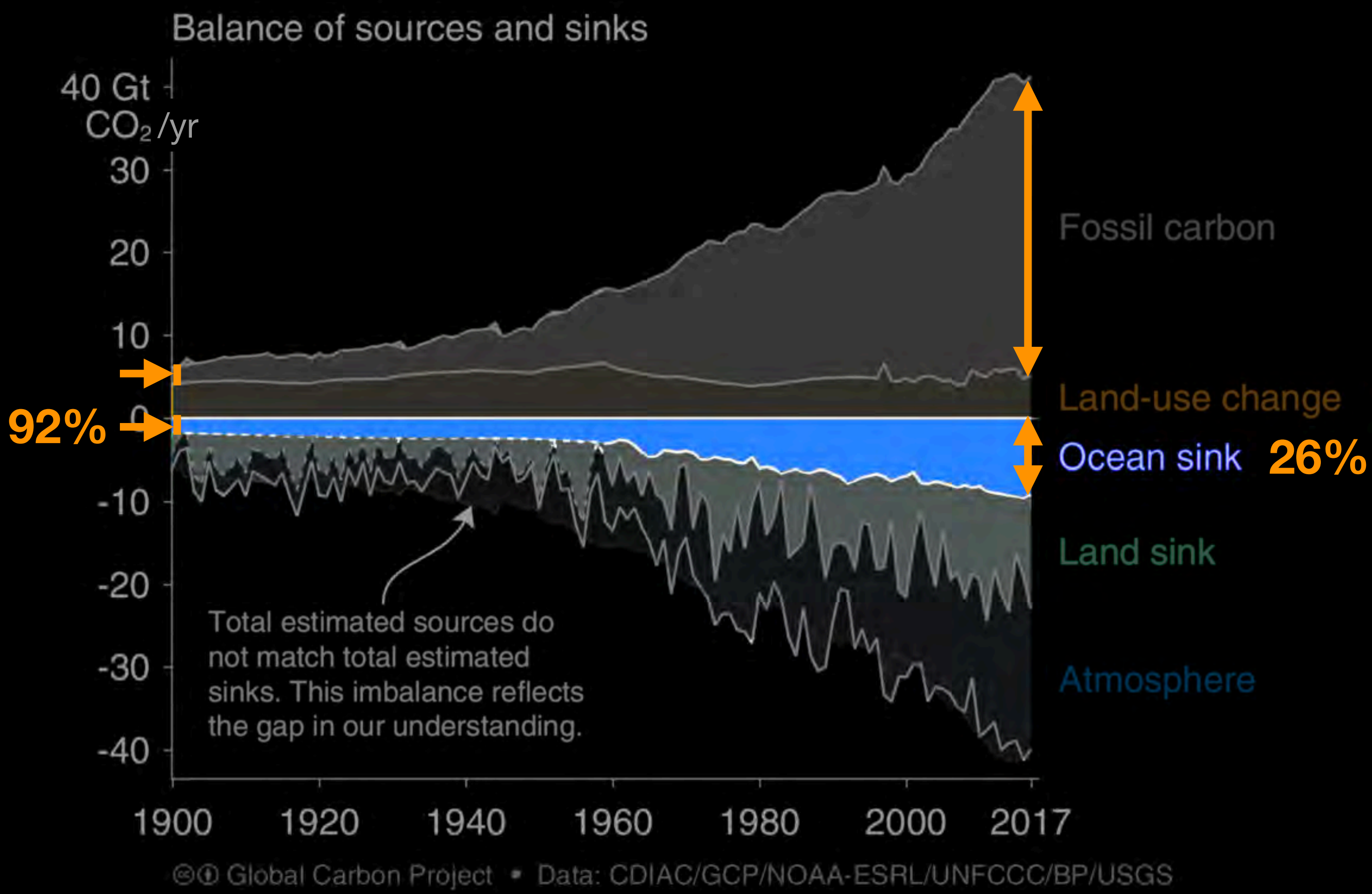

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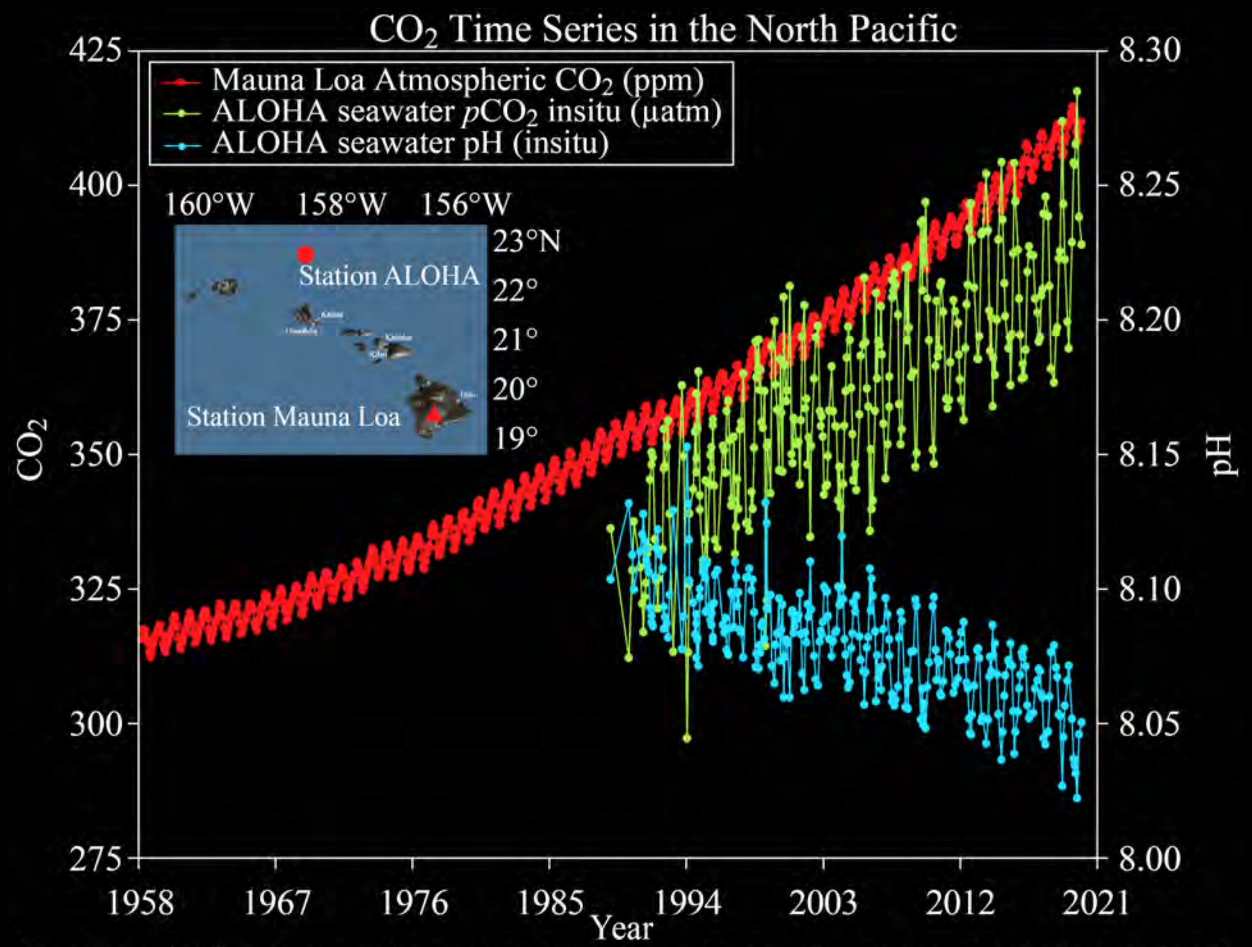
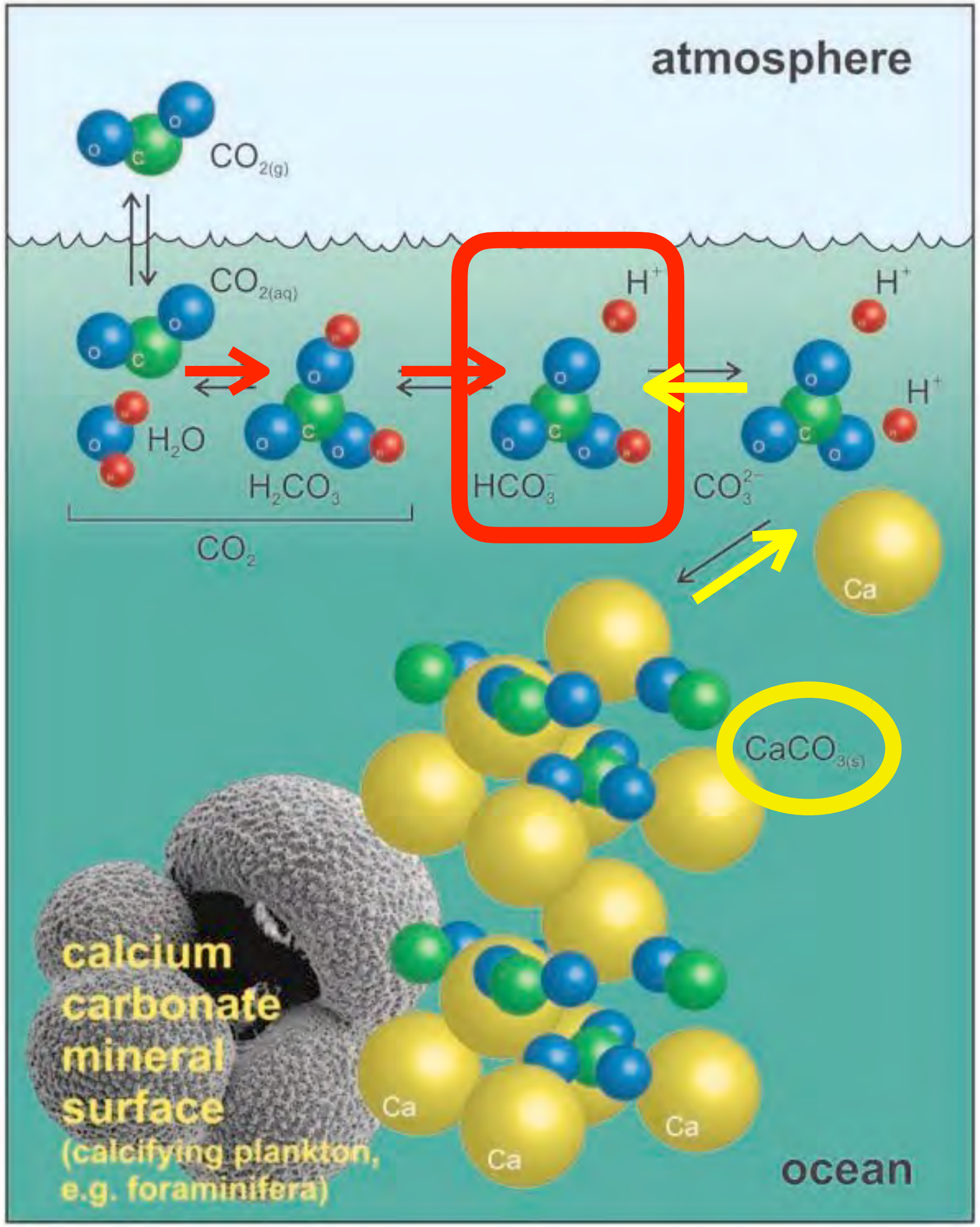
increasing CO_2 makes the oceans more acidic



Data: Mauna Loa (ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt) ALOHA (http://hahana.soest.hawaii.edu/hot/hot-dogs/bextraction.html)
ALOHA pH & pCO_2 are calculated at in-situ temperature from DIC & TA (measured from samples collected on Hawaii Ocean Times-series (HOT) cruises) using co2sys (Pelletier, v25b06) with constants: Lueker et al. 2000, KSO4: Dickson, Total boron: Lee et al. 2010, & KF: seacarb

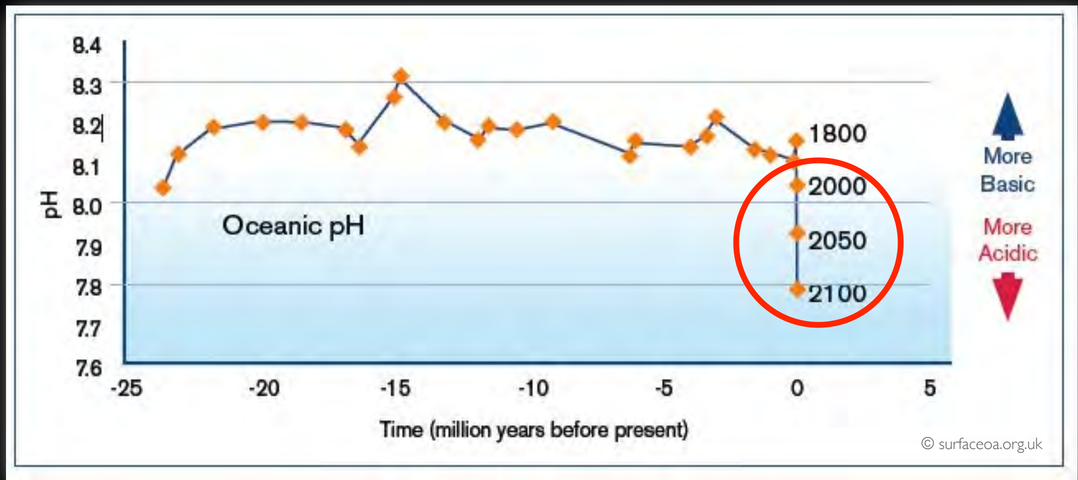
ocean acidification

- CO_2 uptake by the oceans ⇨ ocean acidification
- chemical balance depends on pH
- at ocean pH (~ 8.0) most inorganic carbon is present as HCO_3^-
- so increasing CO_2 uptake causes dissolution of $CaCO_3$



ocean acidification

- since 1800 the oceans have become ~ 27% more acidic (≈ 0.1 pH)
- RCP 8.5 (≈ SSP 5) projects oceans ~ 1.8 x more acidic by the year 2100



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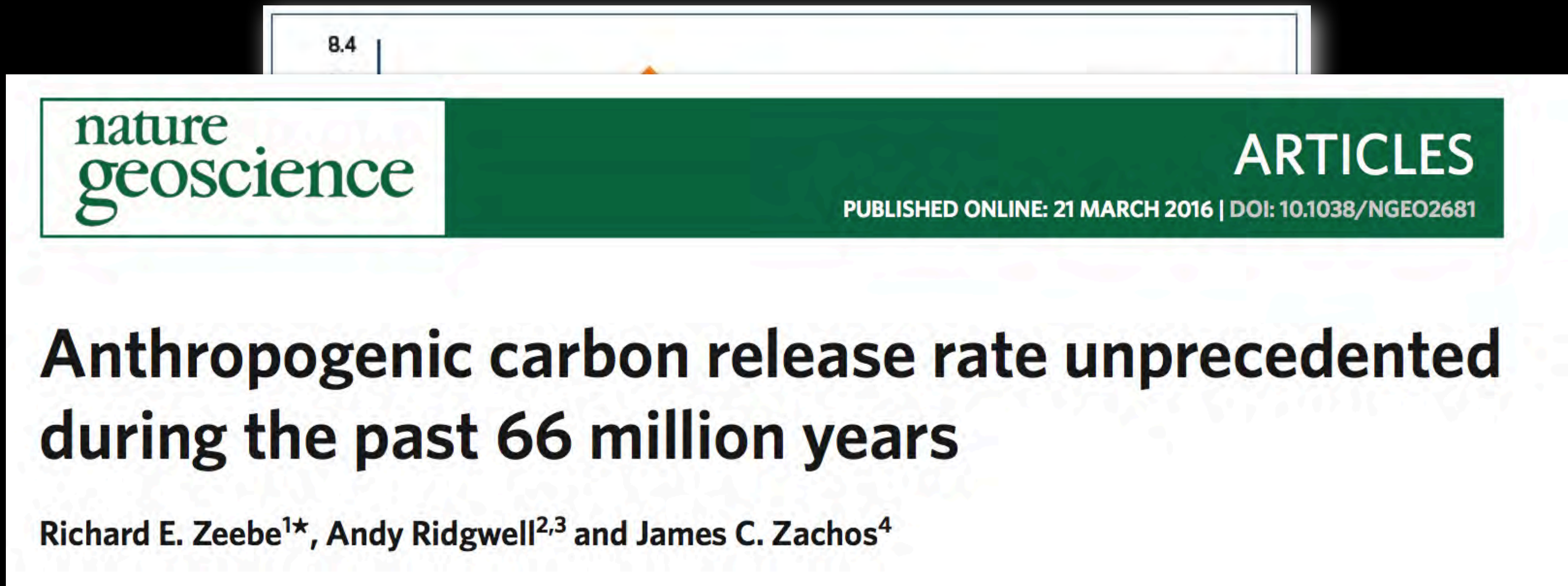
- Largest & **Fastest** change in ocean pH for ~66 million years



nature geoscience
ARTICLES
PUBLISHED ONLINE: 21 MARCH 2016 | DOI: 10.1038/NGEO2681

Anthropogenic carbon release rate unprecedented during the past 66 million years

Richard E. Zeebe[1]*, Andy Ridgwell[2,3] and James C. Zachos[4]


why worry ?
what's happening ? – patterns of change
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multiple drivers ?
what can we do ?

