Ocean Extremes: Marine Heatwaves and Marine Ecosystems

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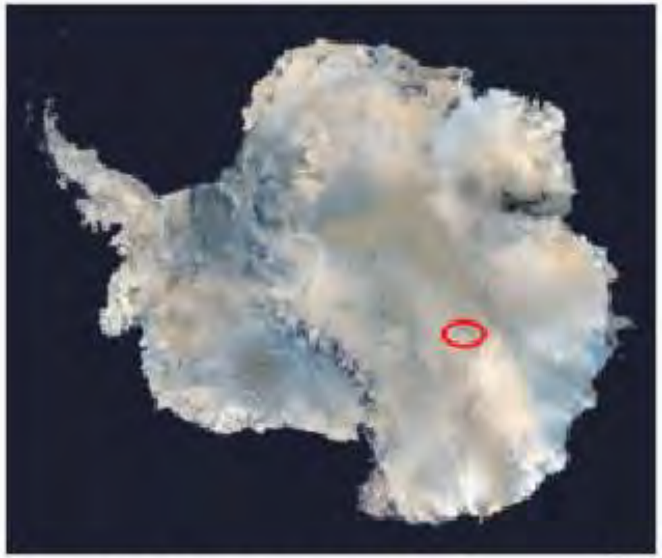
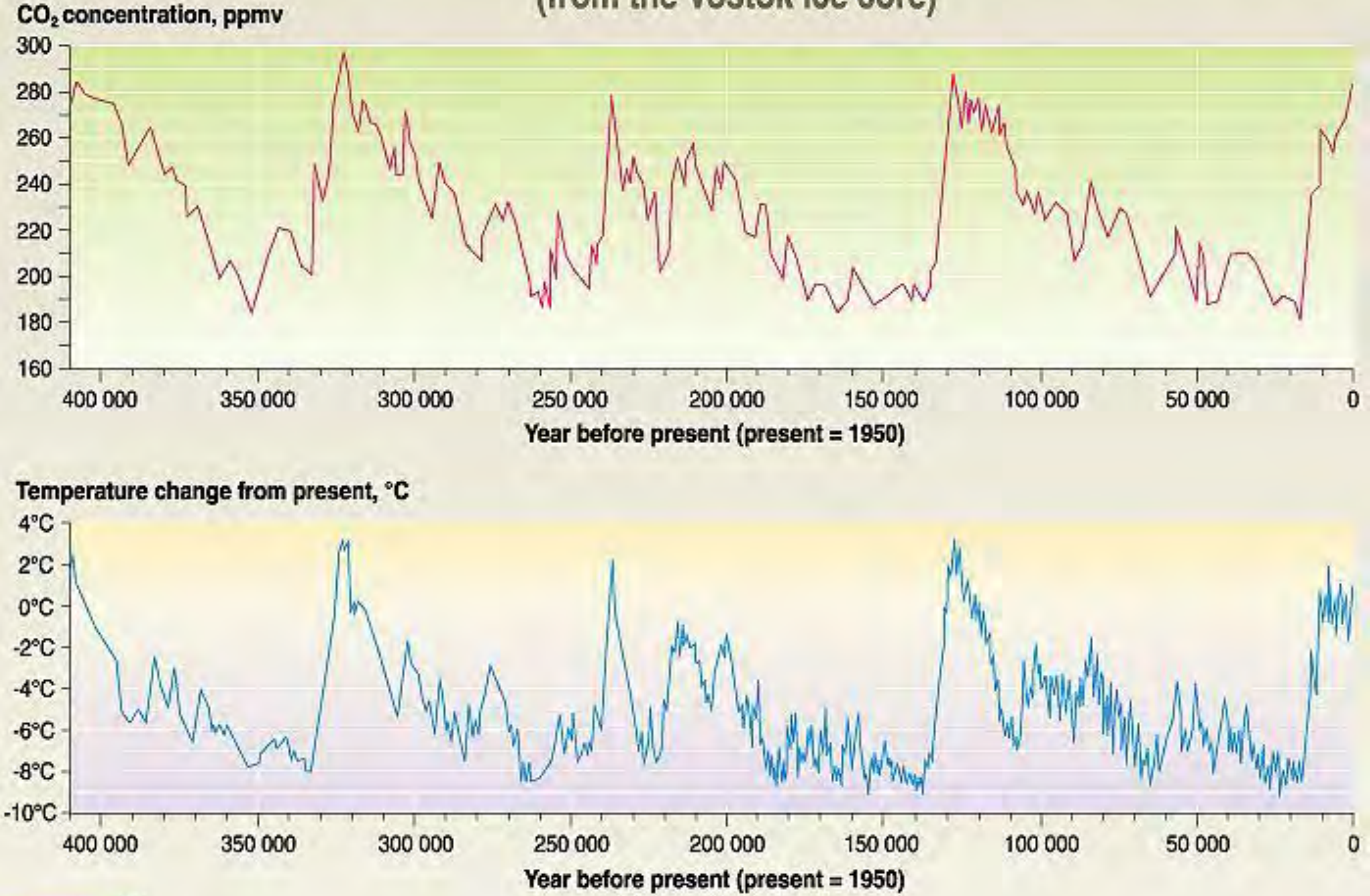
and the Marine Heatwaves Working Group



Lake Vostok composite image (NASA)

Temperature and CO_2 concentration in the atmosphere over the past 400 000 years (from the Vostok ice core)



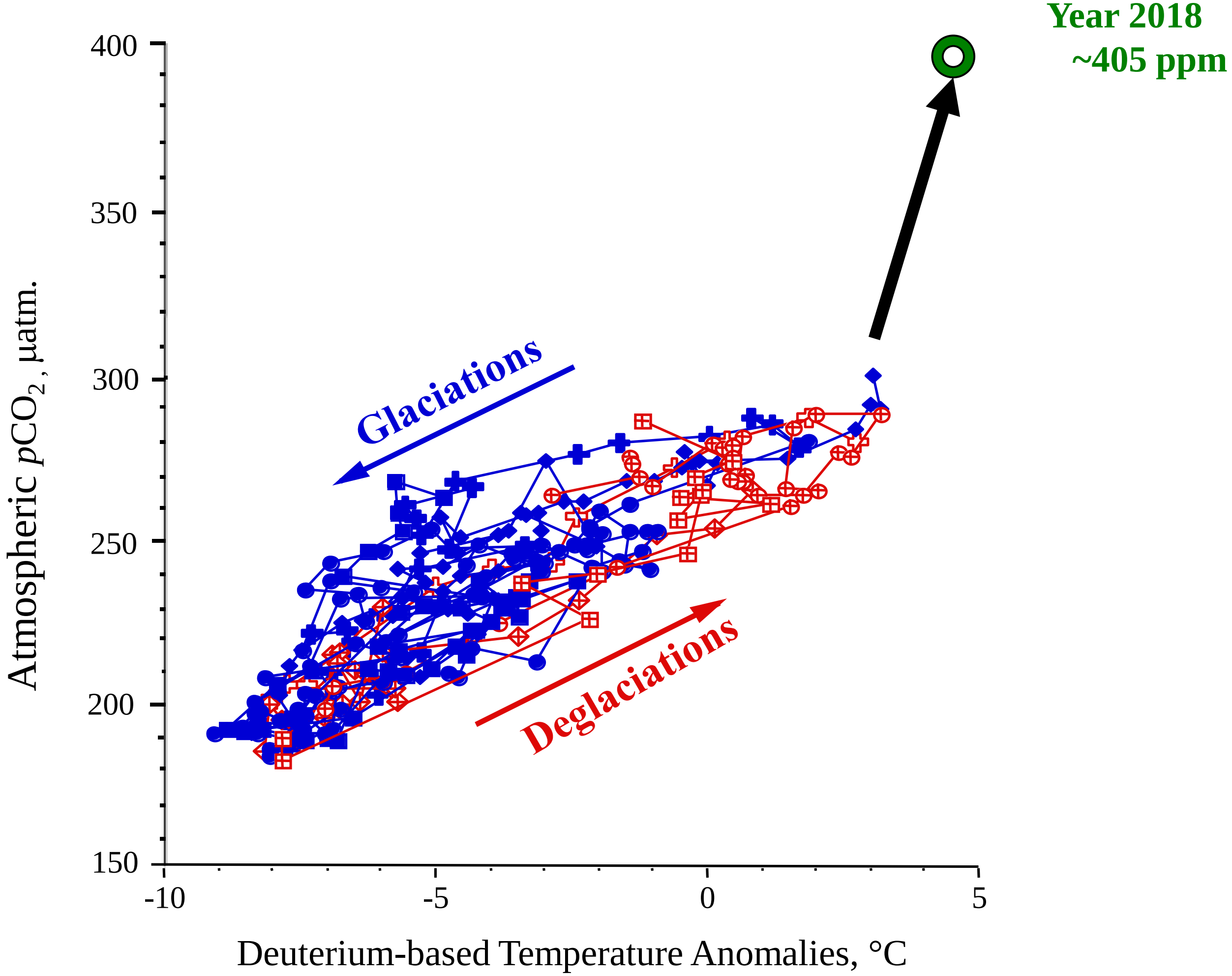
GRID Arendal UNEP

GRAPHIC DESIGN : PHILIPPE REKACEWICZ

Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3 JUne), pp 429-436, 1999.