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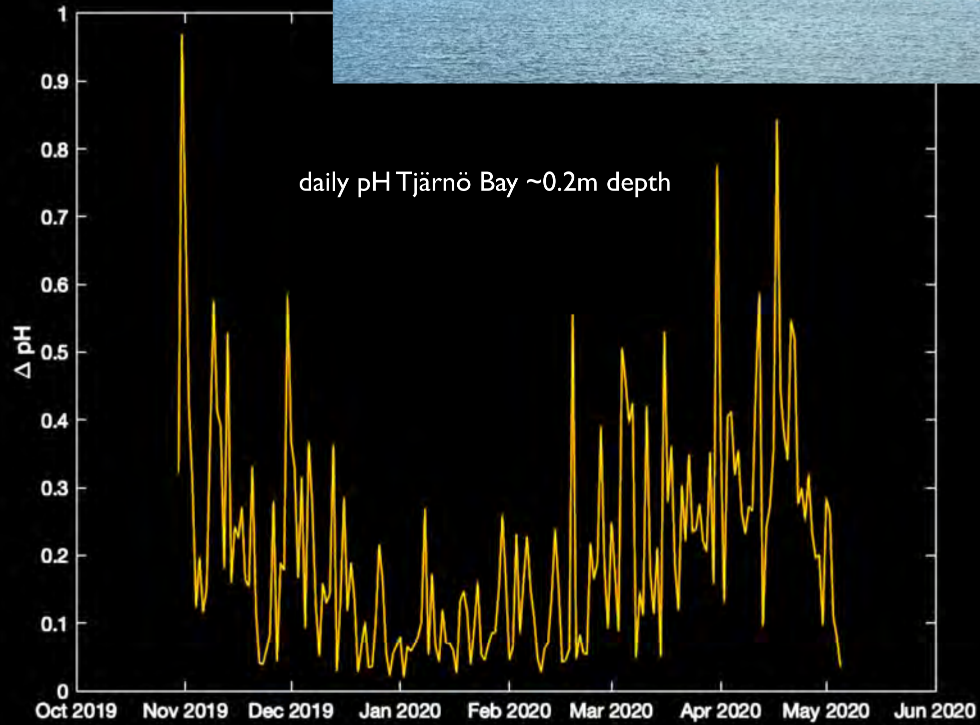
what will happen in an acidified ocean?

- the worlds oceans are already ~0.1 pH units more acidic than 1800's
- modelling projects ≈ 0.35 pH units more acidic by 2100
  - doesn't sound like much but pH scale is $\log_{10}$
  - 0.35 pH units ≈ 2 x more acidic
- but pH varies naturally daily



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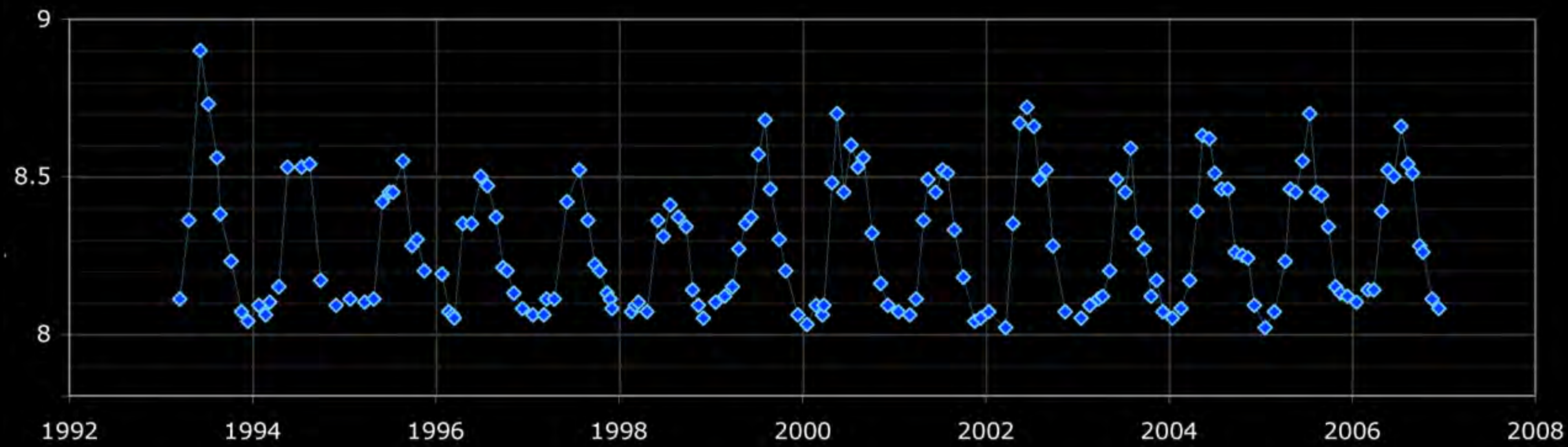

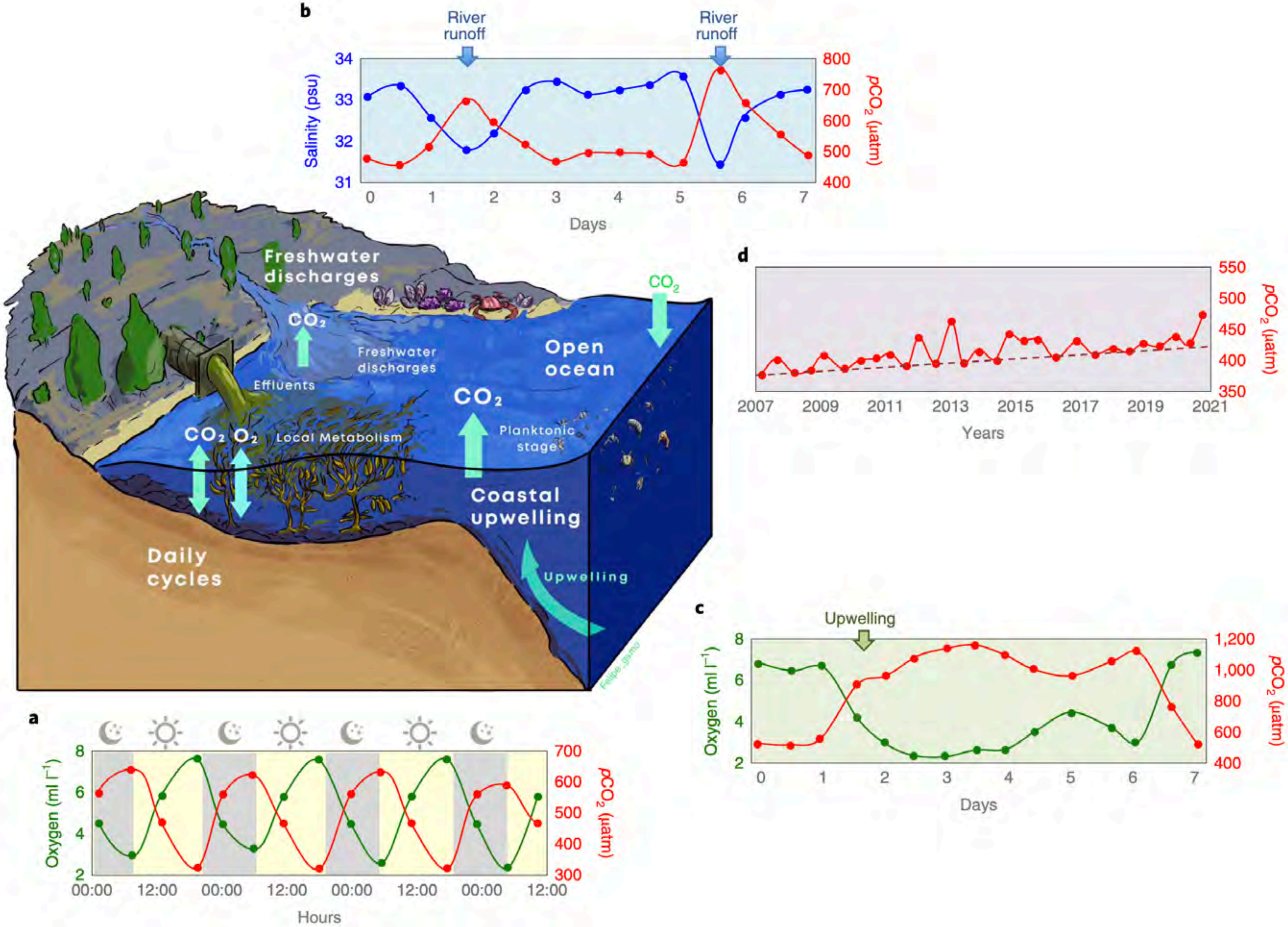
b
River runoff
River runoff
Salinity (psu)
pCO2 (µatm)
Days
d
pCO2 (µatm)
Years
Freshwater discharges
CO2
CO2
Freshwater discharges
Effluents
Open ocean
CO2
CO2 O2
Local Metabolism
Planktonic stage
Coastal upwelling
Daily cycles
Upwelling
c
Upwelling
Oxygen (ml l−1)
pCO2 (µatm)
Days
a
Oxygen (ml l−1)
pCO2 (µatm)
Hours

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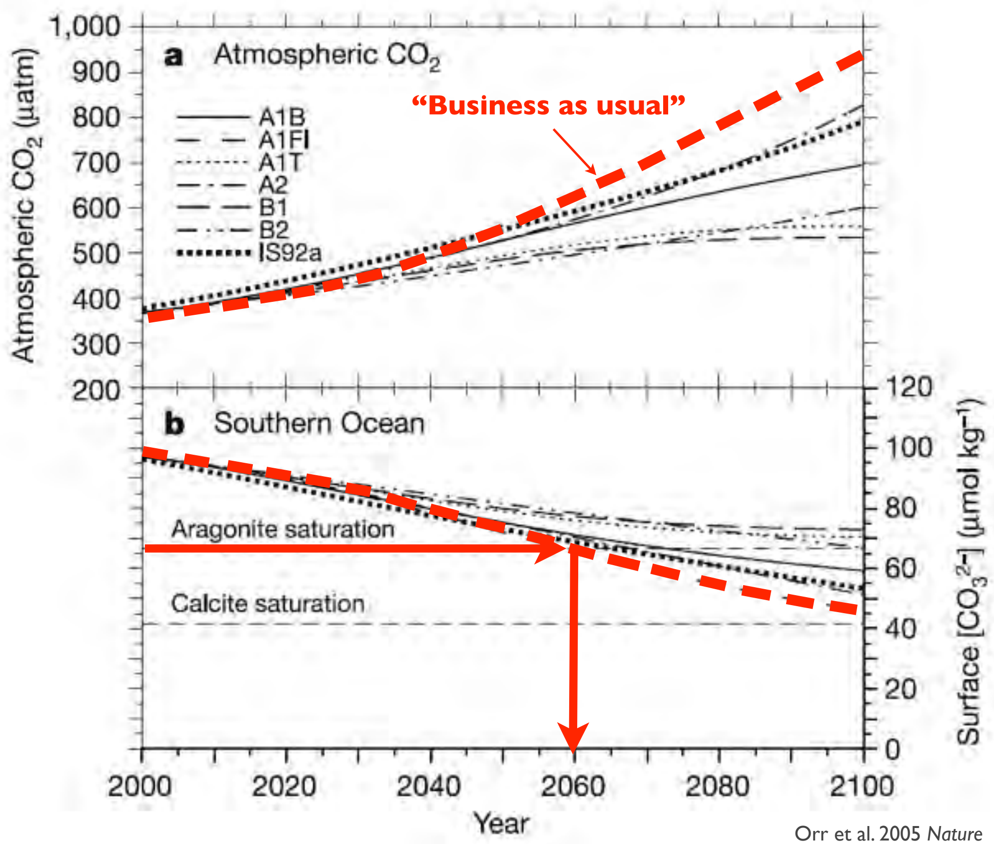
  - 0.35 pH units ≈ 2 x more acidic
- but pH varies naturally daily – and seasonally – and stochastically (e.g. weather)
- makes it very difficult to detect trends
- to date there are no reported ***observations*** of the effects of ocean acidification on marine species *in situ* in Sweden

carbonate chemistry – Southern Ocean



Orr et al. 2005 *Nature*

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what will happen in an acidified ocean? (observations)

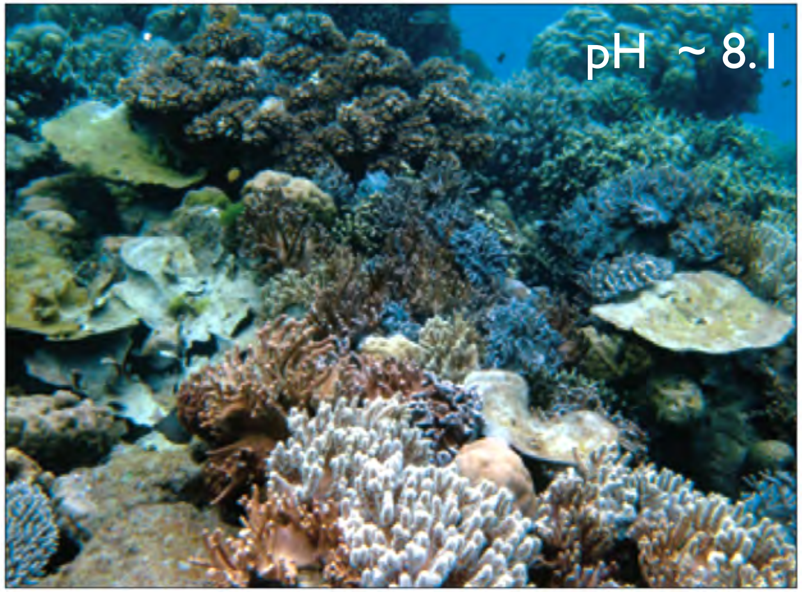
nature climate change

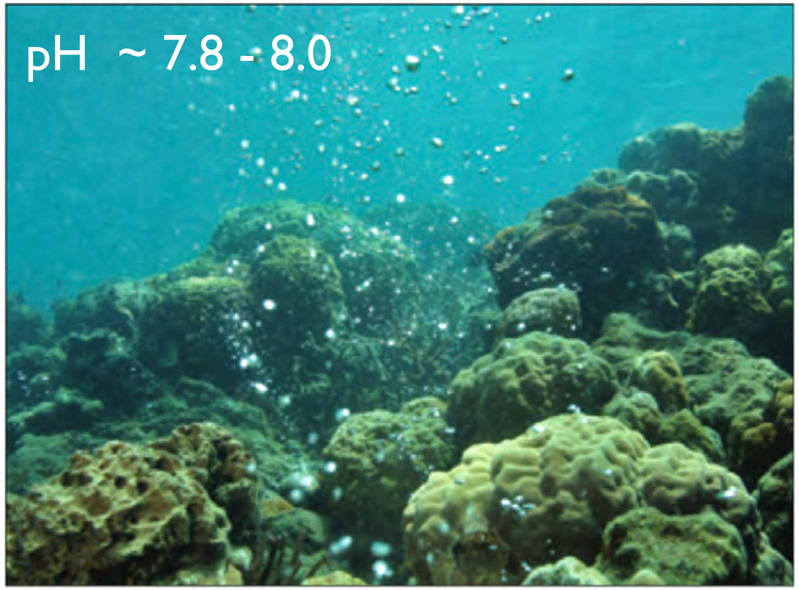
LETTERS

PUBLISHED ONLINE: 29 MAY 2011 | DOI: 10.1038/NCLIMATE1122

Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations

Katharina E. Fabricius[1]*, Chris Langdon[2], Sven Uthicke[1], Craig Humphrey[1], Sam Noonan[1], Glenn De'ath[1], Remy Okazaki[2], Nancy Muehllehner[2], Martin S. Glas[3] and Janice M. Lough[1]

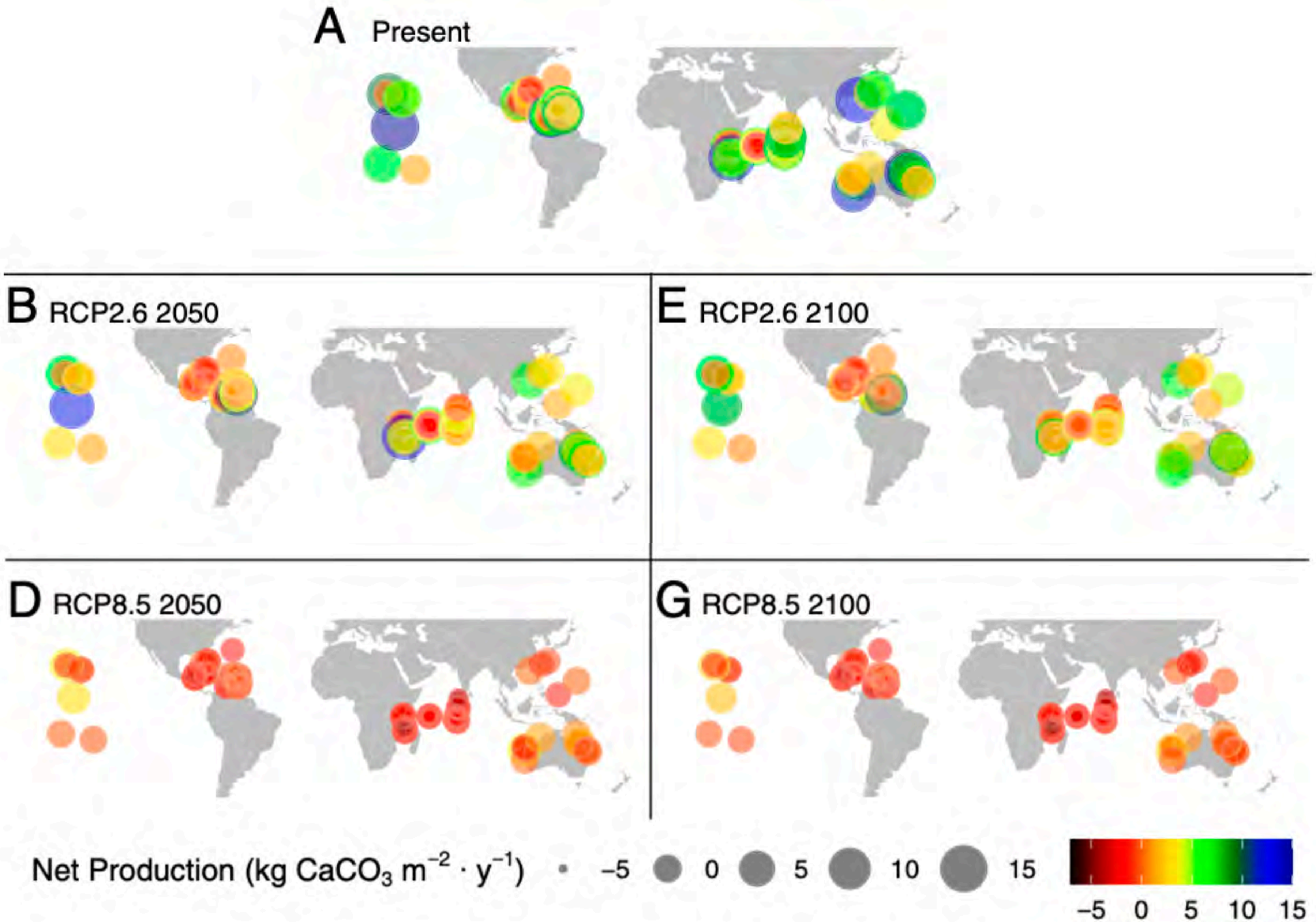




Global declines in coral reef calcium carbonate production under ocean acidification and warming

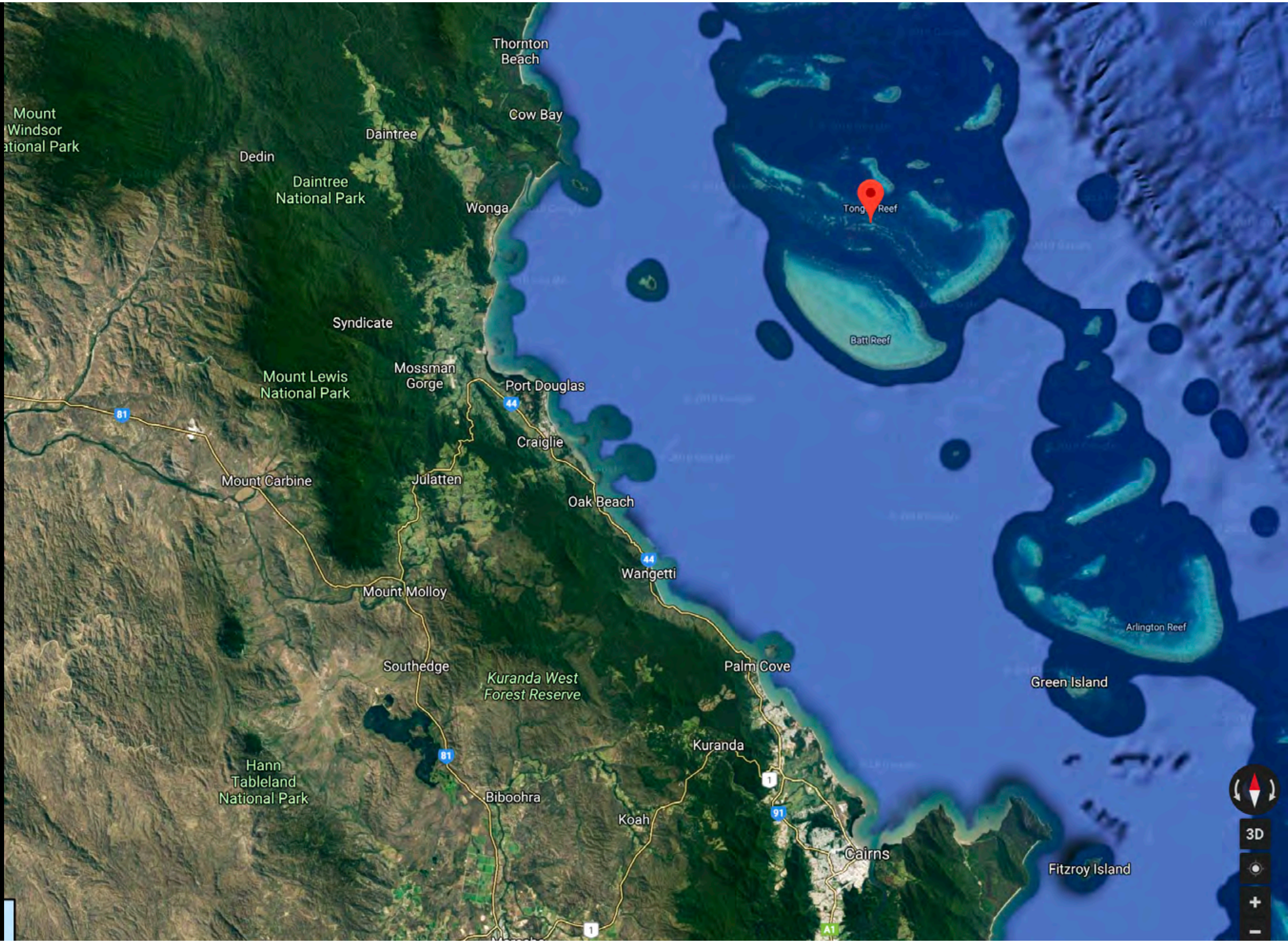
Christopher E. Cornwall[a,b,c,1,2], Steeve Comeau[b,c,d,1], Niklas A. Kornder[e,f], Chris T. Perry[g], Ruben van Hooidonk[h,i], Thomas M. DeCarlo[b,c,j], Morgan S. Pratchett[k], Kristen D. Anderson[k,l], Nicola Browne[m], Robert Carpenter[n], Guillermo Diaz-Pulido[o], Juan P. D'Olivo[b,c,3], Steve S. Doo[n,p], Joana Figueiredo[f], Sofia A. V. Fortunato[q], Emma Kennedy[o,r], Coulson A. Lantz[s,t], Malcolm T. McCulloch[b,c], Manuel González-Rivero[l,r], Verena Schoepf[b,c,e], Scott G. Smithers[q], and Ryan J. Lowe[b,c]

PNAS 2021 Vol. 118 No. 21 e2015265118


A Present
B RCP2.6 2050
E RCP2.6 2100
D RCP8.5 2050
G RCP8.5 2100
Net Production (kg $CaCO_3$ $m^{-2} \cdot y^{-1}$)
−5
0
5
10
15
−5 0 5 10 15

if you haven't snorkelled on a coral reef, do it soon !


NORTH SULAWESI
WEST PAPUA
CENTRAL SULAWESI
BANDA ARC
MALUKU
PAPUA
Bismarck Sea
Indonesia
Banda Sea
Papua New Guinea
Arafura Sea
Timor-Leste
Solomon Sea
Timor Sea
NORTHERN TERRITORY
Coral Sea
QUEENSLAND
Australia
WESTERN


Thornton Beach
Cow Bay
Mount Windsor
ational Park
Daintree
Dedin
Daintree National Park
Wonga
Tong Reef
Batt Reef
Syndicate
Mount Lewis National Park
Mossman Gorge
Port Douglas
Craiglie
Mount Carbine
Julatten
Oak Beach
Wangetti
Arlington Reef
Mount Molloy
Southedge
Kuranda West Forest Reserve
Palm Cove
Green Island
Kuranda
Hann Tableland National Park
Biboohra
Koah
Cairns
Fitzroy Island
3D


Turtle Bay, Tongue Reef
2016

what will happen in an acidified ocean? (experiments)

- cold-water corals (*Lophelia*) unaffected by low pH & low $\Omega_{aragonite}$
  - if given sufficient food

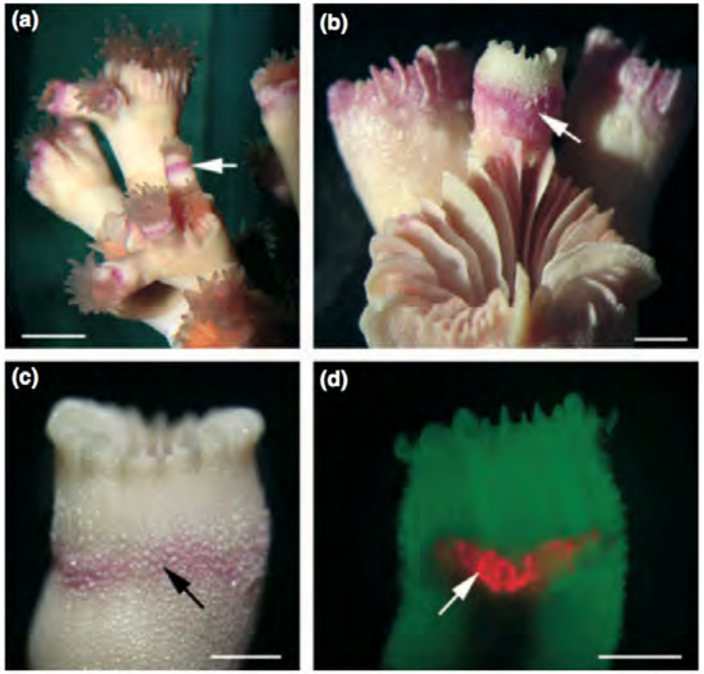


Fig. 1 *Lophelia pertusa* (a) After about 280 days living close to sub-saturated conditions ($\Omega_{Ar} \approx 1$) polyps have a healthy appearance. The arrow indicates the incorporated Alizarin Red S fluorescent dye which marks the start of the long-term experiment. Scale, 10 mm. Growth was highest in newly formed polyps (b) and under sub-saturated conditions ($\Omega_{Ar} < 1$) (c, d). (d) Fluorescence image of a thin section of (c). Scale for b–d, 2 mm.

Form & Riebesell (2011) *Global Change Biology*

what will happen in an acidified ocean? (experiments)

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- many different effects observed
- Δ pH ≈ 0,3 – 0,4
- **direct effects**: pH influences
  - physiology
  - growth
  - survival
  - behaviour
  - taste
- **indirect effects**: pH influences other species /processes in the ecosystem that can affect the species (e.g. through competition)

what will happen in an acidified ocean? (experi

- some species respond negatively

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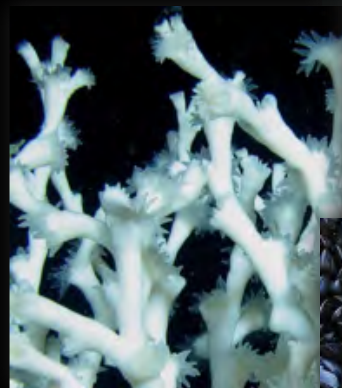
what will happen in an acidified ocean? (experi

- some species respond negatively
- some species can handle acidification if they have sufficient food (energy)



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what will happen in an acidified ocean? (experi

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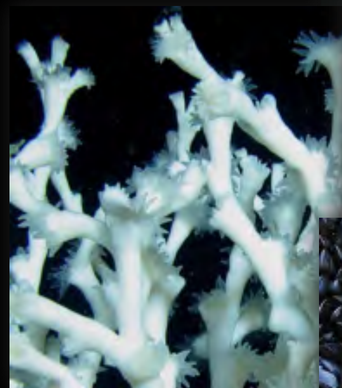
- some species appear unaffected, or even do better in acidified conditions



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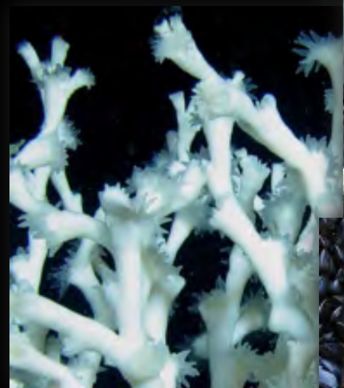

- **much** variation among populations and species


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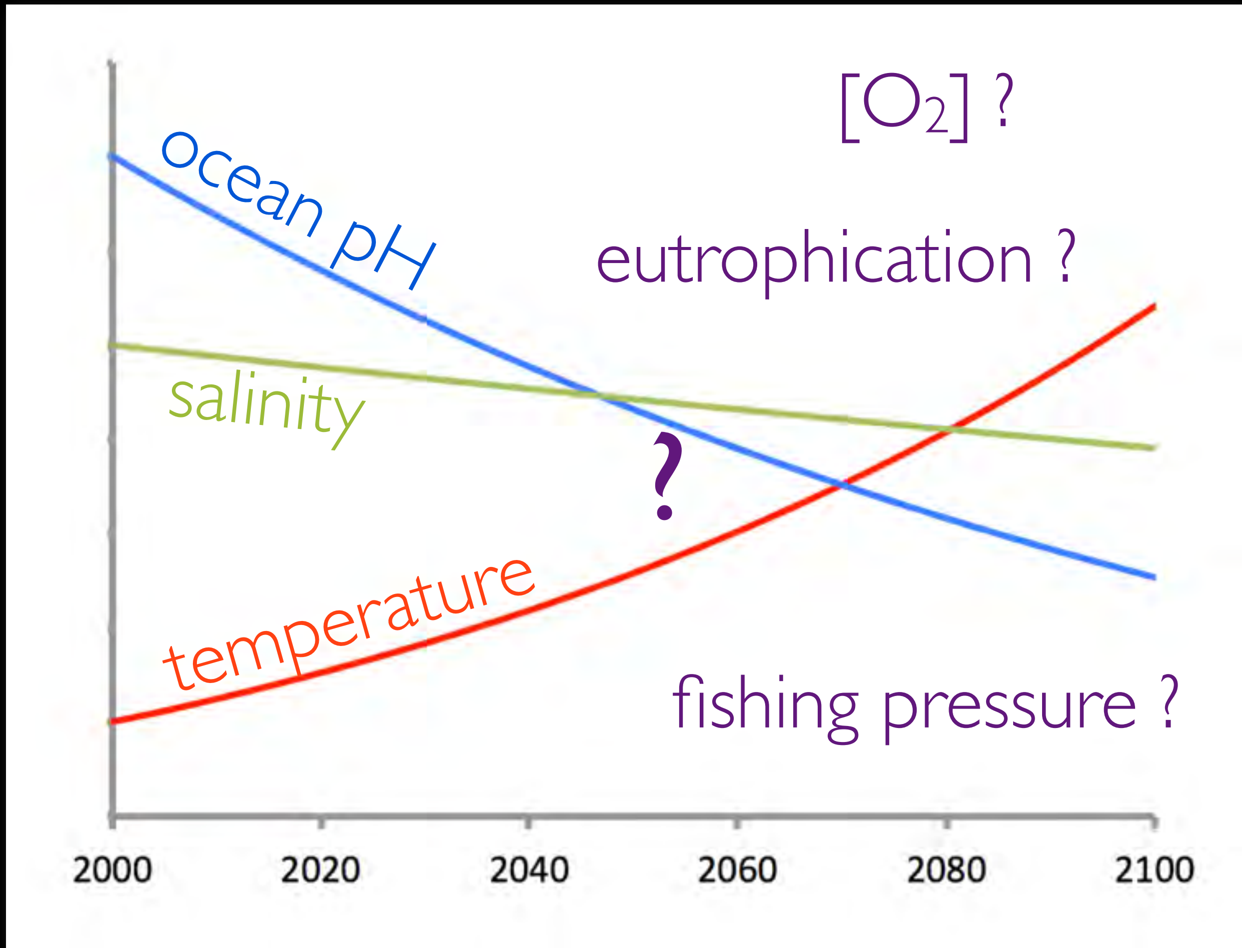
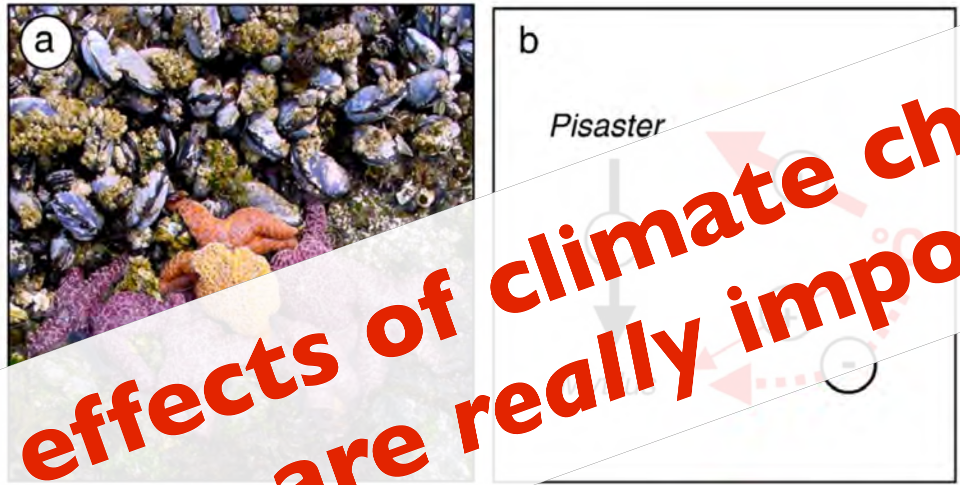
multiple drivers ?
what can we do ?

multiple drivers



multiple drivers



Kordas et al (2011) *J.Exp.Mar.Biol.Ecol.*

indirect effects of climate change in the oceans are really important !