CO_2 & Temperature (~800,000 Years)

Vostok Ice Core Data



IGBP 2000

Courtesy David Ugalde, DCC

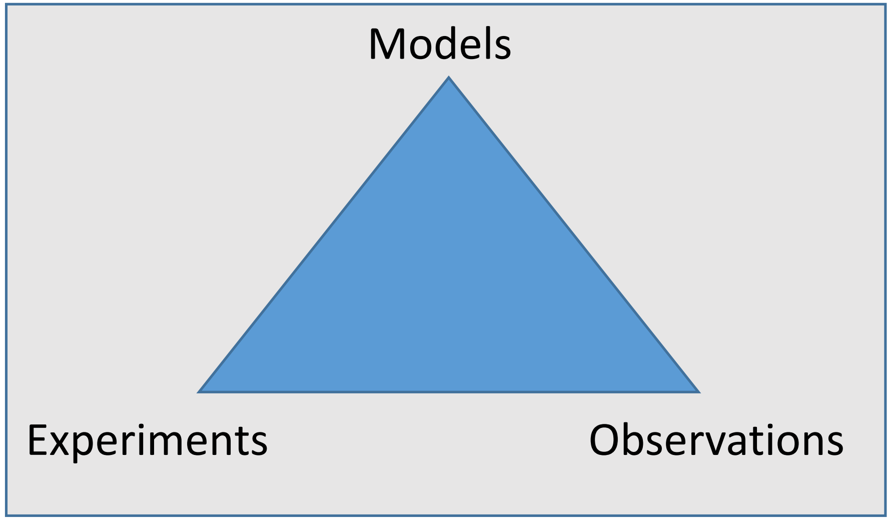
The future will be even more different…

- Past experience less useful
  - Novel combinations of physics, chemistry, and biology
- Need to make decisions that are generally ok even if the details change, based on the best information available at the time
- Learn as fast as we can!

How can we learn faster?

When we can test, or observe, cause-and-effect

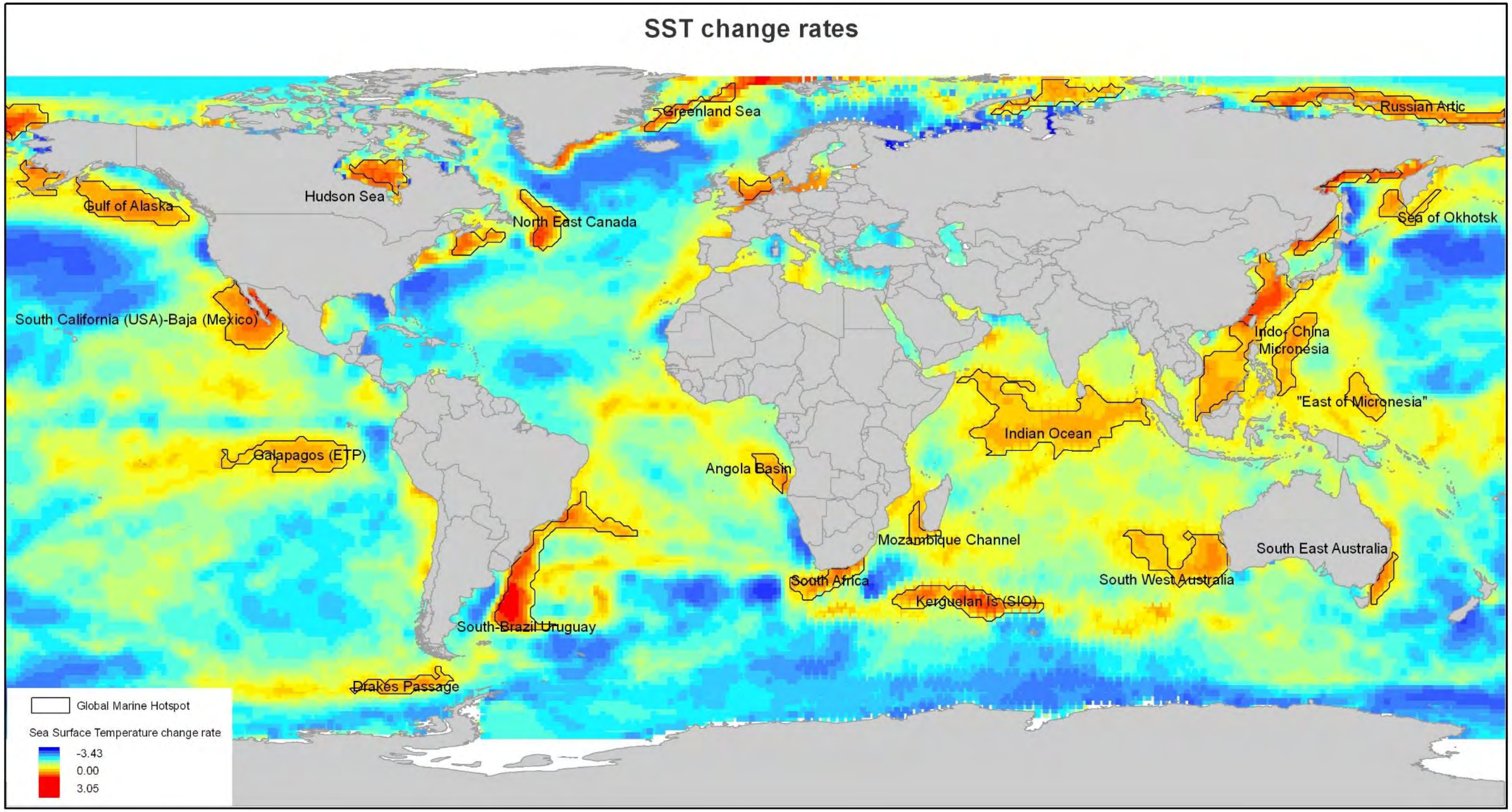
1. Models – process and mechanism limited…
    - Projections (at short time scales) – not 2100!
2. Experiments – scale and factors limited….
3. Observations – replication limited….
    - Local studies – in situ process understanding
    - Spatial contrasts – fast warming areas
    - Temporal contrasts – extremes


Models

Experiments

Observations

1. Learning fast - spatial contrasts



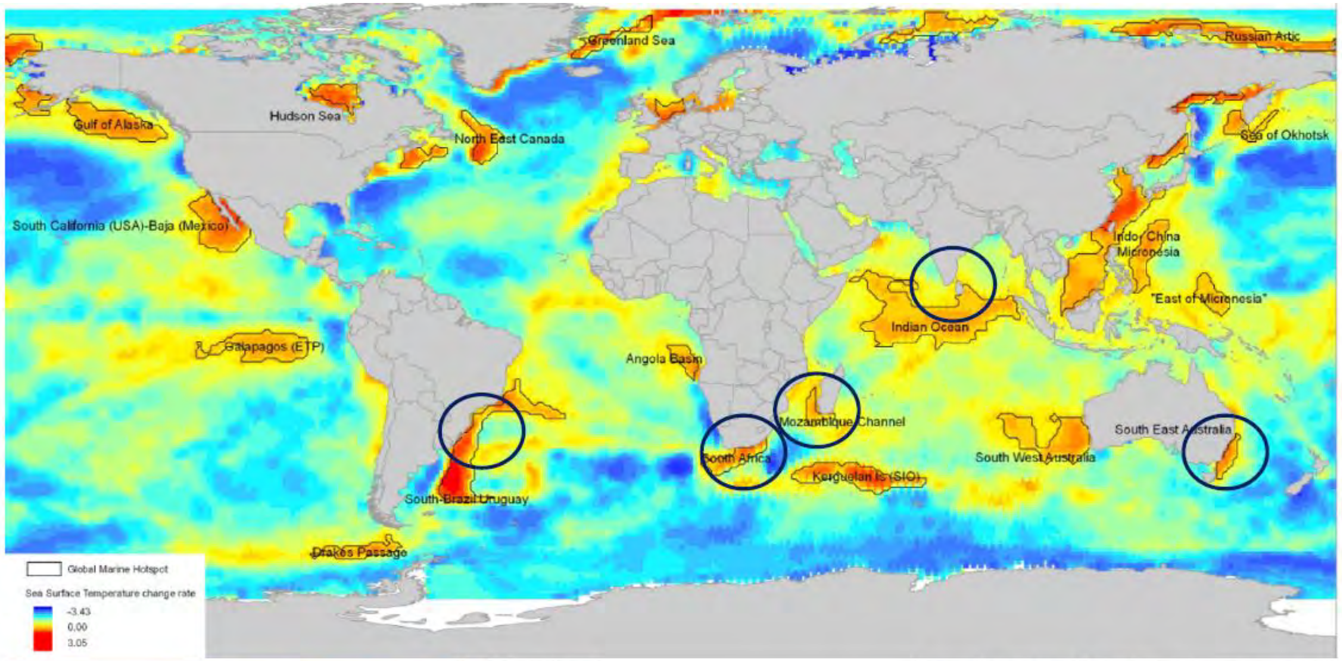
Hobday & Pecl 2014

Comparative approach

Fast warming areas are a natural laboratory for assessing the impacts of climate change