- *Mytilus* and *Pisaster* are more abundant at higher T°
- *Pisaster* benefits more from warming than *Mytilus* does
- direct positive effect of T° on *Mytilus* overwhelmed by negative <u>indirect</u> effect

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what can we do ?

RESEARCH

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3 JULY 2015 • VOL 349 ISSUE 6243

REVIEW

OCEANOGRAPHY

Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios

J.-P. Gattuso,[1,2,3]* A. Magnan,[3] R. Billé,[4] W. W. L. Cheung,[5] E. L. Howes,[6] F. Joos,[7] D. Allemand,[8,9] L. Bopp,[10] S. R. Cooley,[11] C. M. Eakin,[12] O. Hoegh-Guldberg,[13] R. P. Kelly,[14] H.-O. Pörtner,[6] A. D. Rogers,[15] J. M. Baxter,[16] D. Laffoley,[17] D. Osborn,[18] A. Rankovic,[3,19] J. Rochette,[3] U. R. Sumaila,[20] S. Treyer,[3] C. Turley[21]

The ocean moderates anthropogenic climate change at the cost of profound alterations of its physics, chemistry, ecology, and services. Here, we evaluate and compare the risks of impacts on marine and coastal ecosystems—and the goods and services they provide—for growing cumulative carbon emissions under two contrasting emissions scenarios. The current emissions trajectory would rapidly and significantly alter many ecosystems and the associated services on which humans heavily depend. A reduced emissions scenario—consistent with the Copenhagen Accord's goal of a global temperature increase of less than 2°C—is much more favorable to the ocean but still substantially alters important marine ecosystems and associated goods and services. The management options to address ocean impacts narrow as the ocean warms and acidifies. Consequently, any new climate regime that fails to minimize ocean impacts would be incomplete and inadequate.

what can we do ?

RESEARCH
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3 JULY 2015 • VOL 349 ISSUE 6243

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what can we do?

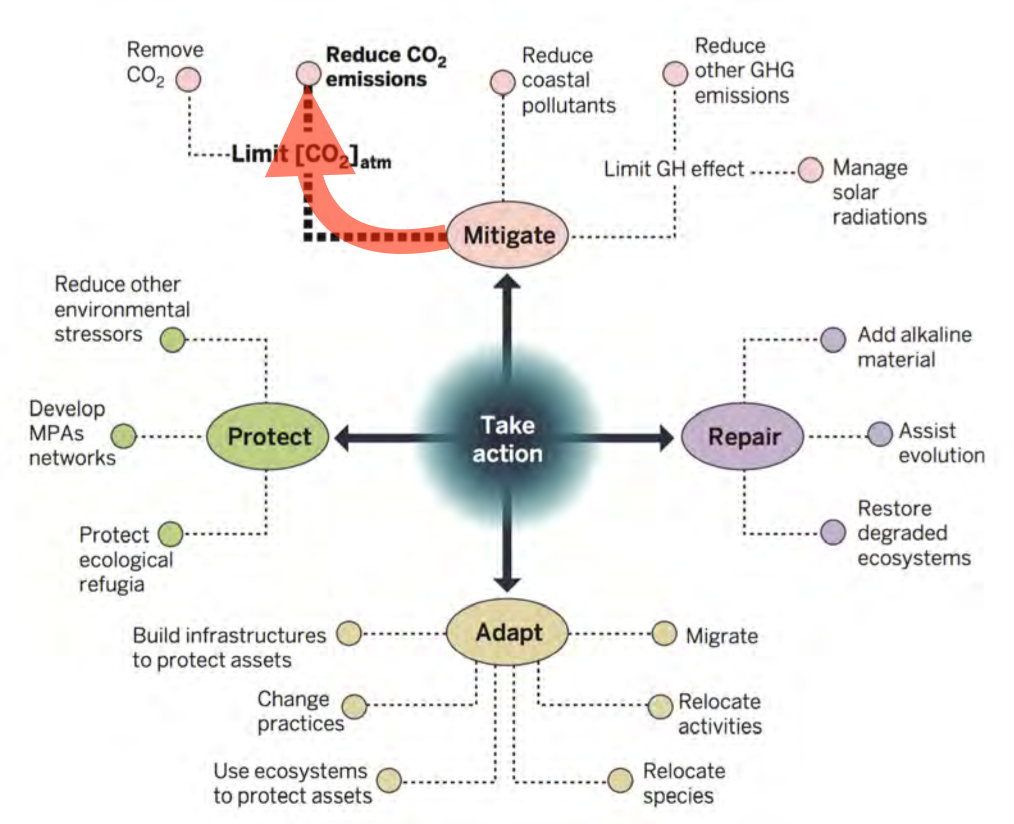


Fig. 4. Four clusters of actions against climate change, including ocean acidification. For each cluster, a nonexhaustive list of actions is shown. $[CO_2]_{atm}$ is concentration of atmospheric CO_2; GH, greenhouse; GHG, greenhouse gases; MPAs, marine protected areas. The mitigation pathway leading to CO_2 reductions is represented in bold, consistent with the consensus view that significant reductions in CO_2 emissions is presently the only actual "solution" to the ocean impacts of climate change and ocean acidification (see main text).

Gattuso et al, 2015, *Science*

Energy & Environmental Science

Dynamic Article Links

Cite this: DOI: 10.1039/c2ee03393c

www.rsc.org/ees

PAPER

CO_2 extraction from seawater using bipolar membrane electrodialysis†

Matthew D. Eisaman,‡* Keshav Parajuly, Alexander Tuganov, Craig Eldershaw, Norine Chang and Karl A. Littau

Received 6th December 2011, Accepted 23rd January 2012
DOI: 10.1039/c2ee03393c

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

Review

Interaction of climate change and marine pollution in Southern India: Implications for coastal zone management practices and policies

Susana Lincoln[a,*], Piyali Chowdhury[a], Paulette E. Posen[a], R.S. Robin[b], Purvaja Ramachandran[b], Nithin Ajith[b], Olivia Harrod[a], Danja Hoehn[a], Richard Harrod[a], Bryony L. Townhill[a]

CrossMark

PERSPECTIVE

Building coral reef resilience through assisted evolution

Madeleine J. H. van Oppen[a,1], James K. Oliver[a], Hollie M. Putnam[b], and Ruth D. Gates[b]
[a]Australian Institute of Marine Science, Townsville MC, QLD 4810, Australia; and [b]Hawaii Institute of Marine Biology, Kaneohe, HI 96744

Edited by Nancy Knowlton, Smithsonian Institution, Washington, DC and approved January 5, 2015 (received for review November 24, 2014)

The genetic enhancement of wild animals and plants for characteristics that benefit human populations has been practiced for thousands of years, resulting in impressive improvements in commercially valuable species. Despite these benefits, genetic manipulations are rarely considered for noncommercial purposes, such as conservation and restoration initiatives. Over the last century, humans have driven global climate change through industrialization and the release of increasing amounts of CO_2, resulting in shifts in ocean temperature, ocean chemistry, and sea level, as well as increasing frequency of storms, all of which can profoundly impact marine ecosystems. Coral reefs are highly diverse ecosystems that have suffered massive declines in health and abundance as a result of these and other direct anthropogenic disturbances. There is great concern that the high rates, magnitudes, and complexity of environmental change are overwhelming the intrinsic capacity of corals to adapt and survive. Although it is important to address the root causes of changing climate, it is also prudent to explore the potential to augment the capacity of reef organisms to tolerate stress and to facilitate recovery after disturbances. Here, we review the risks and benefits of the improvement of natural and commercial stocks in noncoral reef systems and advocate a series of experiments to determine the feasibility of developing coral stocks with enhanced stress tolerance through the acceleration of naturally occurring processes, an approach known as (human)-assisted evolution, while at the same time initiating a public dialogue on the risks and benefits of this approach.

CRISP

Coral Reef InitiativeS for the Pacific
Initiatives Corail pour le Pacifique

COMPONENT 3A - PROJECT 3A3
Institutional strengthening & technical support

Improvement of socio-economics of coral reefs

April 2009

STUDY REPORT

STATUS AND POTENTIAL OF LOCALLY-MANAGED MARINE AREAS IN THE SOUTH PACIFIC:
Meeting nature conservation and sustainable livelihood targets through wide-spread implementation of LMMAs

By Hugh GOVAN

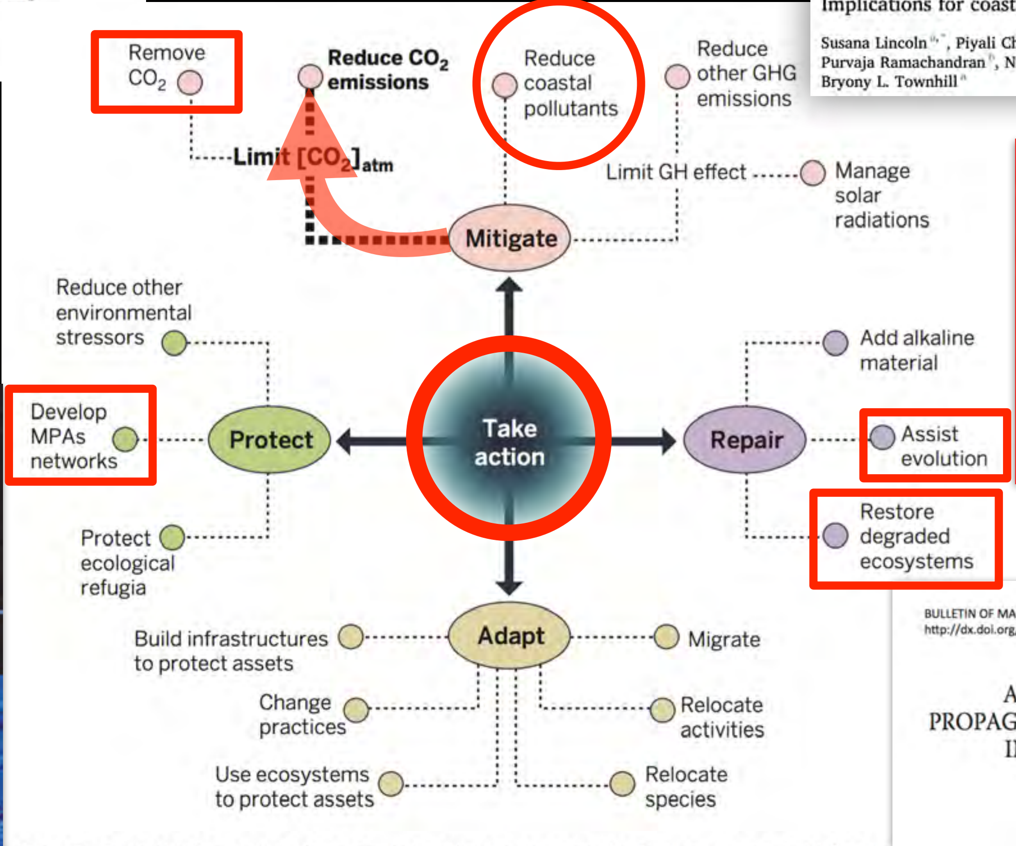


Fig. 4. Four clusters of actions against climate change, including ocean acidification. For each cluster, a nonexhaustive list of actions is shown. $[CO_2]_{atm}$ is concentration of atmospheric CO_2; GH, greenhouse; GHG, greenhouse gases; MPAs, marine protected areas. The mitigation pathway leading to CO_2 reductions is represented in bold, consistent with the consensus view that significant reductions in CO_2 emissions is presently the only actual "solution" to the ocean impacts of climate change and ocean acidification (see main text).

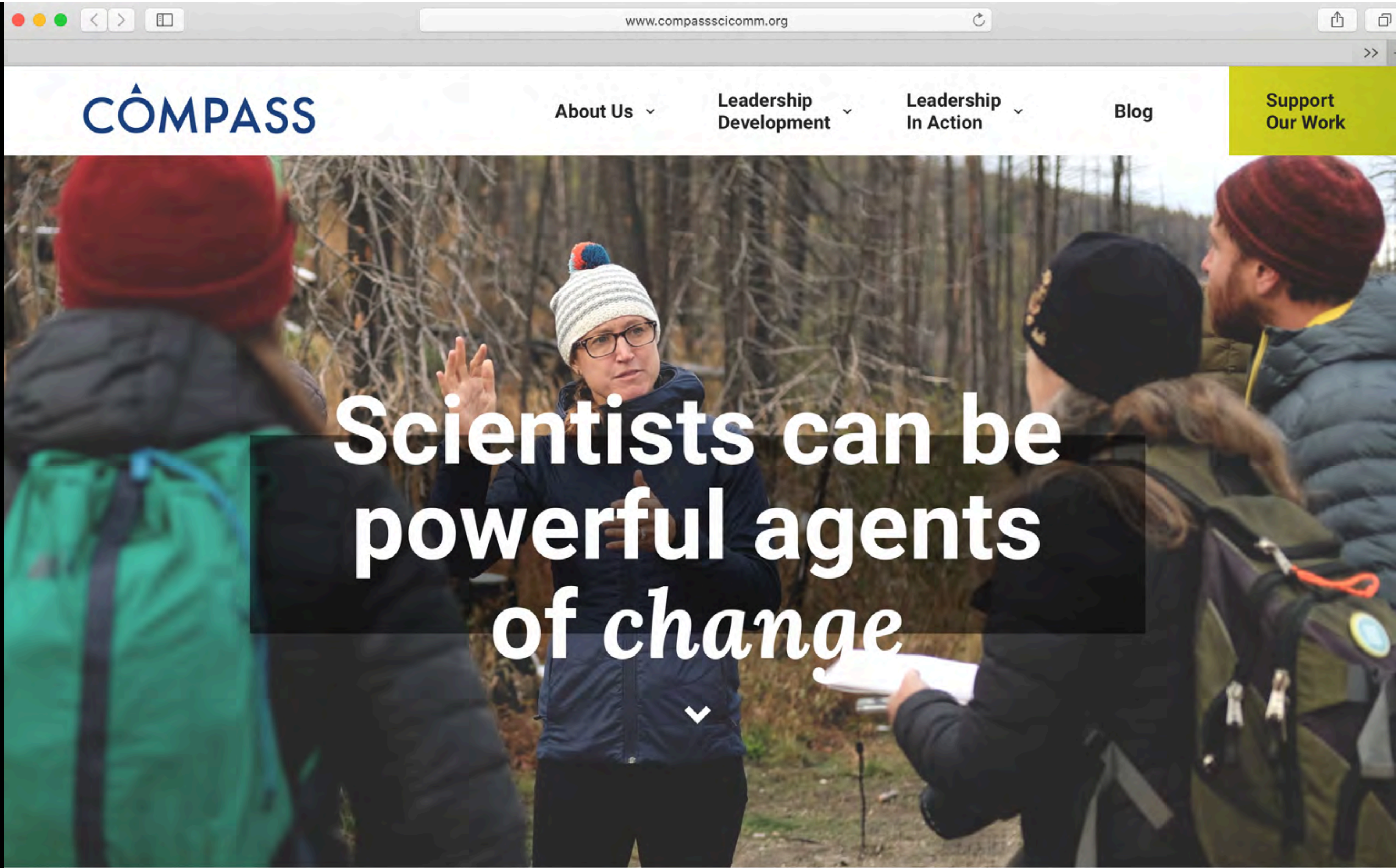
Gattuso et al, 2015, *Science*

BULLETIN OF MARINE SCIENCE. 88(4):1075–1098. 2012
http://dx.doi.org/10.5343/bms.2011.1143

CORAL REEF PAPER

A REVIEW OF REEF RESTORATION AND CORAL PROPAGATION USING THE THREATENED GENUS *ACROPORA* IN THE CARIBBEAN AND WESTERN ATLANTIC

CN Young, SA Schopmeyer, and D Lirman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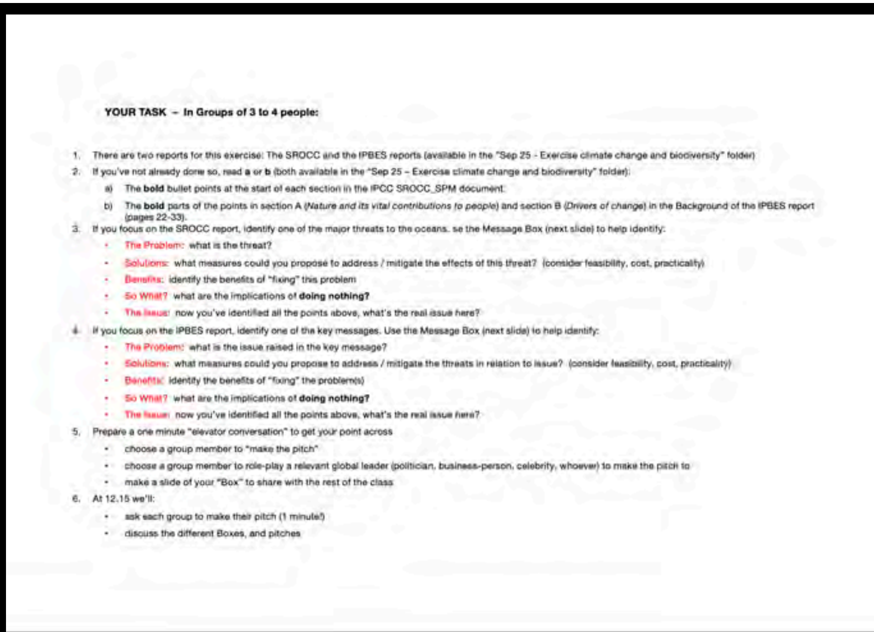
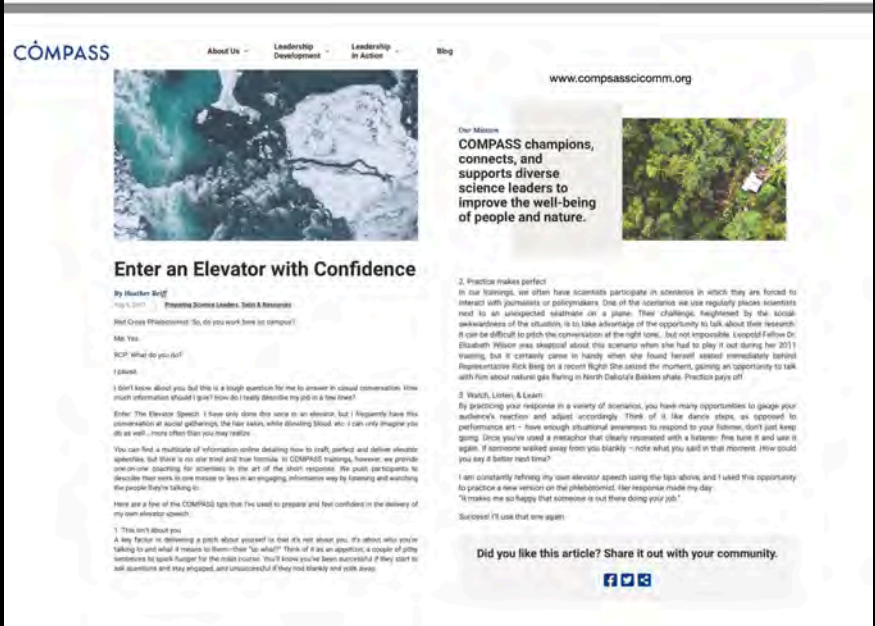
Scientists can be powerful agents of change

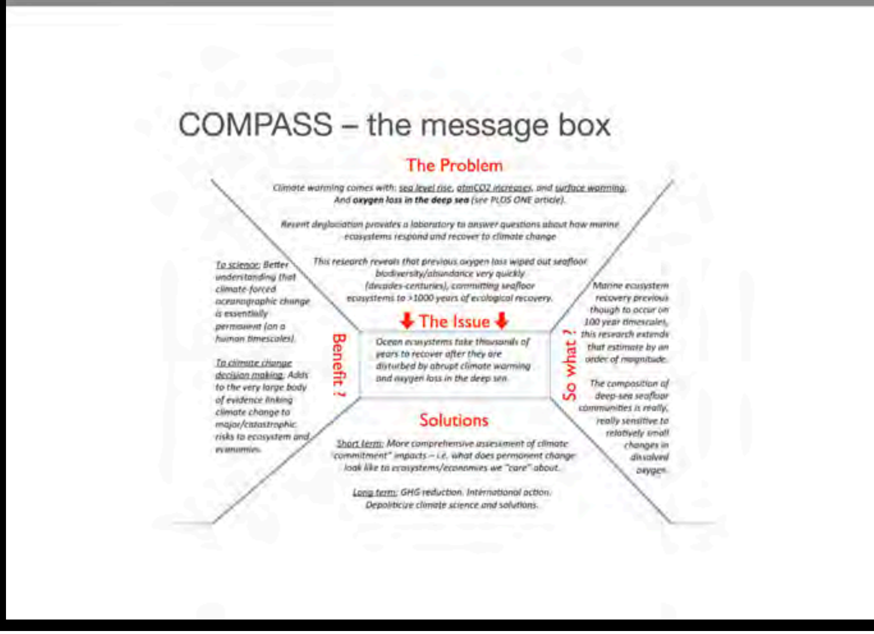
tomorrow!

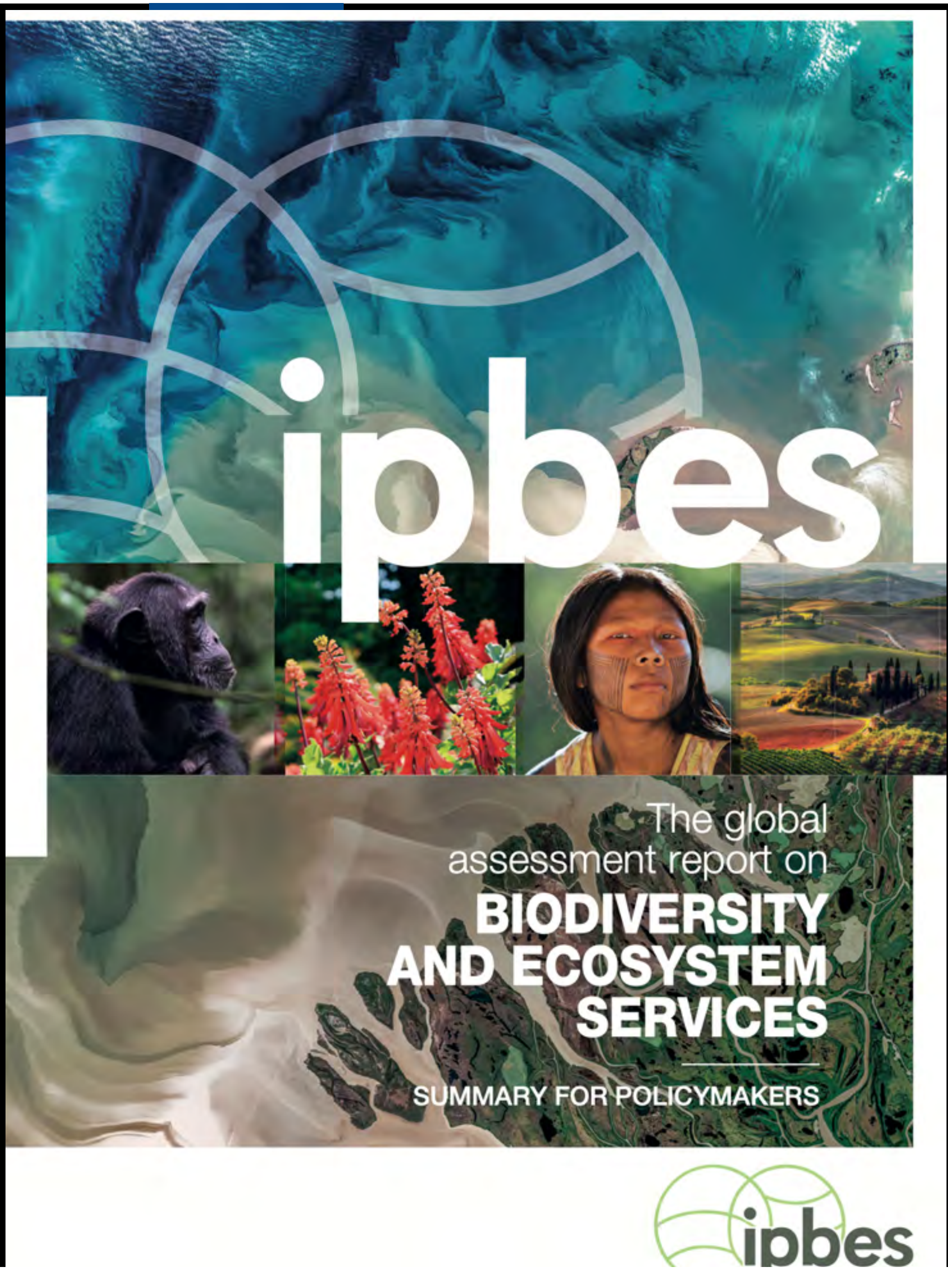


YOUR TASK – In Groups of 3 to 4 people:

1. There are two reports for this exercise: The SROCC and the IPBES reports (available in the "Sep 25 - Exercise climate change and biodiversity" folder)
2. If you've not already done so, read **a** or **b** (both available in the "Sep 25 – Exercise climate change and biodiversity" folder):
   a) The **bold** bullet points at the start of each section in the IPCC SROCC_SPM document.
   b) The **bold** parts of the points in section A (*Nature and its vital contributions to people*) and section B (*Drivers of change*) in the Background of the IPBES report (pages 22-33).
3. If you focus on the SROCC report, identify one of the major threats to the oceans. se the Message Box (next slide) to help identify:
   - The Problem: what is the threat?
   - Solutions: what measures could you propose to address / mitigate the effects of this threat? (consider feasibility, cost, practicality)
   - Benefits: identify the benefits of "fixing" this problem
   - So What? what are the implications of **doing nothing?**
   - The Issue: now you've identified all the points above, what's the real issue here?
4. If you focus on the IPBES report, identify one of the key messages. Use the Message Box (next slide) to help identify:
   - The Problem: what is the issue raised in the key message?
   - Solutions: what measures could you propose to address / mitigate the threats in relation to issue? (consider feasibility, cost, practicality)
   - Benefits: identify the benefits of "fixing" the problem(s)
   - So What? what are the implications of **doing nothing?**
   - The Issue: now you've identified all the points above, what's the real issue here?
5. Prepare a one minute "elevator conversation" to get your point across
   - choose a group member to "make the pitch"
   - choose a group member to role-play a relevant global leader (politician, business-person, celebrity, whoever) to make the pitch to
   - make a slide of your "Box" to share with the rest of the class
6. At 12.15 we'll:
   - ask each group to make their pitch (1 minute!)
   - discuss the different Boxes, and pitches






ipbes
The global assessment report on
BIODIVERSITY AND ECOSYSTEM SERVICES
SUMMARY FOR POLICYMAKERS
ipbes


#SROCC
IPCC Special Report on the
Ocean and Cryosphere in a Changing Climate
(SROCC)
Photo: Austin Schmid, Unsplash

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what can we do?

- climate change is already influencing marine ecosystems
  - *urgent need to understand how this is happenening*
  - *focus on multiple drivers (including acidification):*
  - *e.g. in seagrass beds warming & acidification drive ecosystems in same direction as eutrophication and overfishing*
    - *can reduce effects of warming and acidification by reducing other stressors*
- multiple drivers may be sub-additive, additive, or super-additive
  - *now have tools to address these experimentally*
- reduce, remove, restore, assist . . .

DEFEAT IS A STATE OF MIND. YOU ARE DEFEATED ONLY WHEN YOU ACCEPT DEFEAT, AND ASSUME THE HOPELESS MINDSET OF A DEFEATED PERSON.

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DEFEAT IS A STATE OF MIND. YOU ARE DEFEATED ONLY WHEN YOU ACCEPT DEFEAT, AND ASSUME THE HOPELESS MINDSET OF A DEFEATED PERSON.

-DONALD TRUMP

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resources

- https://climatescenario.org/primer/socioeconomic-development/
- https://www.globalcarbonproject.org
- https://www.carbonbrief.org

Opportunities with Renewable Wave Energy –
Challenges in the Design of Wave Energy Converters Systems

Professor Jonas W Ringsberg

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CHALMERS UNIVERSITY OF TECHNOLOGY
Department of Mechanics and Maritime Sciences
Division of Marine Technology
Gothenburg, SWEDEN

Two questions for you

- How can wave energy be extracted from the ocean?
- What do you think are the biggest challenges with extracting wave energy offshore?

Outline

Wave energy in our oceans

Economic and technical challenges

Simulations and models

Experiences from a selection of studies

Concluding remarks

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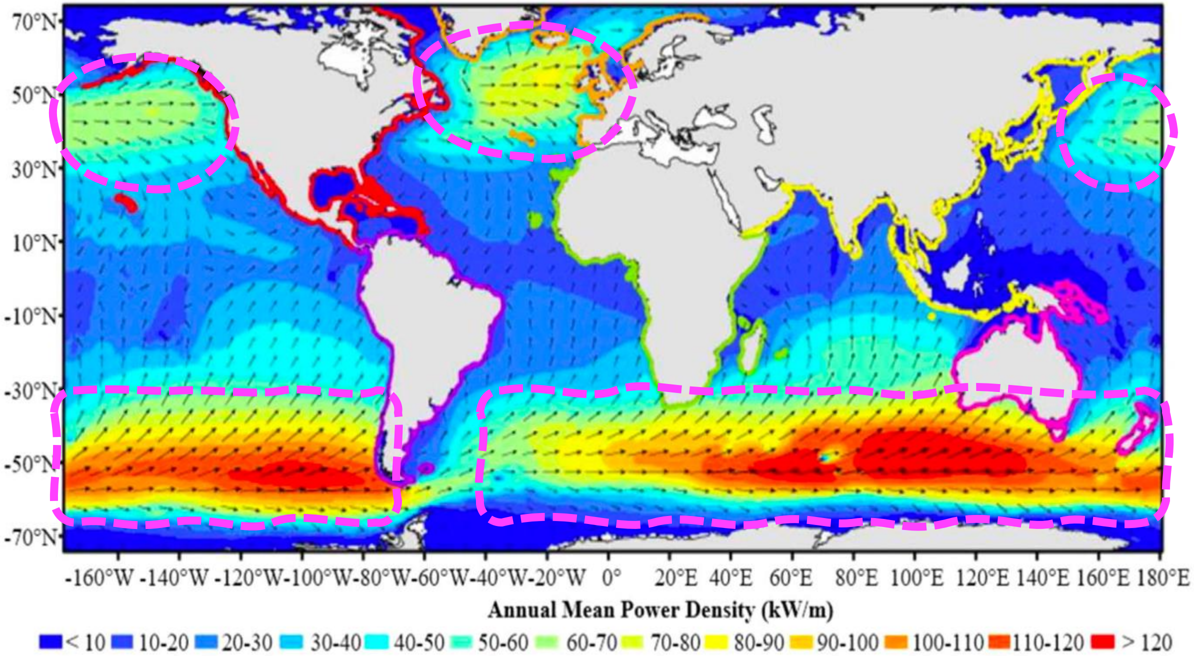
Division of Marine Technology

Professor Jonas W Ringsberg, 2025-03-13

Wave energy in our oceans



Mustapa et al. (2017)