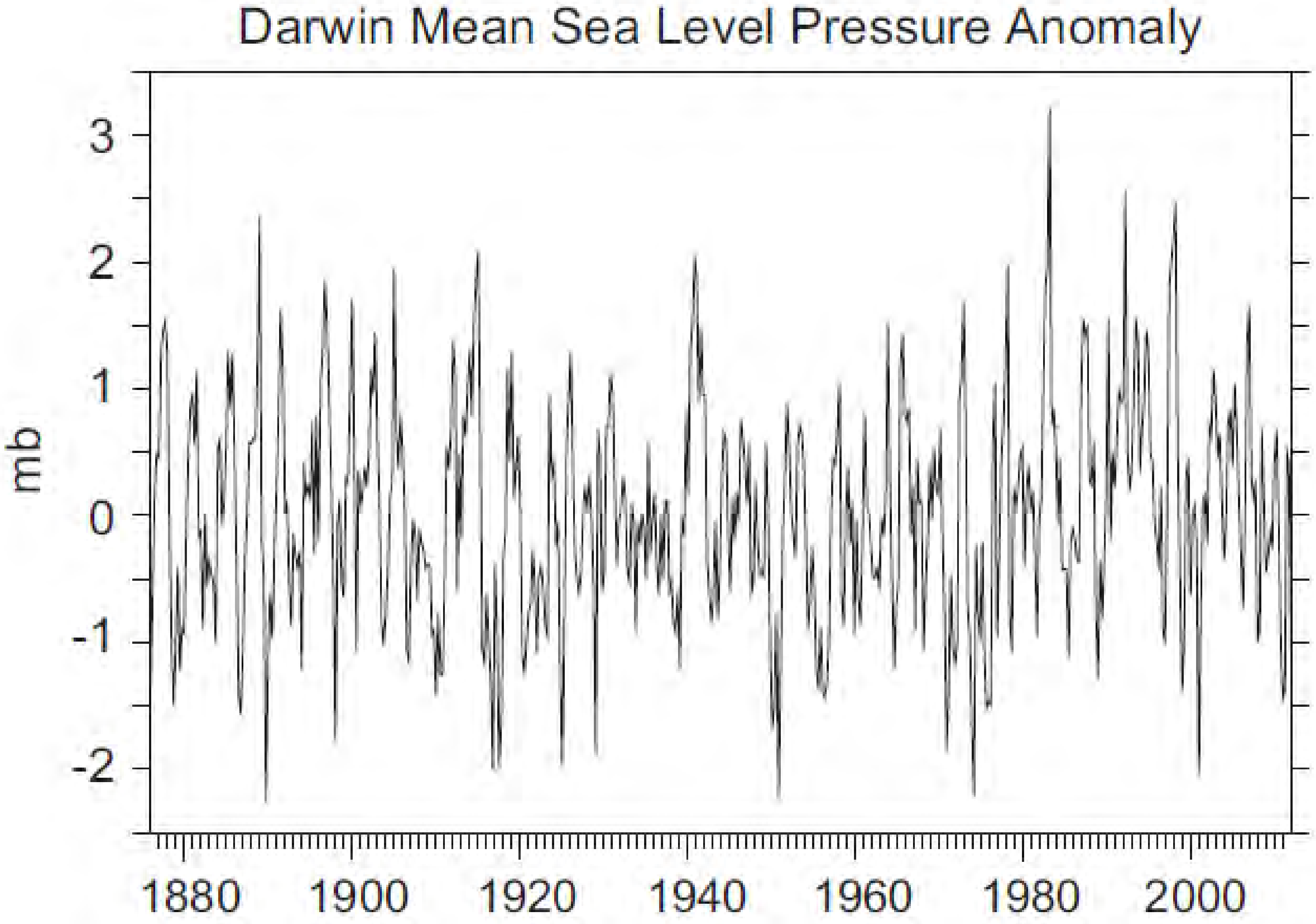
Pecl et al. 2014 (RFBF)

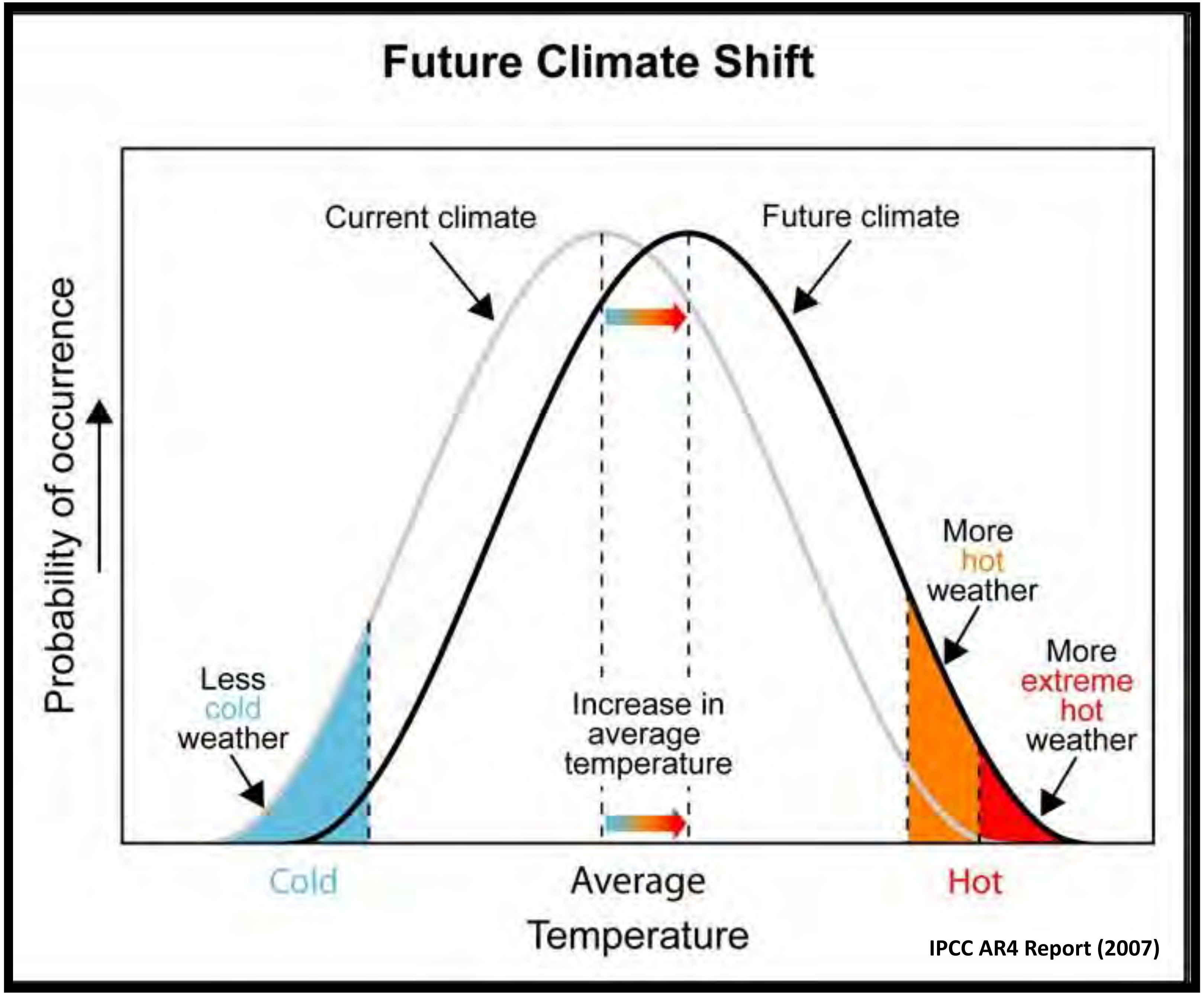
Belmont project Global Understanding and Learning for Local Solutions (GULLS)



Hobday et al. (2016) RFBF

2. Learning fast – temporal contrasts


Darwin Mean Sea Level Pressure Anomaly



IPCC AR4 Report (2007)

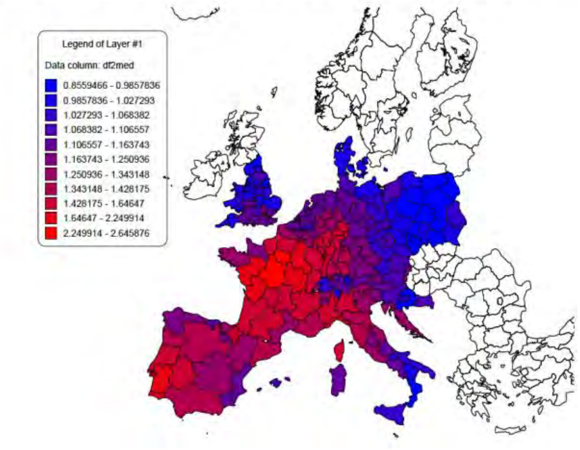
Extreme events

- Cyclones and Hurricanes
- Storm surges
- Tsunamis
- Deoxygenation
- Upwelling (cold)
- Marine heatwaves

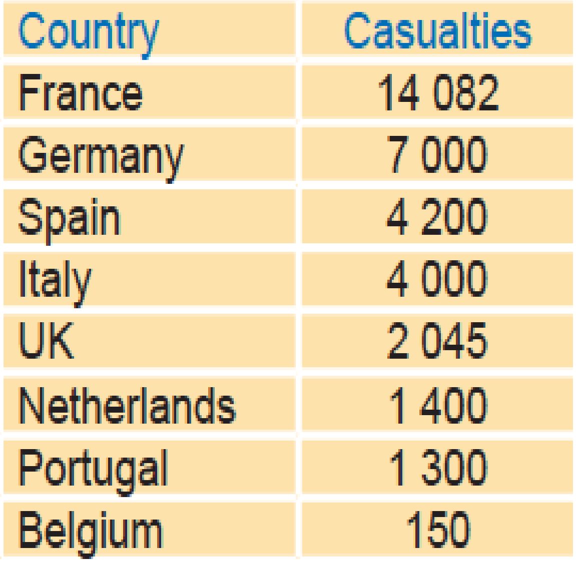
Heatwaves ~2011

- Extreme warm events that persist for extended periods of time, ***heatwaves***, can have disastrous consequences
    - e.g. 2003 in Europe *~30,000 deaths*

- However, equivalent ocean events not identified in the same way (ENSO)



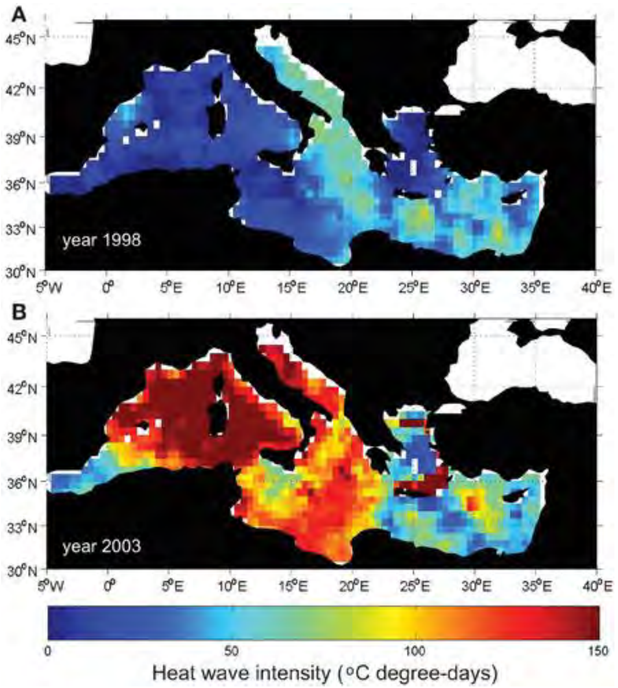
Map 1: Daily death frequencies cumulated from August 3rd to 16th 2003, divided by fourteen times the daily reference median frequency for 1998-2002 summer period, sixteen European countries, NUTS 2.