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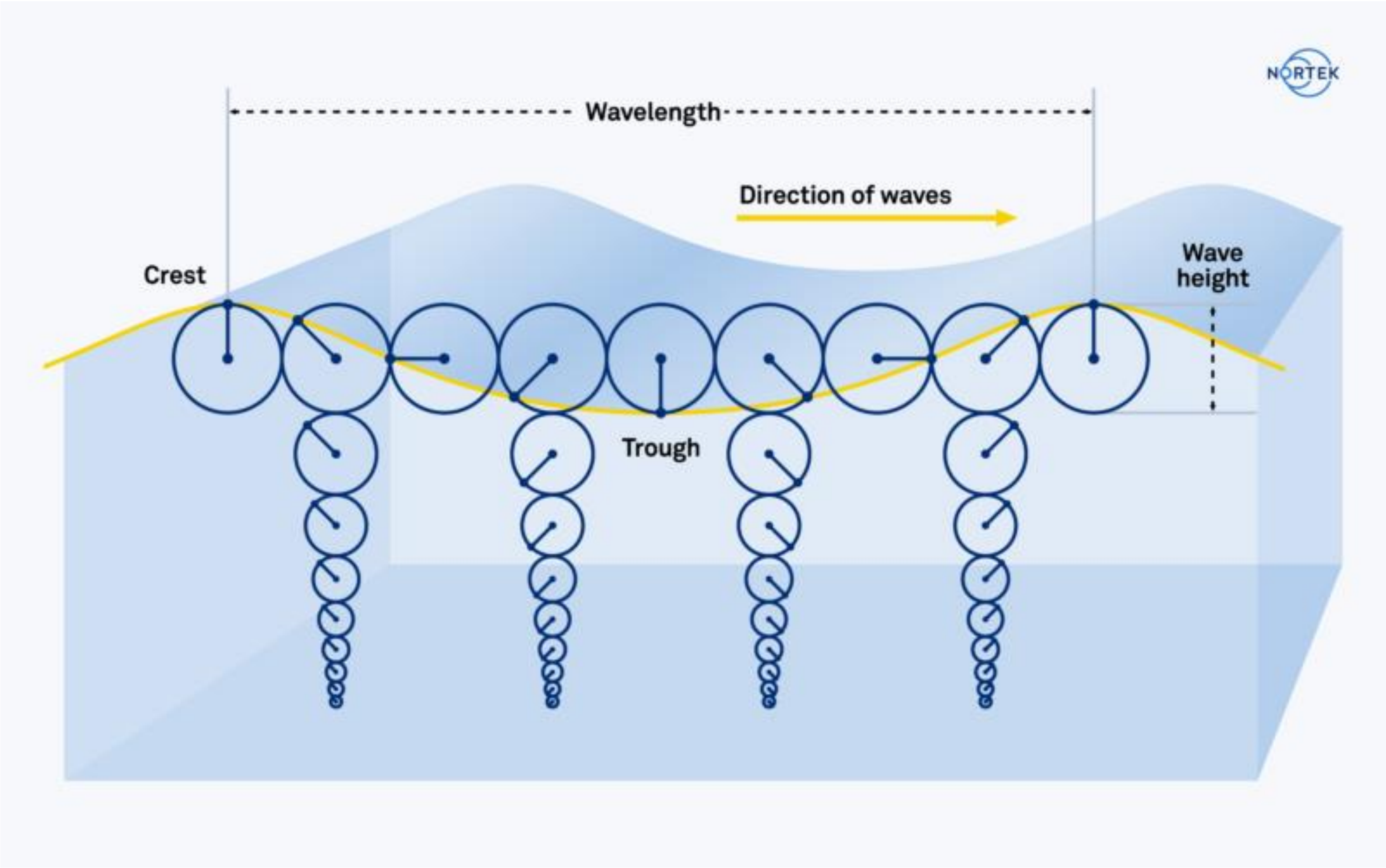
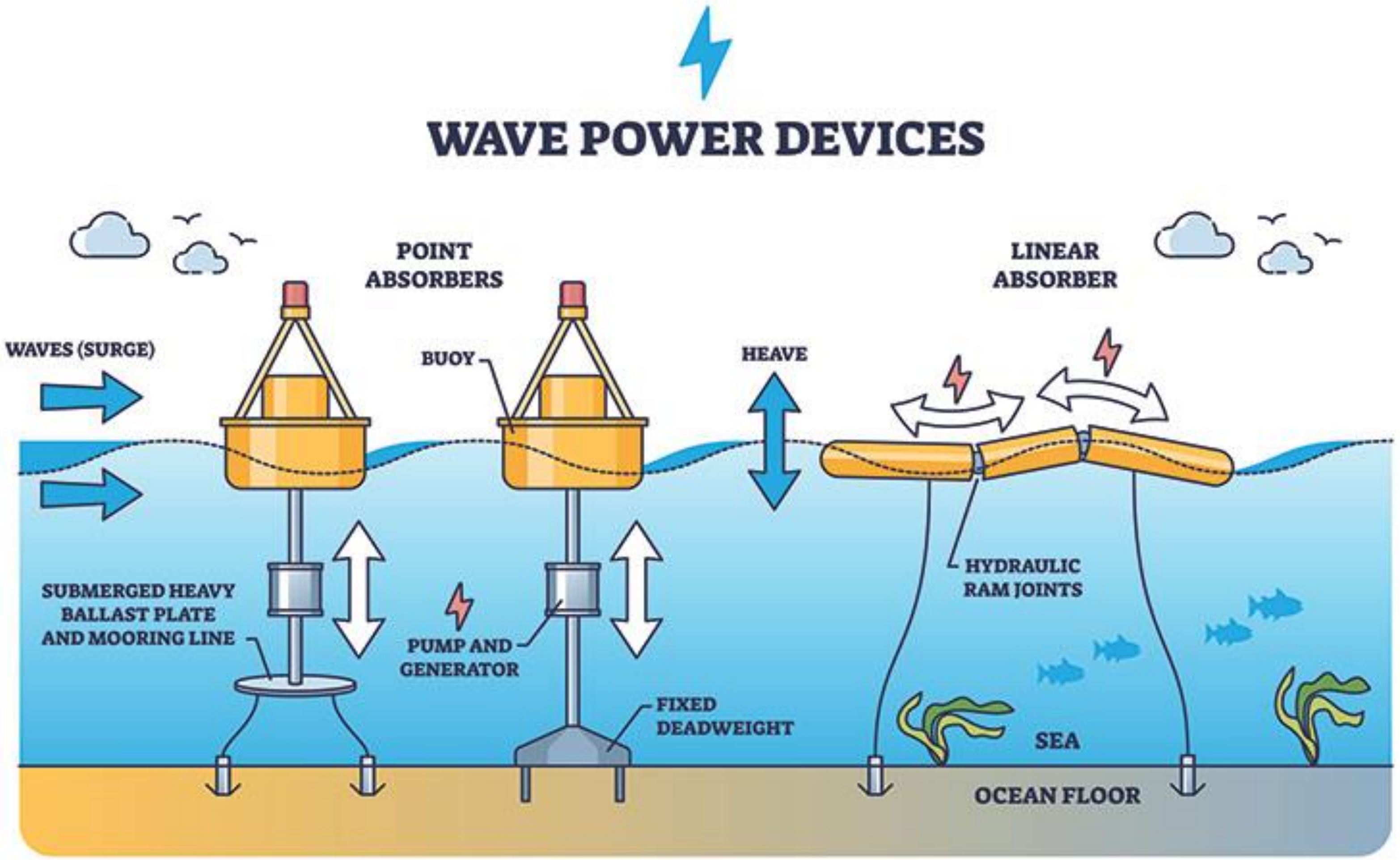
70% of the Earth’s surface is covered by oceans

Opportunity: an unlimited free resource of renewable wave energy

Challenges: technical, operational and economic

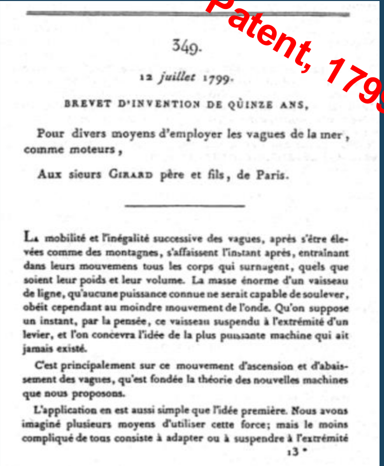

Wavelength
Direction of waves
Crest
Wave
height
Trough


WAVE POWER DEVICES
POINT ABSORBERS
LINEAR ABSORBER
WAVES (SURGE)
BUOY
HEAVE
HYDRAULIC RAM JOINTS
SUBMERGED HEAVY BALLAST PLATE AND MOORING LINE
PUMP AND GENERATOR
FIXED DEADWEIGHT
SEA
OCEAN FLOOR

Innovation of concepts

Once upon a time in France 200 years ago, …

To run pumps and sawmills



349.

12 *juillet* 1799.

BREVET D'INVENTION DE QÛINZE ANS,

Pour divers moyens d'employer les vagues de la mer, comme moteurs,

Aux sieurs GIRARD père et fils, de Paris.

LA mobilité et l'inégalité successive des vagues, après s'être élevées comme des montagnes, s'affaissent l'instant après, entraînant dans leurs mouvemens tous les corps qui surnagent, quels que soient leur poids et leur volume. La masse énorme d'un vaisseau de ligne, qu'aucune puissance connue ne serait capable de soulever, obéit cependant au moindre mouvement de l'onde. Qu'on suppose un instant, par la pensée, ce vaisseau suspendu à l'extrémité d'un levier, et l'on concevra l'idée de la plus puissante machine qui ait jamais existé.

C'est principalement sur ce mouvement d'ascension et d'abaissement des vagues, qu'est fondée la théorie des nouvelles machines que nous proposons.

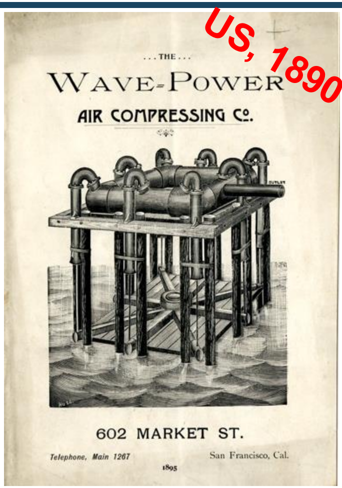
L'application en est aussi simple que l'idée première. Nous avons imaginé plusieurs moyens d'utiliser cette force; mais le moins compliqué de tous consiste à adapter ou à suspendre à l'extrémité

13 *

Patent, 1799

Bernhoff et al. (2004)

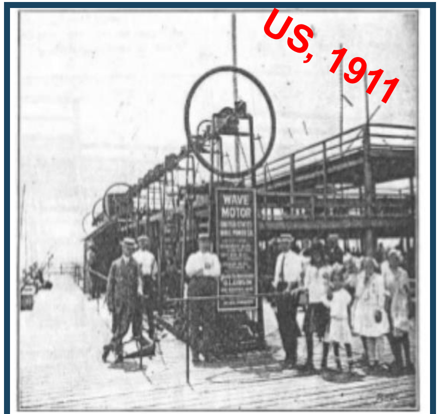
"Bottling of wave energy"



US, 1890

Bernhoff et al. (2004)

To run pumps and sawmills



US, 1911

US Wave Power Corporation New Jersey

Polinder (2012)

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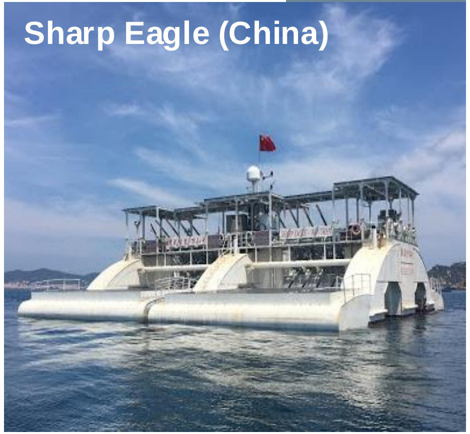
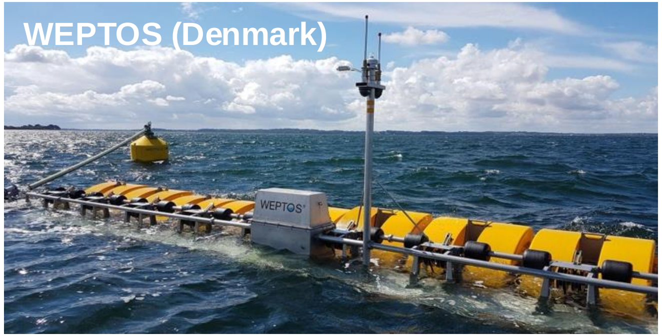
Division of Marine Technology

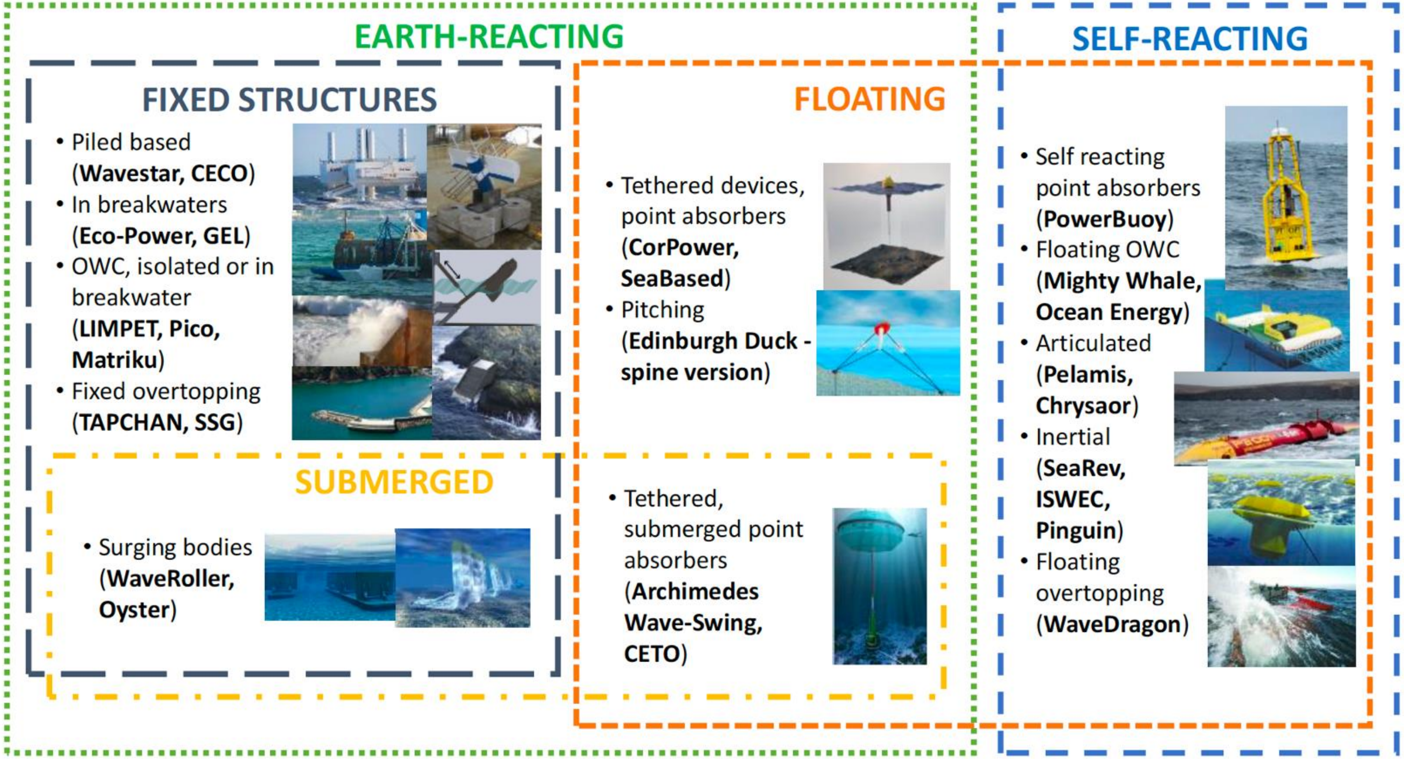
Professor Jonas W Ringsberg, 2025-03-13

More than 1,000 patented concepts!





Categorization of PTO systems



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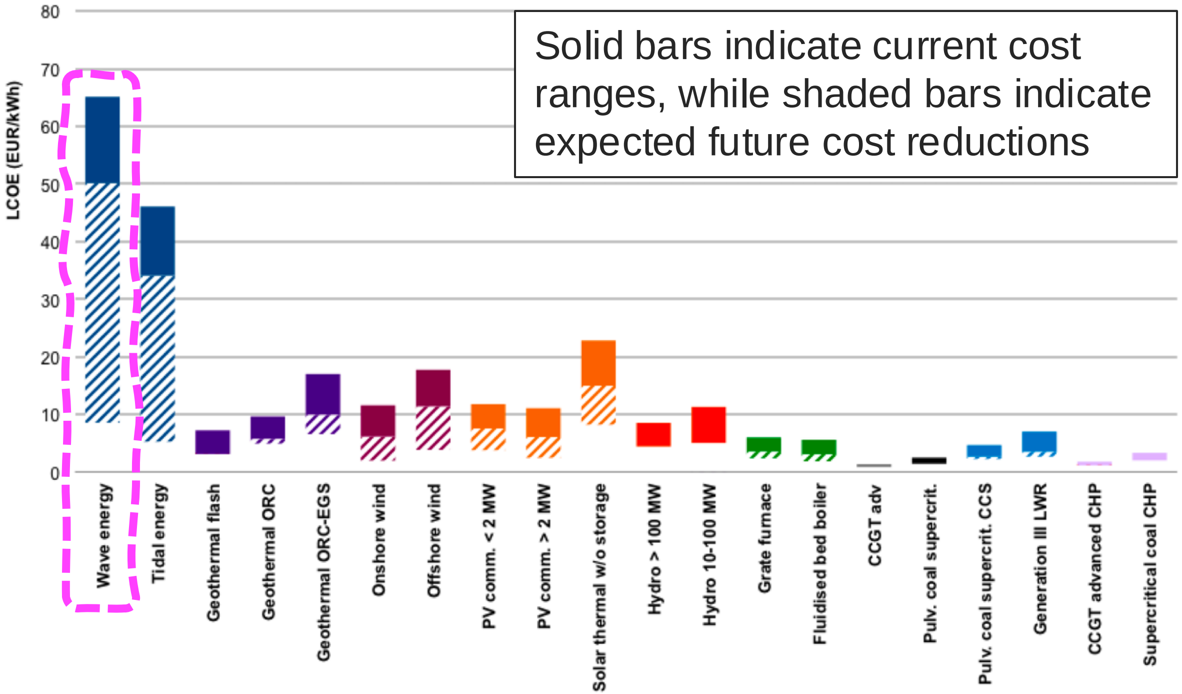
Economic and technical challenges



Solid bars indicate current cost ranges, while shaded bars indicate expected future cost reductions

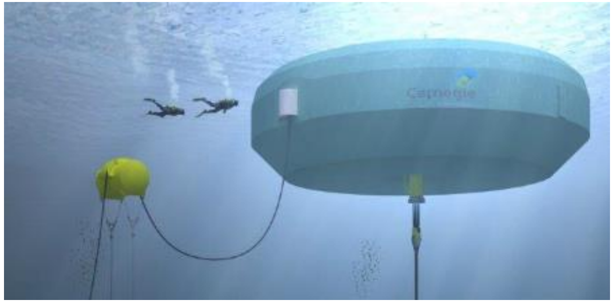
Magagna & Uihlein (2015)

Floating point absorbers

PB3 PowerBuoy (USA)

WaveEL (Sweden)

CETO 6 (Australia)



AquaBuoy (Canada)

CorPower Ocean (Sweden)

Wave power farms – smart installations of single units into arrays of devices

Floating point-absorbers

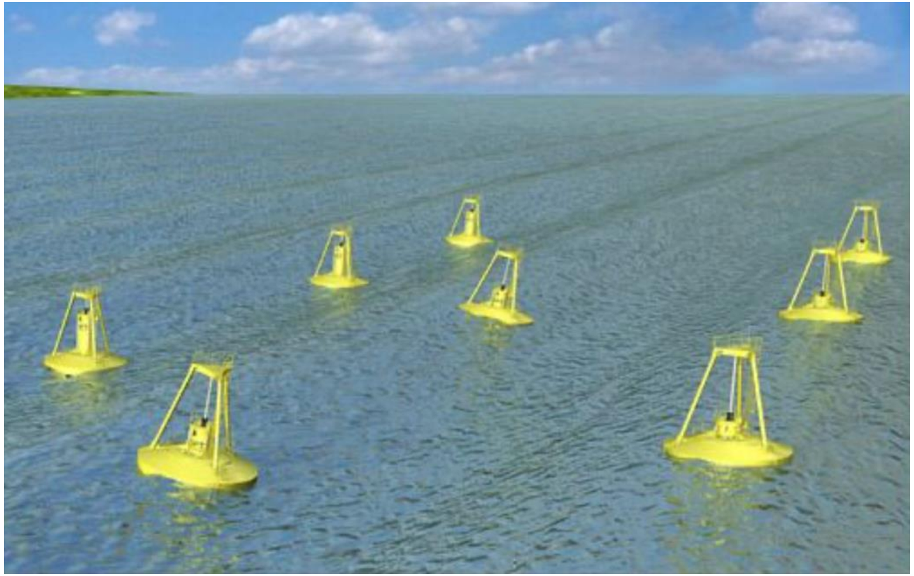
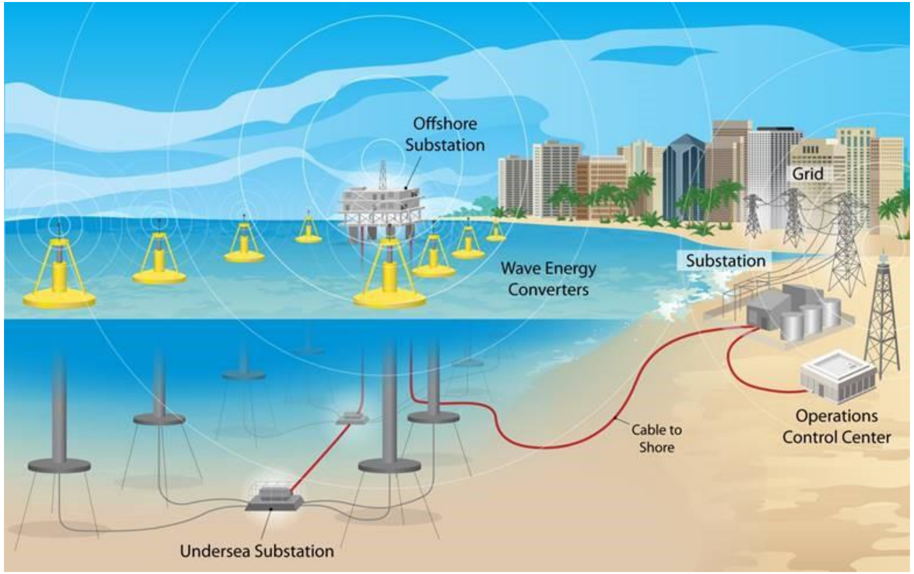


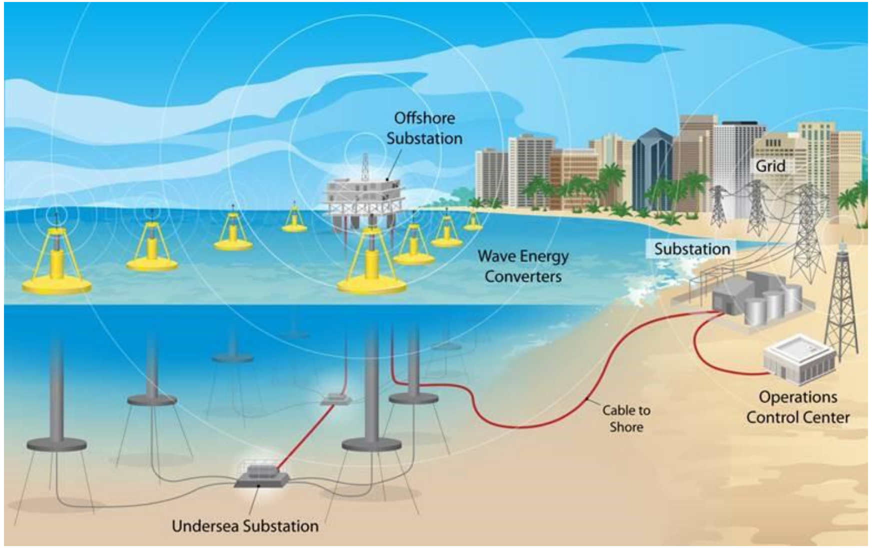
Illustration from PB3 PowerBuoy (USA)



Artist's impression of a wave energy farm (Illustration by Alfred Hicks, NREL)

Simulations and models

Complex system → holistic analysis



(Illustration by Alfred Hicks, NREL)

- **MetOcean models and data**
- **Electrical engineering**
  - PTO system and characteristics
- **Hydrodynamics response analysis**
  - Motions
  - Energy production
- **Structural response analysis**
  - Extreme loads – survivability
  - Fatigue of components – reliability
- **Fouling models**
- **Reliability and maintenance**
- **Levelized cost of energy (LCoE)**
  - Optimization of the "system"
- **Validation and verification**
  - Laboratory conditions
  - Realistic conditions: trials and installations in the ocean

Department of Mechanics and Maritime Sciences
Division of Marine Technology

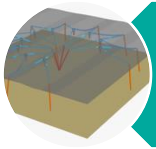
Professor Jonas W Ringsberg, 2025-03-13

Experiences from a selection of studies

The WaveEL 3.0 WEC

Influnce from bioufouling

Dynamic power cables



WaveEL in array configurations

Projects, publications and results

Professor Jonas Ringsberg
https://research.chalmers.se/en/person/jwri

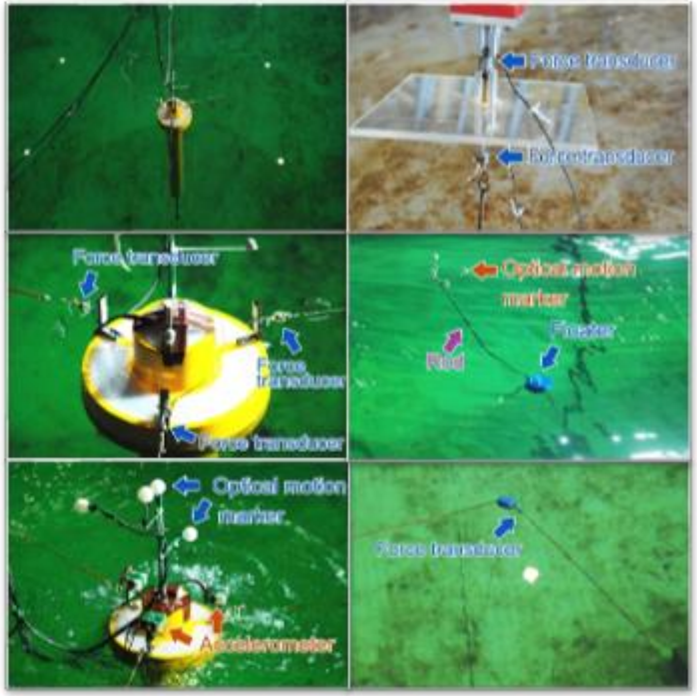
 The WaveEL 3.0 WEC

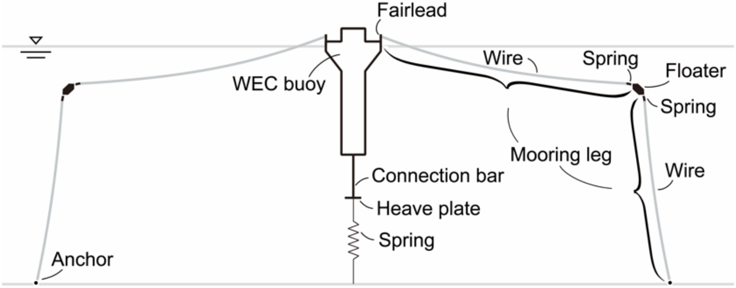
Department of Mechanics and Maritime Sciences
Division of Marine Technology

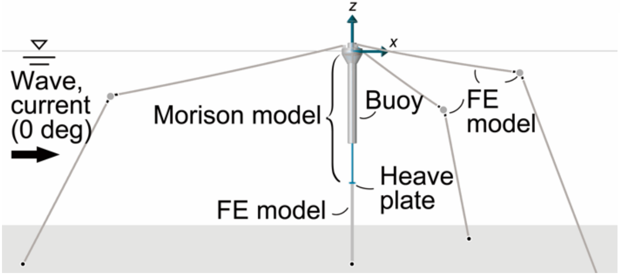
Professor Jonas W Ringsberg, 2025-03-13

Validation of simulation procedures – the SJTU deepwater ocean basin

Motions and mooring forces: model scale 1:20



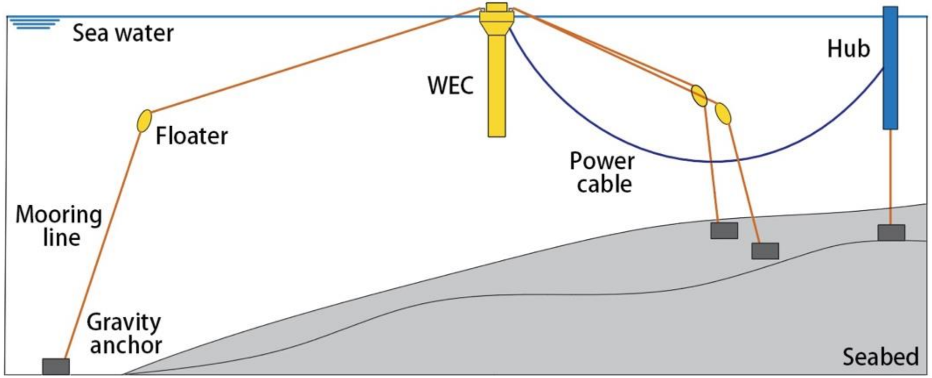




Yang, S.H., Ringsberg, J.W., Johnson, E. and Hu, Z. (2020). Experimental and numerical investigation of a taut-moored wave energy converter: a validation of simulated mooring line forces. *Ships and Offshore Structures*. https://doi.org/10.1080/17445302.2020.1772667.

The WaveEL 3.0 WEC

- **February, 2016**
  - Installation of the WEC
- **May, 2017**
  - Installation of the hub and the power cable
- **June-November, 2017**
  - Connected to the Norwegian grid



Full-scale measurements

- **Measurement system for mooring forces: Dacell CLM-T50 pressure sensor**

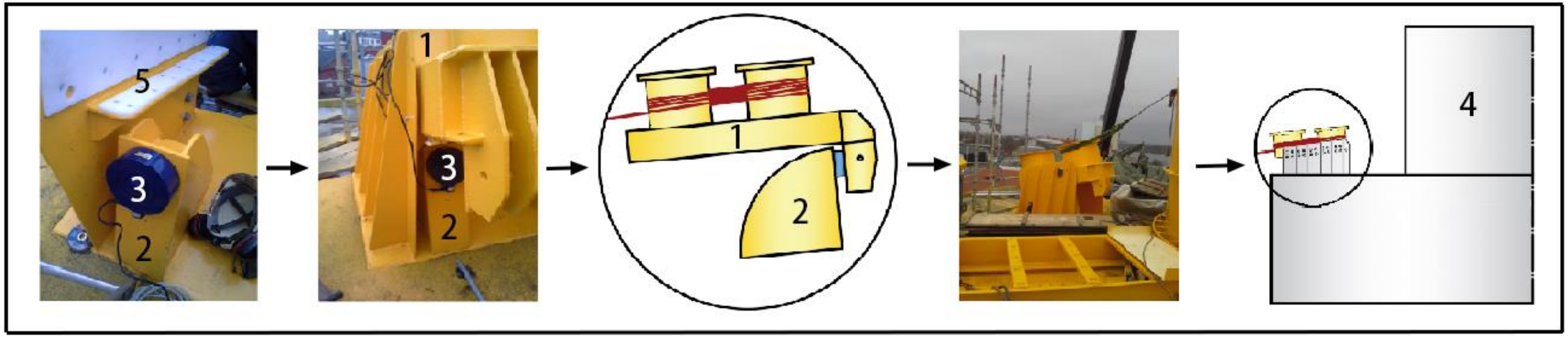


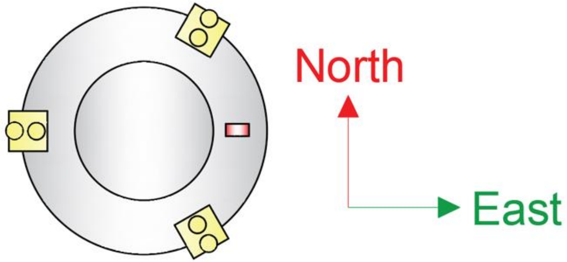
Illustration of the pressure sensor installation:
(1) bollard structure, (2) fixed structure, (3) pressure sensor, (4) WEC buoy, and (5) moving sledge.

- **Mooring force measurements (2017): June 1 to July 3**

Full-scale measurements

- **Measurement systems for WEC motions**

→ Rotation (MEMSIC VG-350)



→ Position track (JAVAD receiver & LEICA antenna)

- **WEC motions measurements (2017): June 13 (15:00:00) to June 19 (22:00:00)**

Influence from biofouling

(Source: M. Salta, 2014, Biomimetic strategies in antifouling coatings)

(Source: http://www.channelcoast.org/gallery/viewphoto/equipment/oceanographic_instruments/directional_waverider/2004)

Biofouling affects the WEC system

- Motions
- Forces
- Fatigue life
- Maintenance
- Power performance
- LCoE

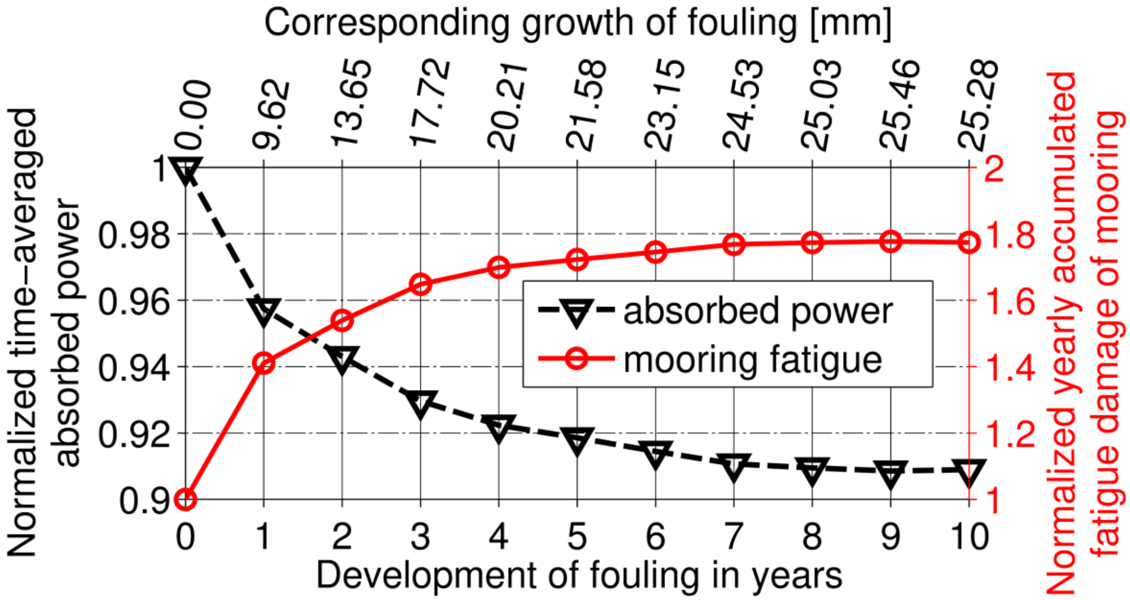
Biofouling models

- NORSOK (2007)
- Tiron et al. (2012)

Modelling

- Increase the masses and drag coefficients of the WEC, the moorings and the power cable

Maintenance model and strategy



Yang, S.H., Ringsberg, J.W., Johnson, E. and Hu, Z. (2017). Biofouling on mooring lines and power cables used in wave energy converter systems - analysis of fatigue life and energy performance. *Applied Ocean Research*. https://doi.org/10.1016/j.apor.2017.04.002.