Country	Casualties
France	14 082
Germany	7 000
Spain	4 200
Italy	4 000
UK	2 045
Netherlands	1 400
Portugal	1 300
Belgium	150

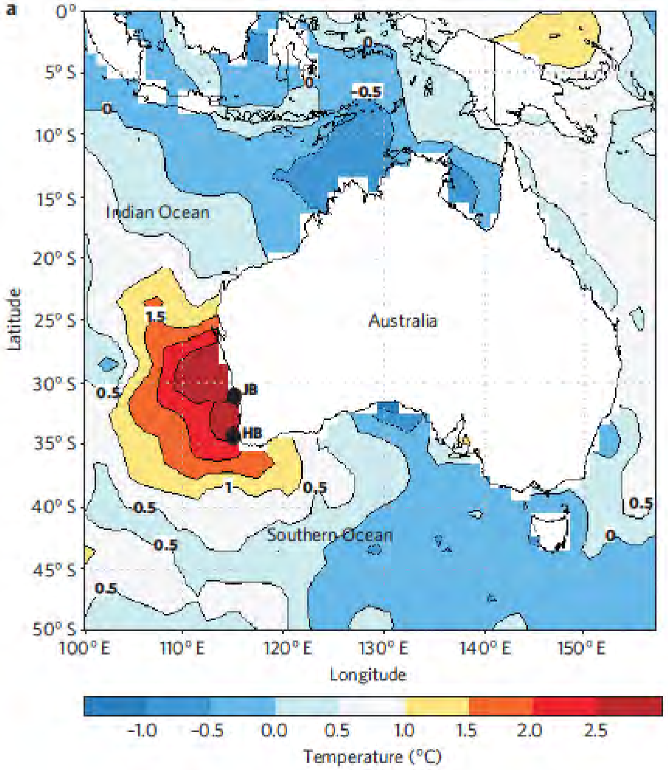
Marine heatwaves – extreme events

Mediterranean 2003



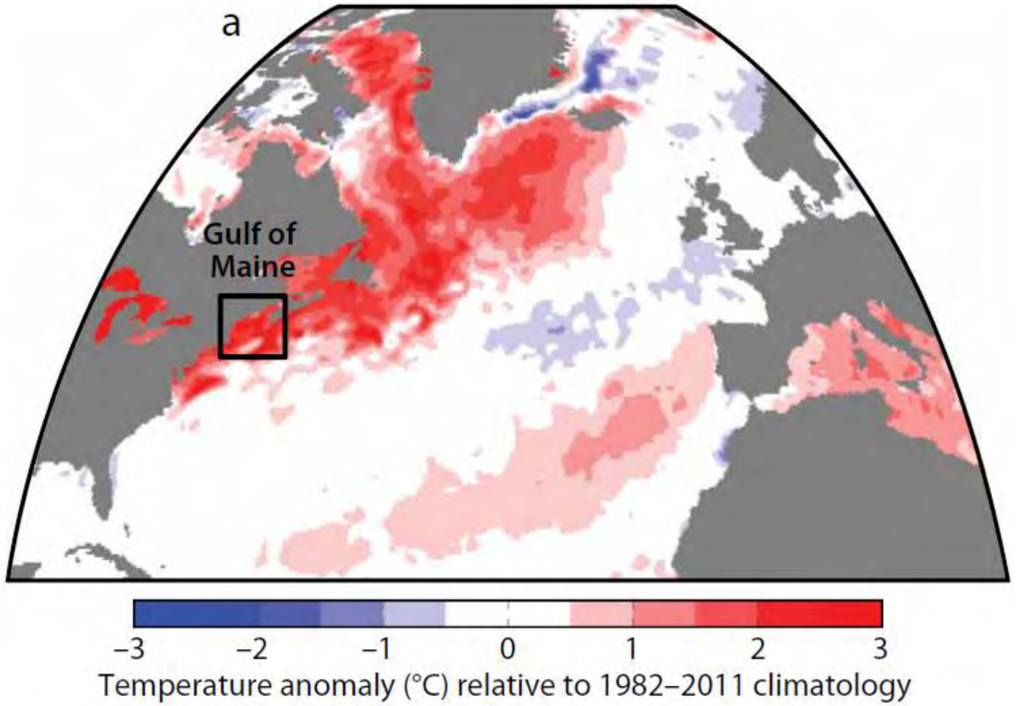
Garrabou et al 2009

Western Australia – 2011



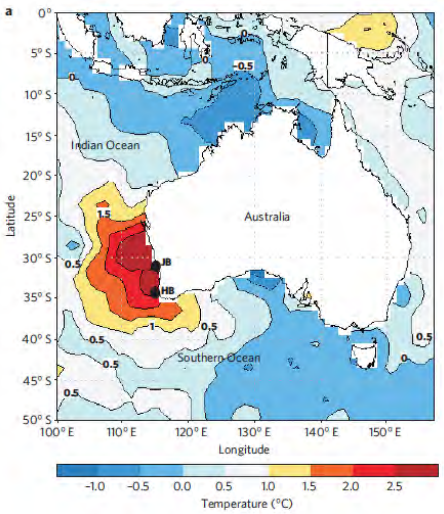
Wernberg et al 2011

NW Atlantic 2012

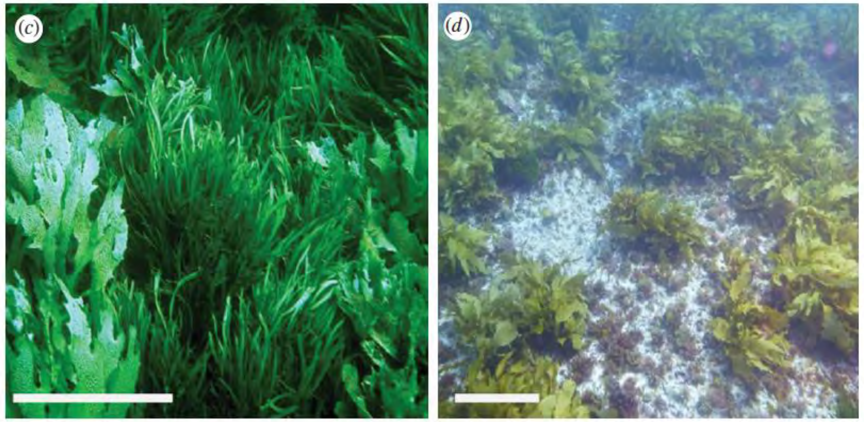