Dynamic power cables

- **Dynamic power cables**
  - Low bending stiffness
  - Low torsional stiffness
  - Relatively large axial stiffness

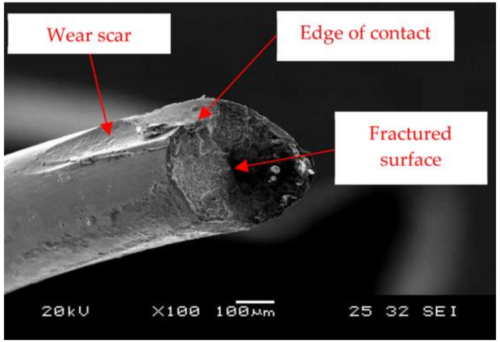
- **Millions of load cycles every year**
  - Design life (mechanical fatigue life): 10-15 years of operation

- **Power cable functional requirements**
  - Minimise the loss in conductivity due to degradation (fatigue, wear) of the conductors
  - Ensure that the fiber optics cable will not fail
  - The isolation material must remain intact

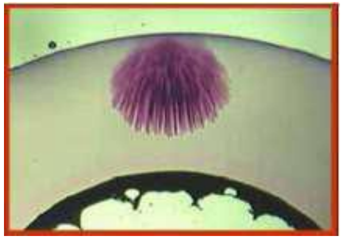
- **Many scholars have contributed to develop the theory and the models required for the analysis of cable structures**
  - See Buitrago et al. (2013); Nasution (2013); Thies et al. (2012); Yang et al. (2018)

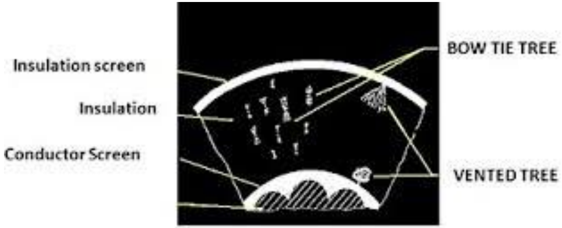
Deterioration mechanisms

- **Mechanical fatigue**
  - Cyclic stress variations (axial, bending, twisting)
- **Contact fatigue**
  - Fretting
- **Fatigue growth of “water tree” defects**
  - Problem in e.g. polyethylene insulation materials
  - New approach, see e.g. Young et al. (2018)
    - Growth due to electrical loadings (Maxwell stress)
    - Growth due to external loadings (mechanical stresses)



Llavori et al. (2019)

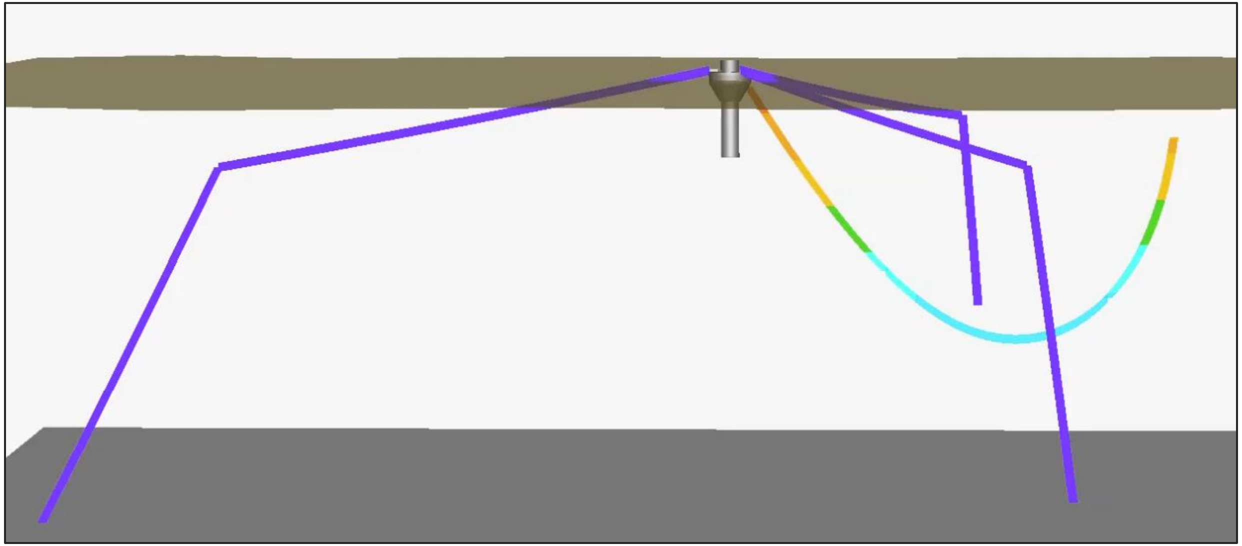




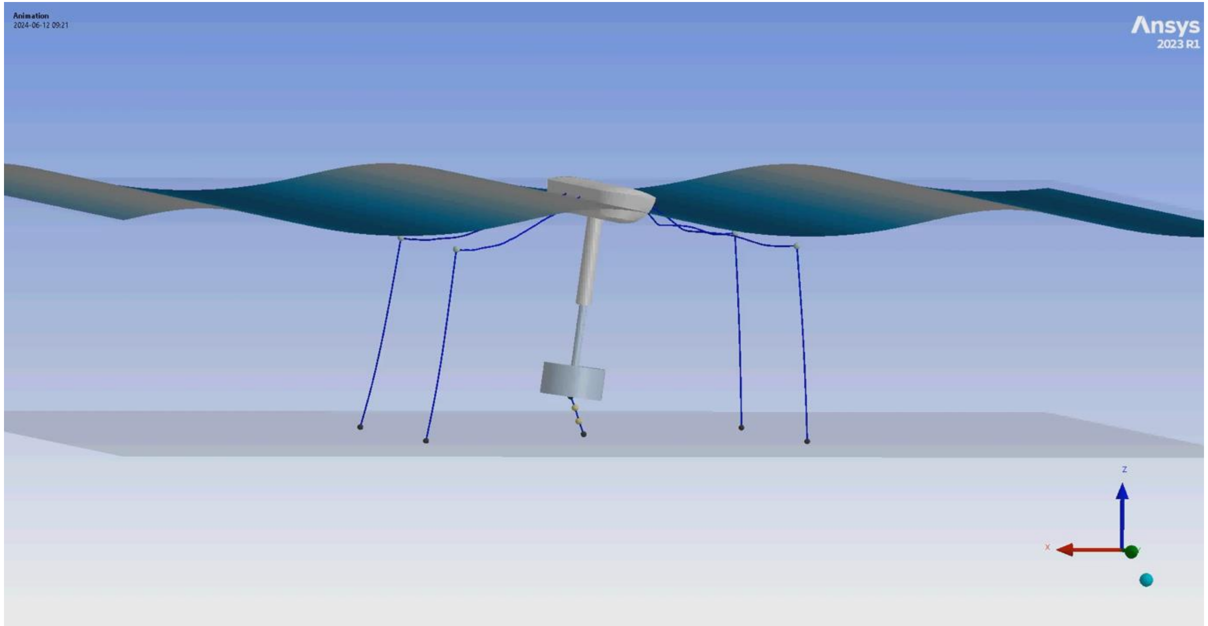
Young et al. (2019)

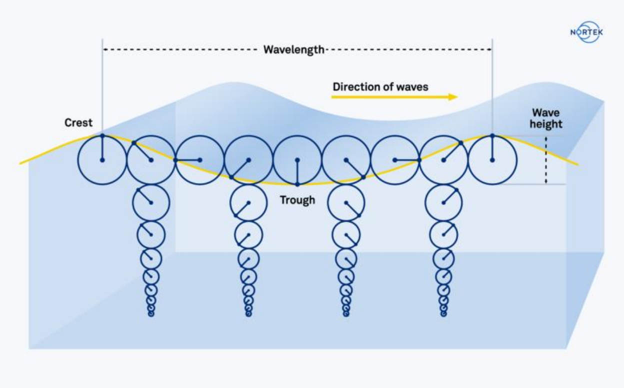
Response analysis

- **Cable motions induced by the WEC, waves and ocean current**
- **Internal reaction forces**
  - Axial forces
  - Bending moments
  - Twisting moments

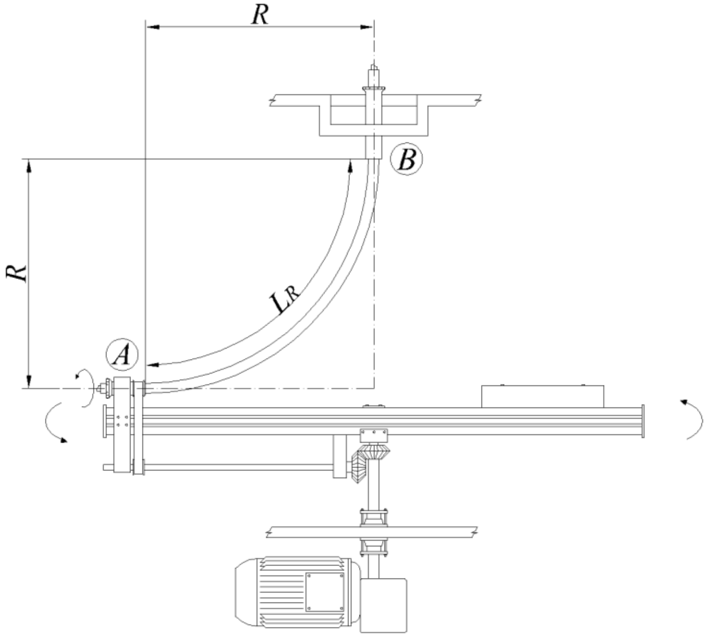


Response analysis



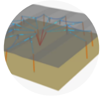


Verification – cable fatigue test rig



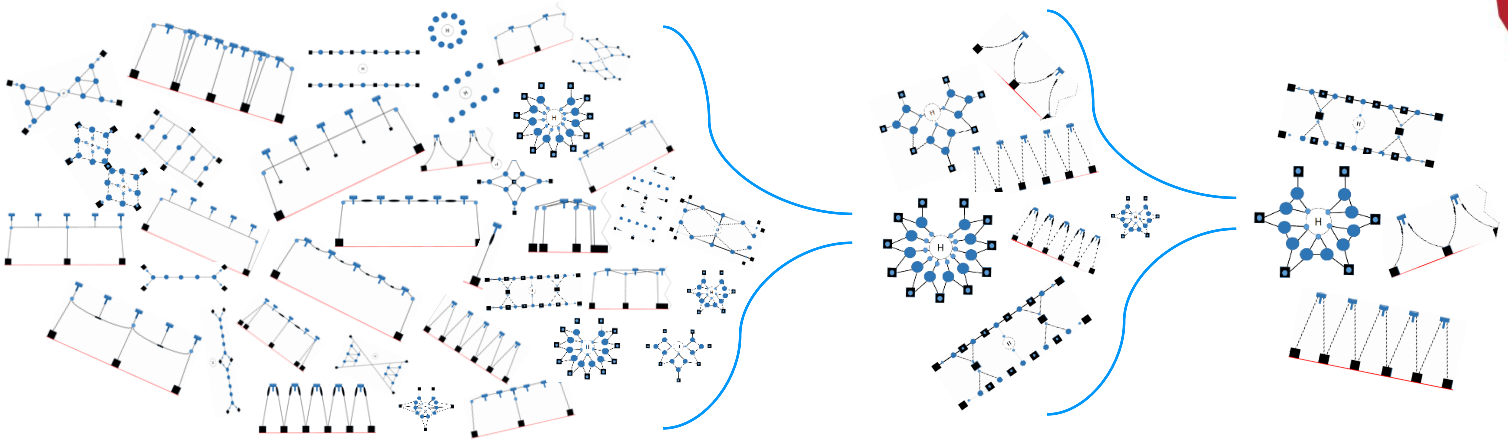
Rotating bending test
Rotating frequency: 1.5-2 Hz
The bending radius can be adjusted


Contours
Above
19.0250
6.21593
-0.198981
-6.59389
-19.4037
-32.2135
-38.6185
-45.0234
-51.4283
Below
Neg Y
Frame: 1/199
Time: 0.005
1: Time 0.005 s



WaveEL in array configurations

22 Concepts → **Pugh matrix** → 7 Concepts → **Kesselring matrix** → 4 Top concepts



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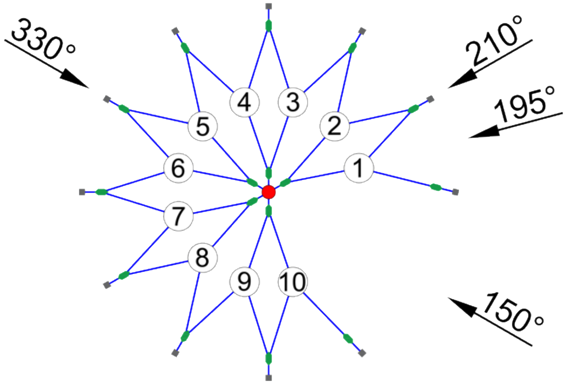
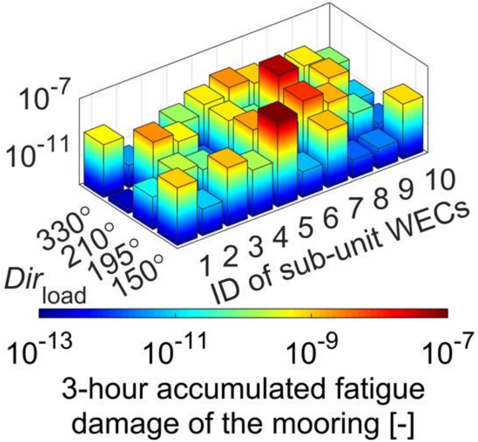
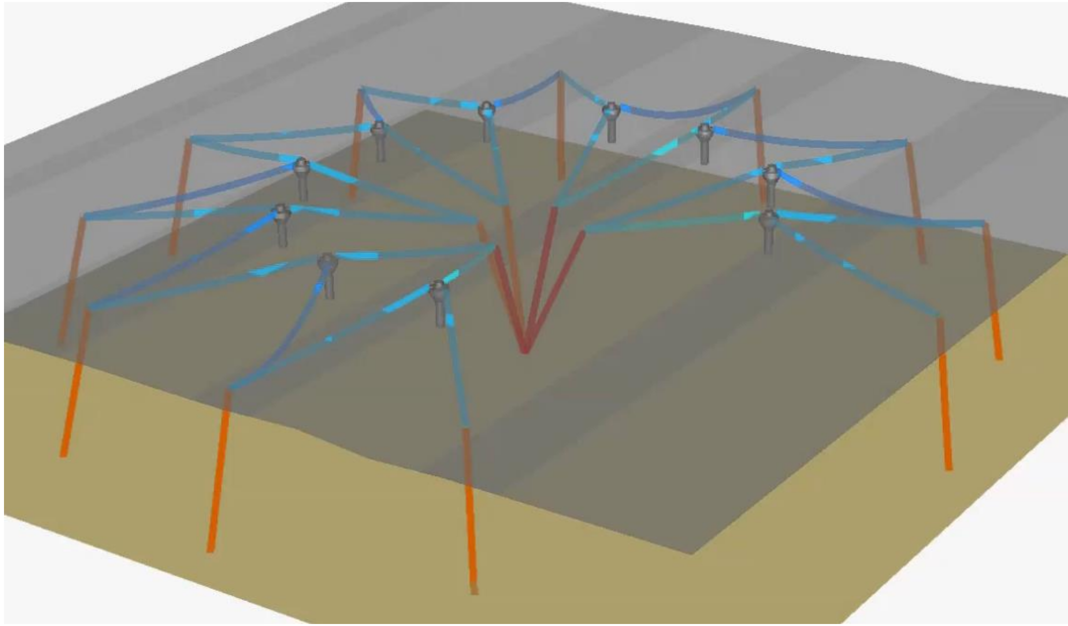
The StarBuoy conecpt







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Concluding remarks

- **Wave energy has an important role in the global production of renewable energy**
- **The derivative of innovation pace of new WEC concepts is steep**
  - Competetive market, many developers do not survive “the valley of death”
  - The EMEC (http://www.emec.org.uk) test-sites are important for validation and verification
- **LCoE is too high compared to other energy sources**
- **Future research and development**
  - Integrate knowledge between academia, research institutes and industry
  - Apply simulation procedures and models, and business models,
    in holistic analyses making use of LCoE as a tool

Two questions for you

- How can wave energy be extracted from the ocean?
- What do you think are the biggest challenges with extracting wave energy offshore?

CHALMERS

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