Mills et al. 2013

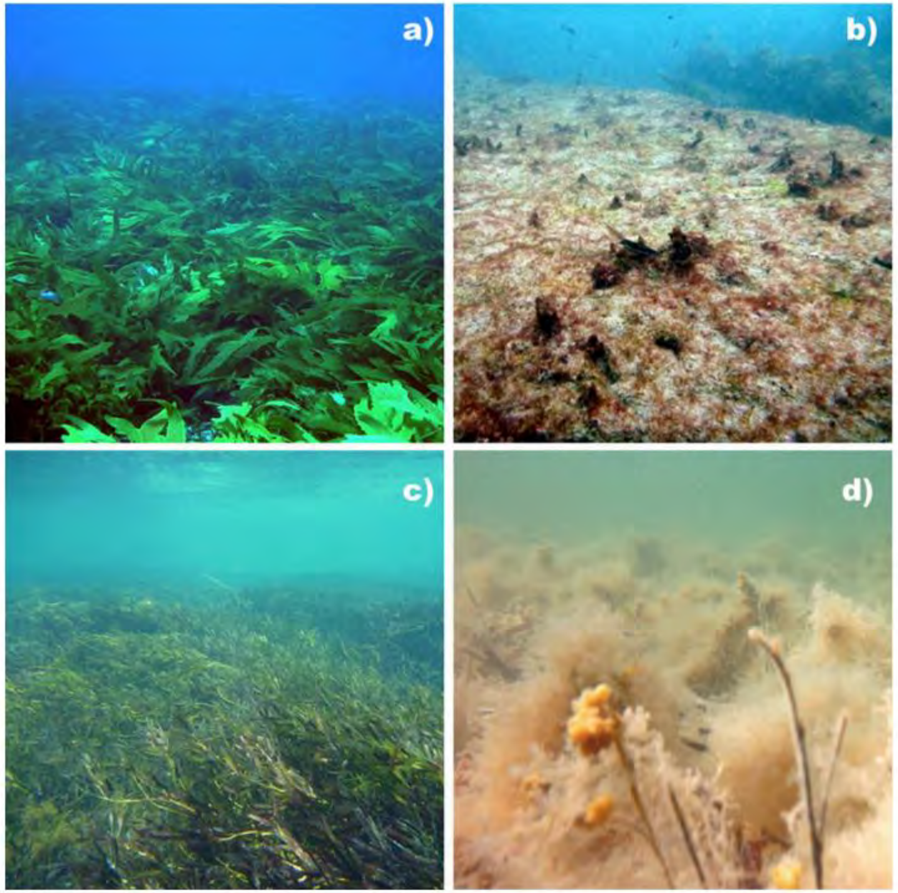
Impacts of marine heatwaves



Range change



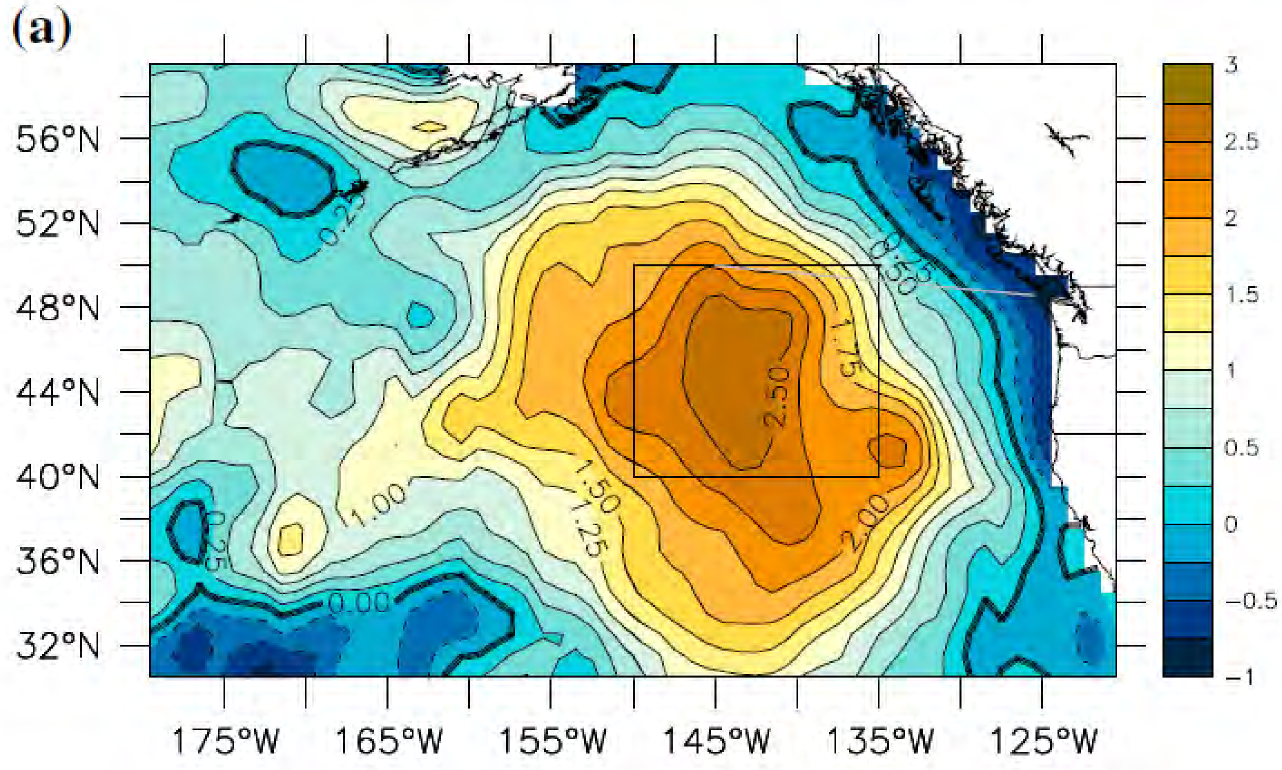
Habitat change



Lacked comprehensive global understanding about the distribution, frequency, duration or intensity of MHWs, or the underlying **physical causes**

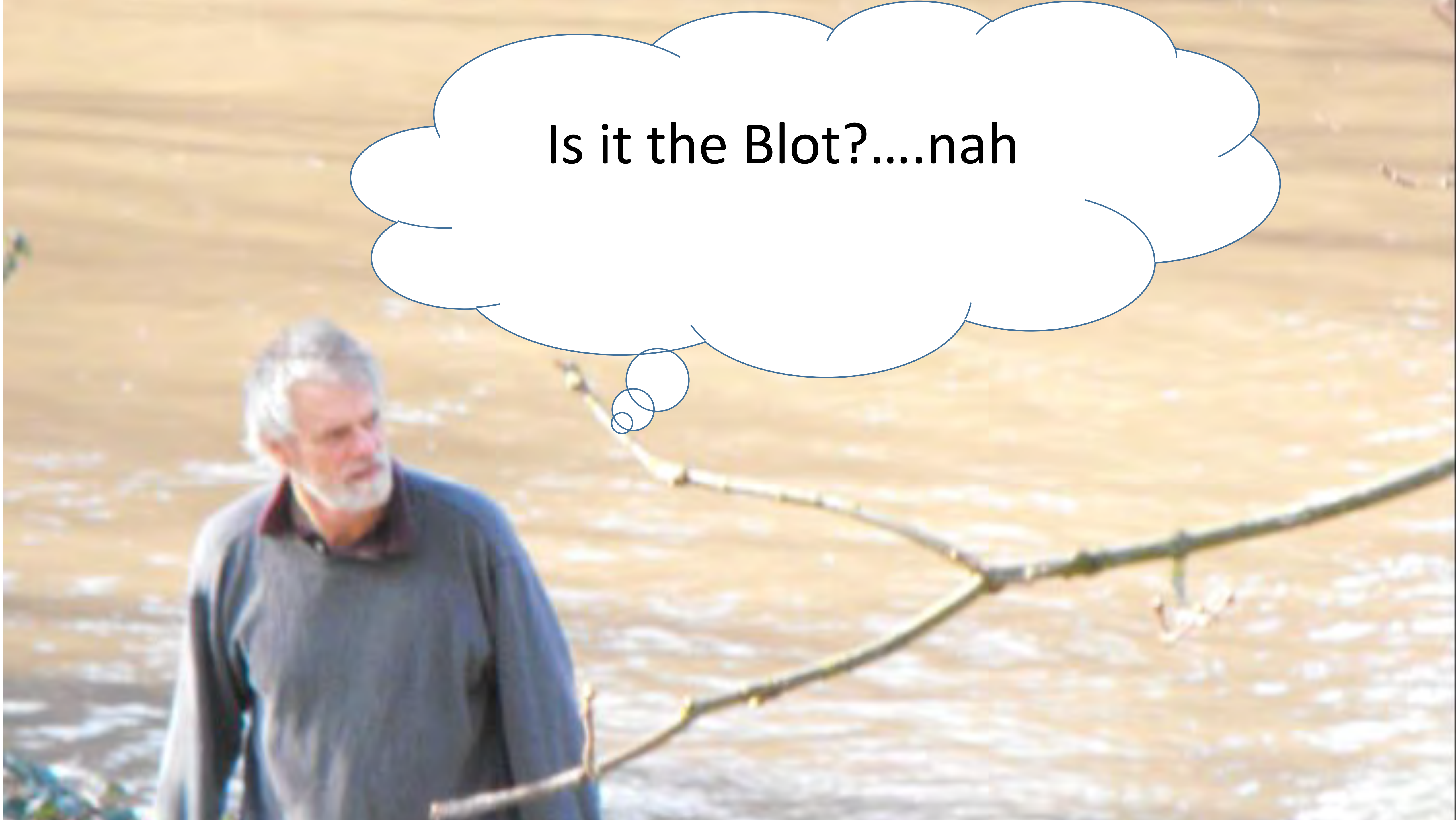
Then in the north-east Pacific ~2014

- Warm pool
- Warm water anomaly
- What is this thing….?

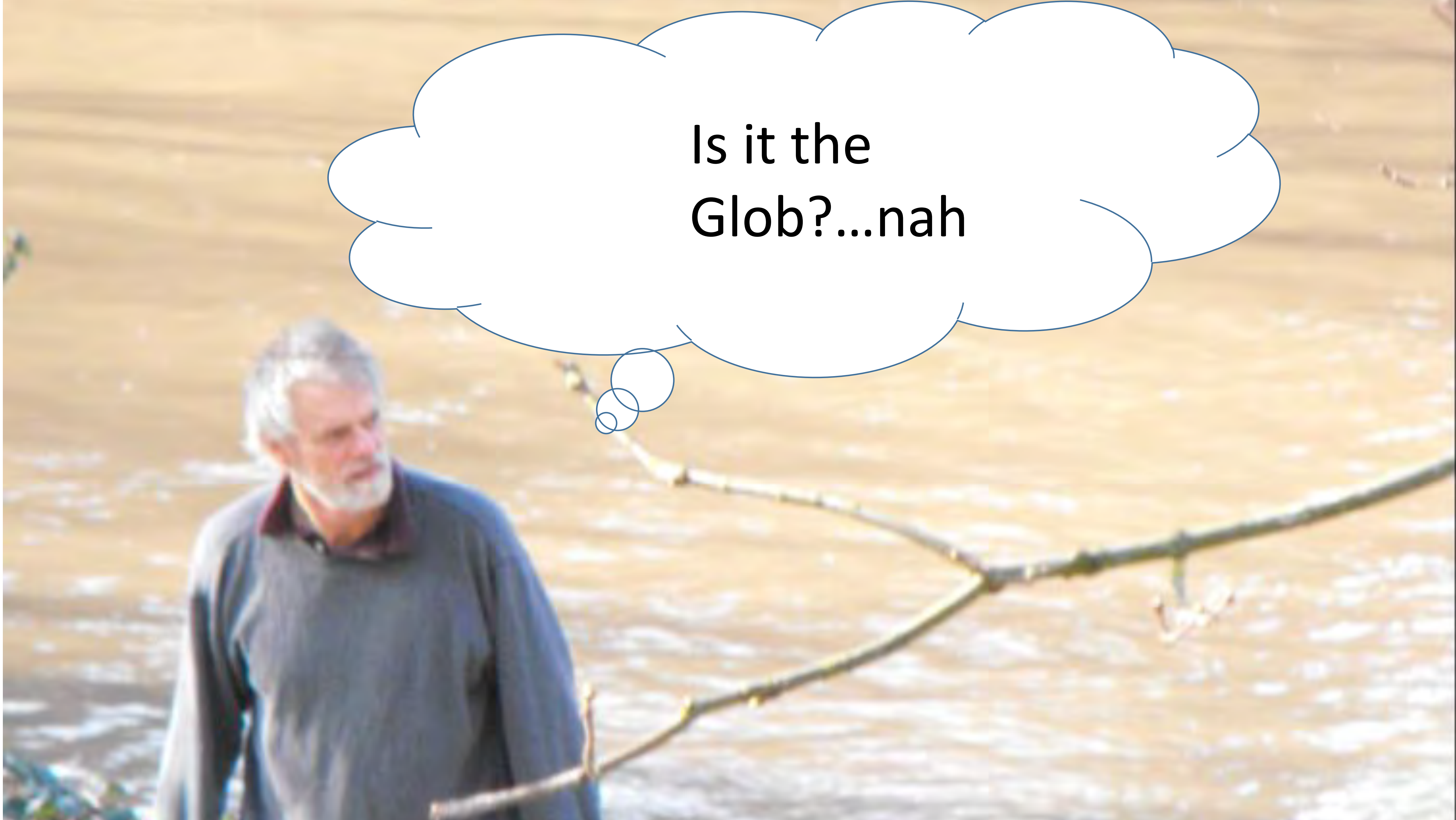


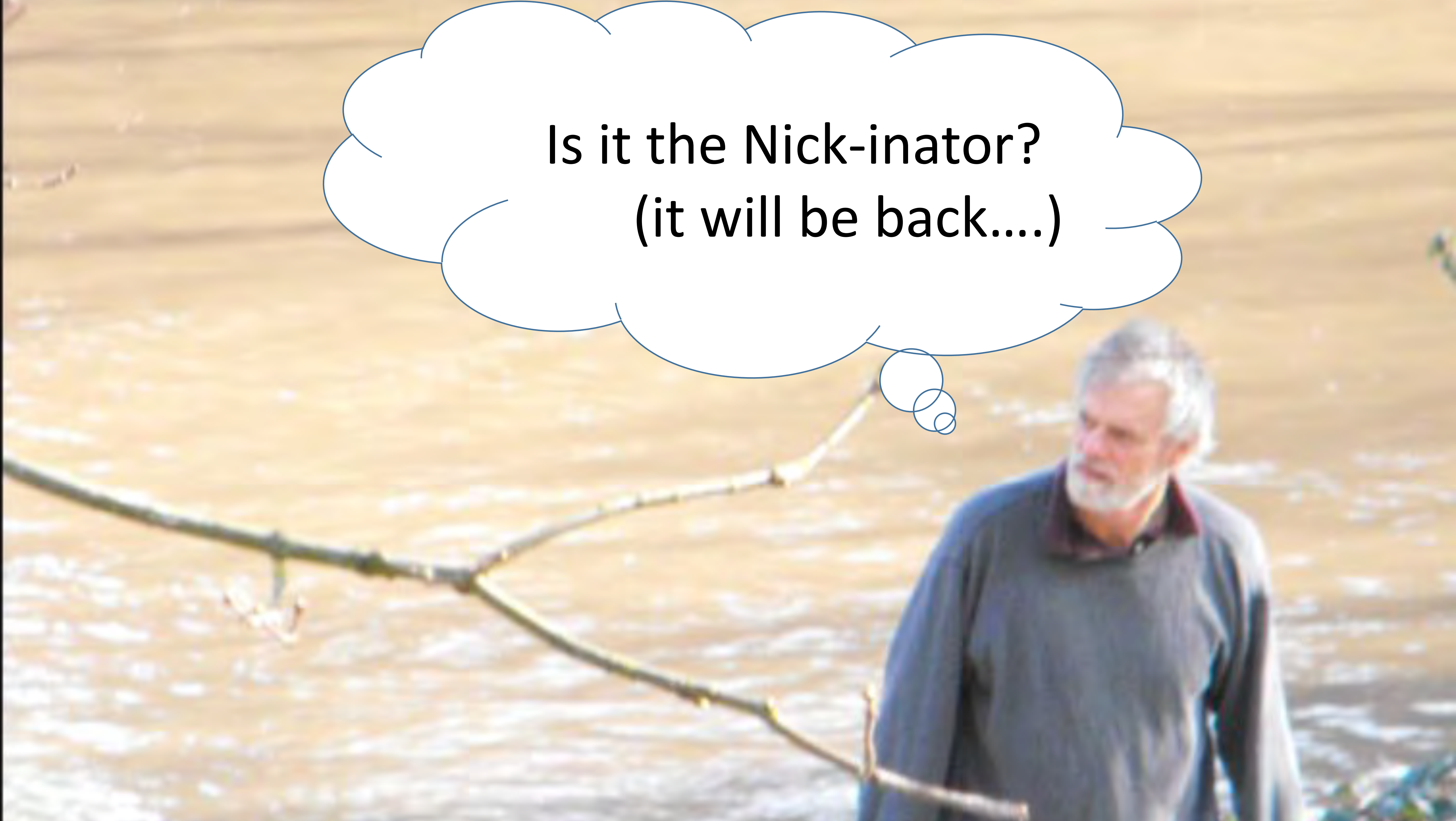
……a quest (the true story)

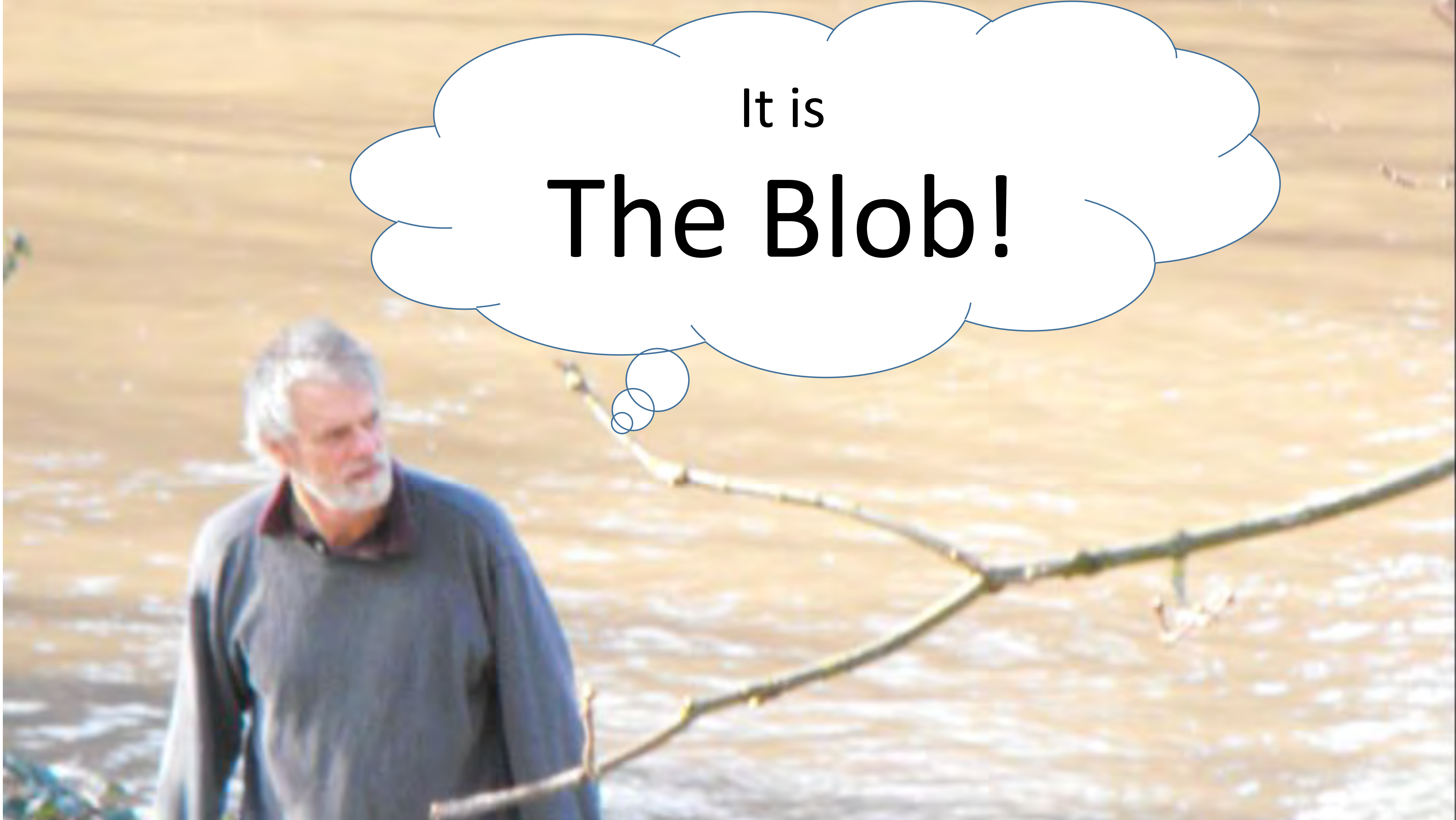
“I will go into the wilderness….”


Is it the Blot?....nah

Is it the Blog?....nah


Is it the Glob?...nah

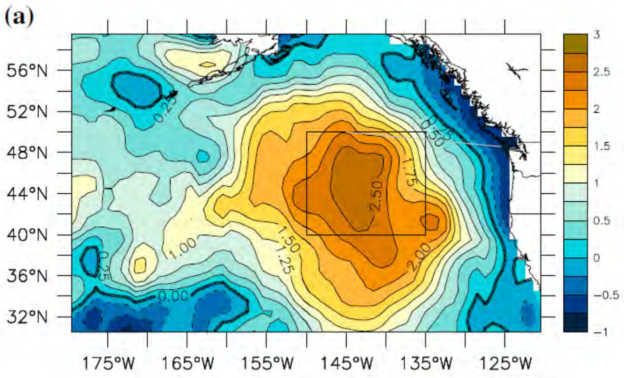

Is it the Nick-inator?
(it will be back....)

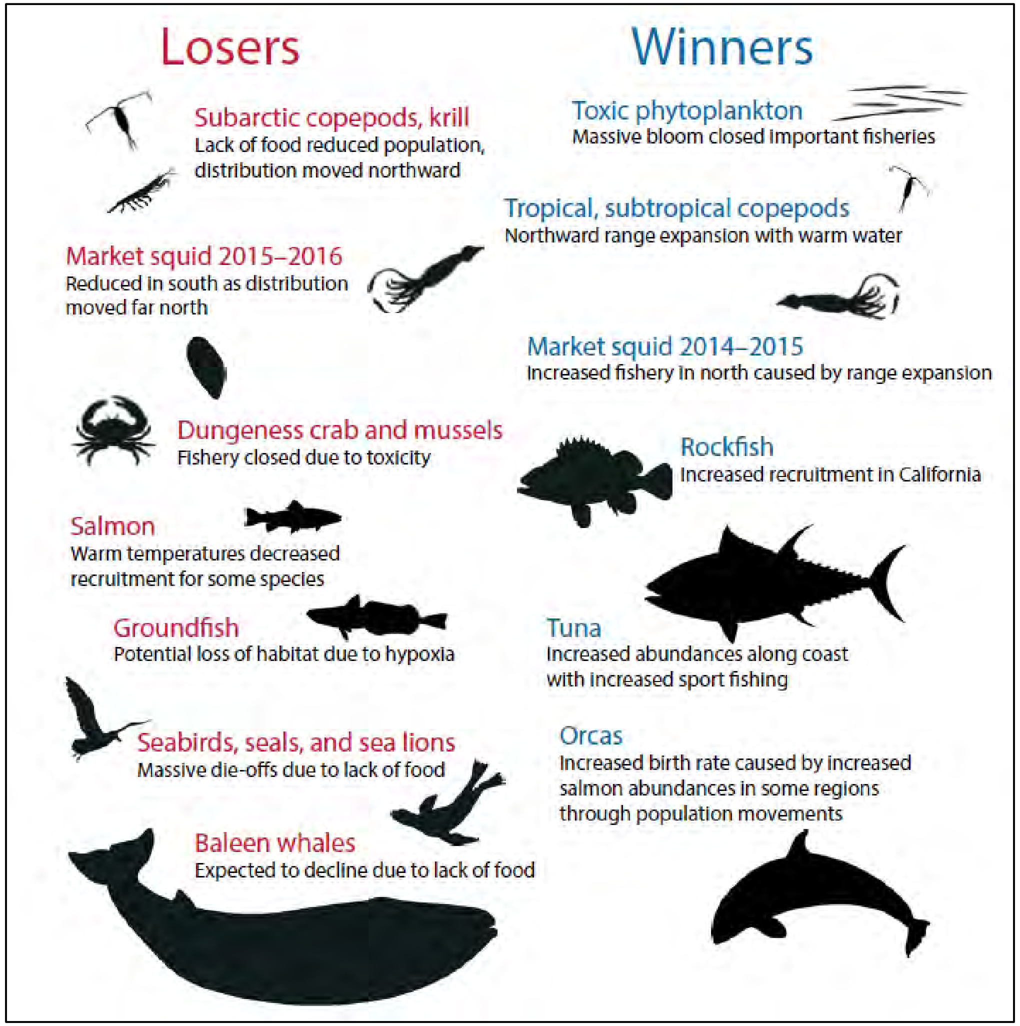


It is

The Blob!

The Blob….we've heard a lot about it here!





Losers

Subarctic copepods, krill
Lack of food reduced population, distribution moved northward

Market squid 2015–2016
Reduced in south as distribution moved far north

Dungeness crab and mussels
Fishery closed due to toxicity

Salmon
Warm temperatures decreased recruitment for some species

Groundfish
Potential loss of habitat due to hypoxia

Seabirds, seals, and sea lions
Massive die-offs due to lack of food

Baleen whales
Expected to decline due to lack of food

Winners

Toxic phytoplankton
Massive bloom closed important fisheries

Tropical, subtropical copepods
Northward range expansion with warm water

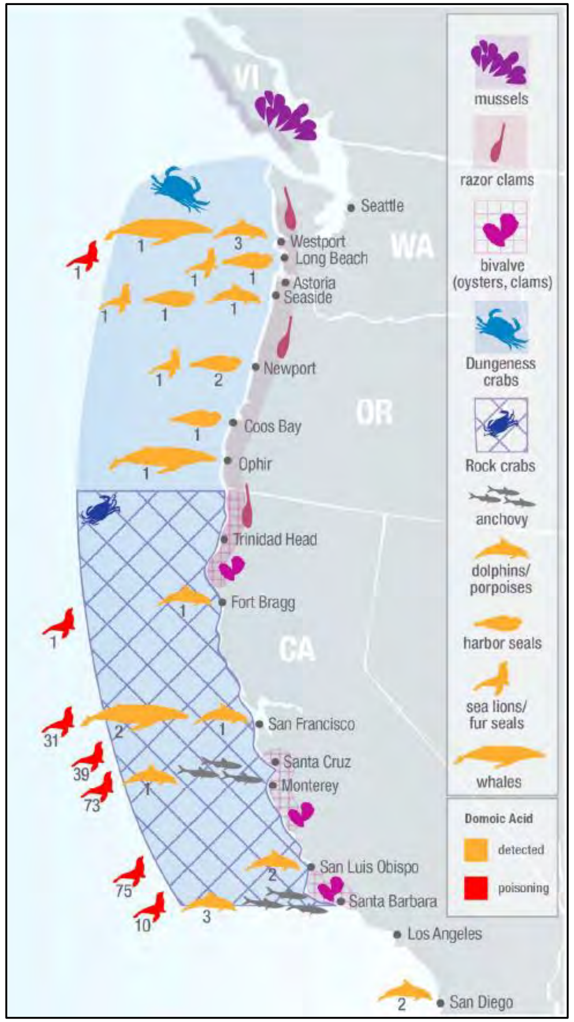
Market squid 2014–2015
Increased fishery in north caused by range expansion

Rockfish
Increased recruitment in California

Tuna
Increased abundances along coast with increased sport fishing

Orcas
Increased birth rate caused by increased salmon abundances in some regions through population movements

Cavole et al 2016



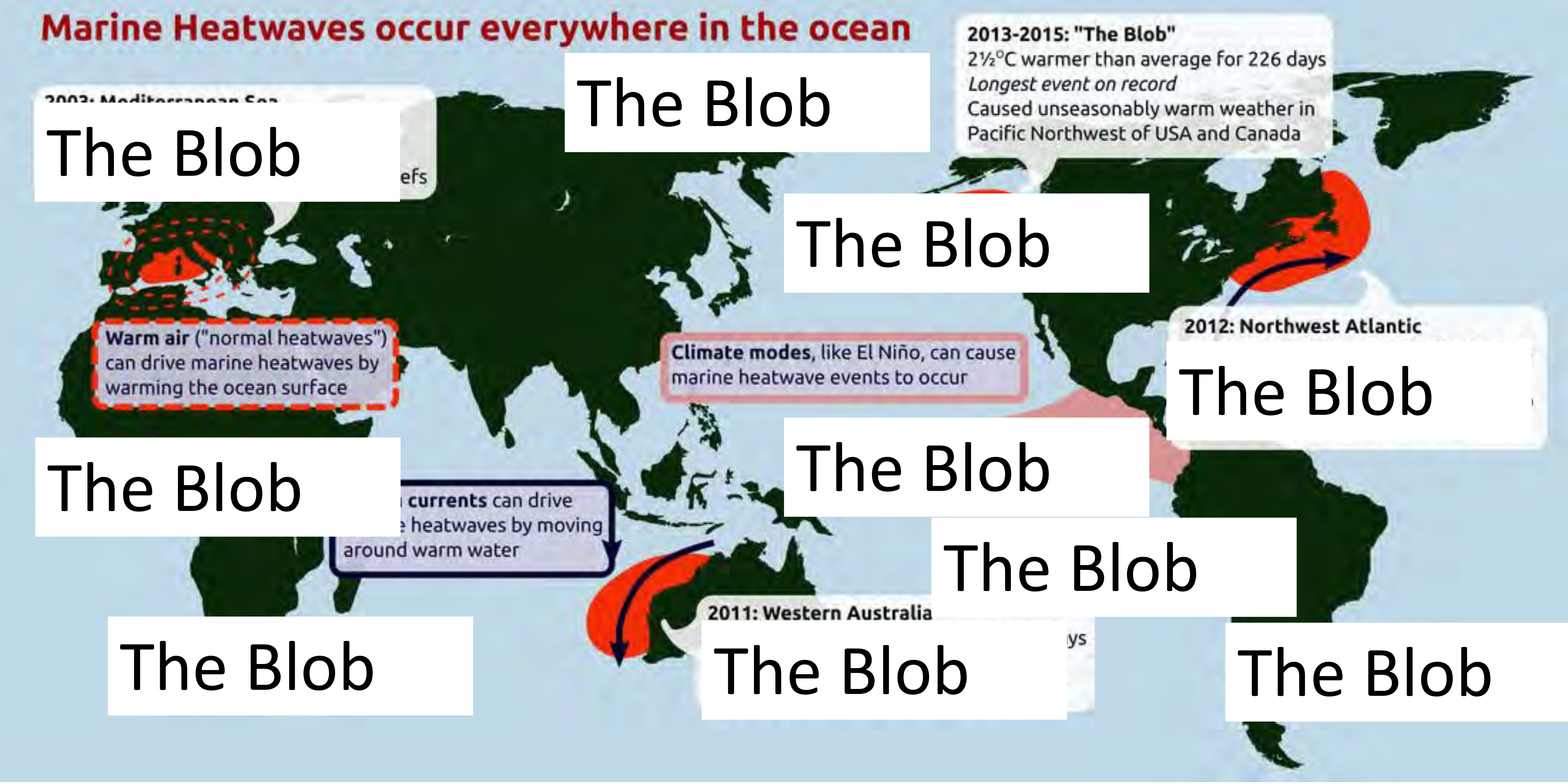
McCabe et al 2016

But…it’s just a marine heatwave!

- Blob (2014-2016)

- What to do next time?

- Blob Returns (2020)
- Son of a Blob (2023)
- Blob III (2025-2026)
- ….



Marine Heatwaves occur everywhere in the ocean

The Blob

2013-2015: "The Blob"
2½°C warmer than average for 226 days
Longest event on record
Caused unseasonably warm weather in Pacific Northwest of USA and Canada

2003: Mediterranean Sea

The Blob

efs

The Blob

2012: Northwest Atlantic

The Blob

Warm air ("normal heatwaves") can drive marine heatwaves by warming the ocean surface

Climate modes, like El Niño, can cause marine heatwave events to occur

The Blob

The Blob

currents can drive
heatwaves by moving
around warm water

The Blob

2011: Western Australia

The Blob

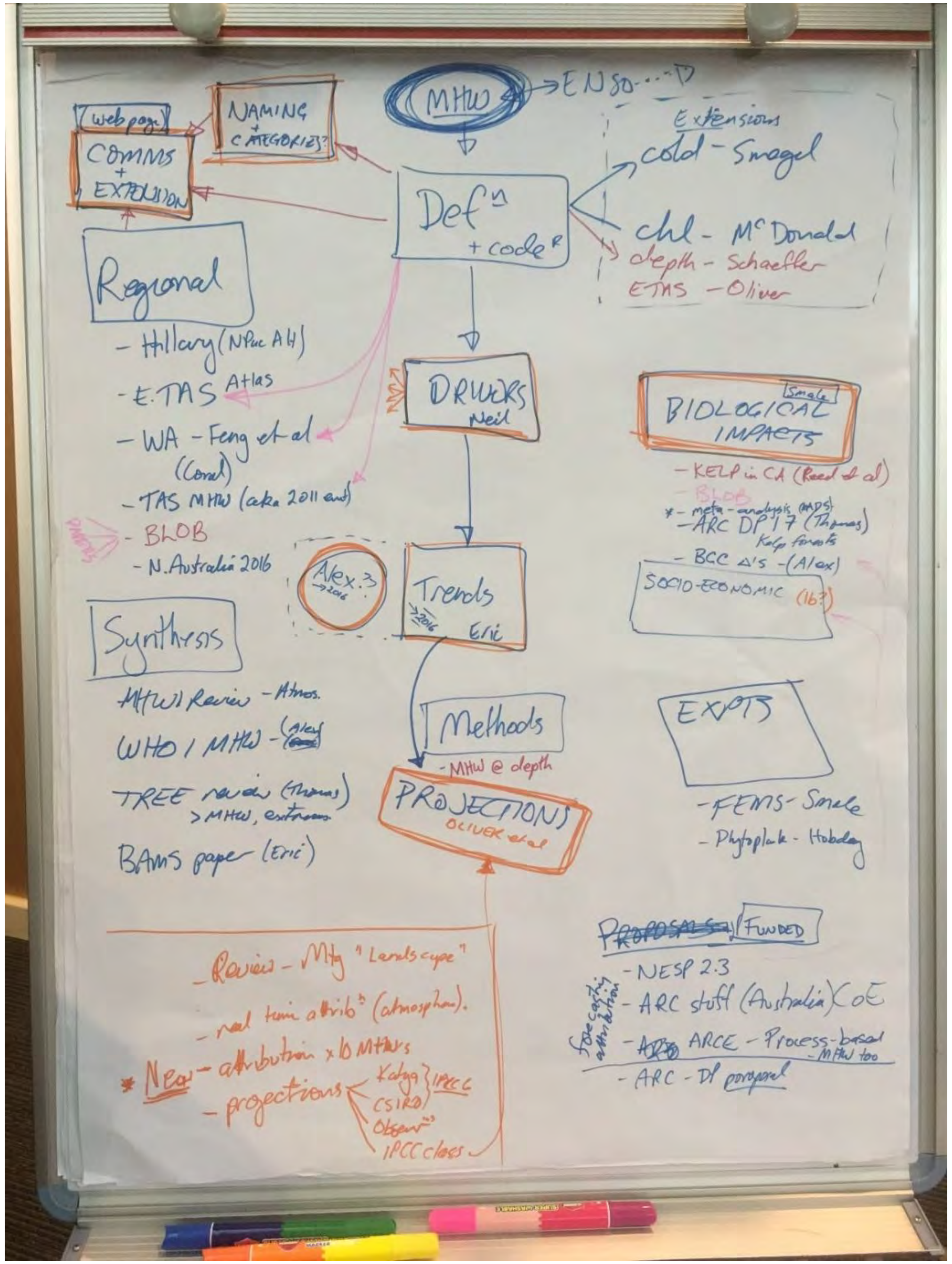
ys

The Blob

The Blob


MARINE HEATWAVES
International Working Group

Workshops…(n=3)



Step 1 – qualitatively define an MHW

A discrete prolonged anomalously warm water event at a particular location

- Does not assume location, physical mechanism or impact
- Is flexible, can become more targeted to end-user applications
- Not limited to time of year
- Can be applied sub-surface
- Applied to different data products
- Can also describe various “types” of heatwaves
- Consistency in quantitative measurements encouraged…

Step 2 – quantitatively define an MHW

Based on the qualitative definition:

Anomalously warm: a MHW must lie above a high percentile, calculated from a baseline climatology

- 90th percentile; vary with climatology throughout year
- Common baseline among studies/data if possible (e.g. 1990-2010)

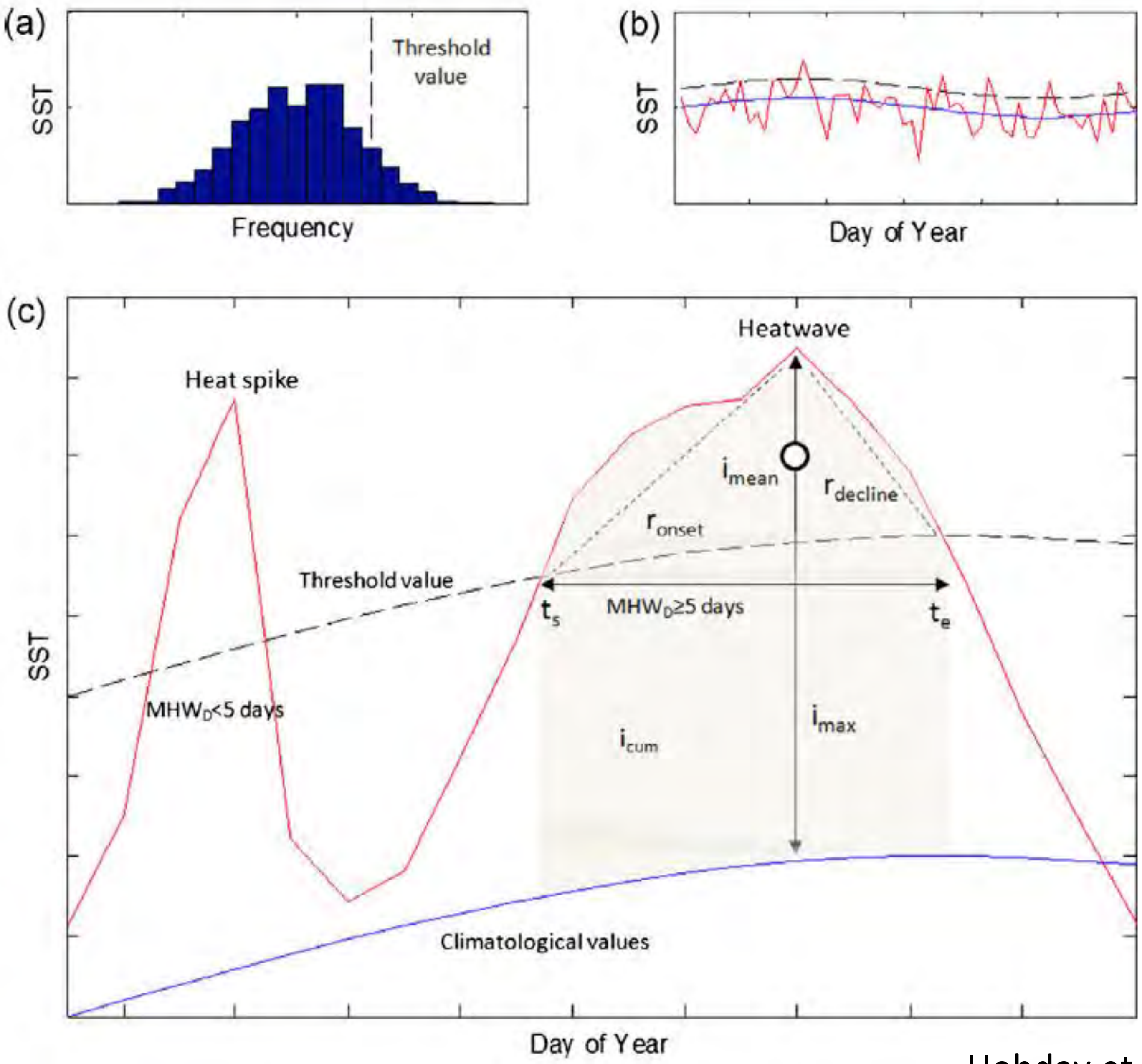
Prolonged: MHW persists under above conditions for at least 5 days (thoroughly tested)

Discrete: clear start and end dates.

- Events punctuated by 2 or less days considered 1 event

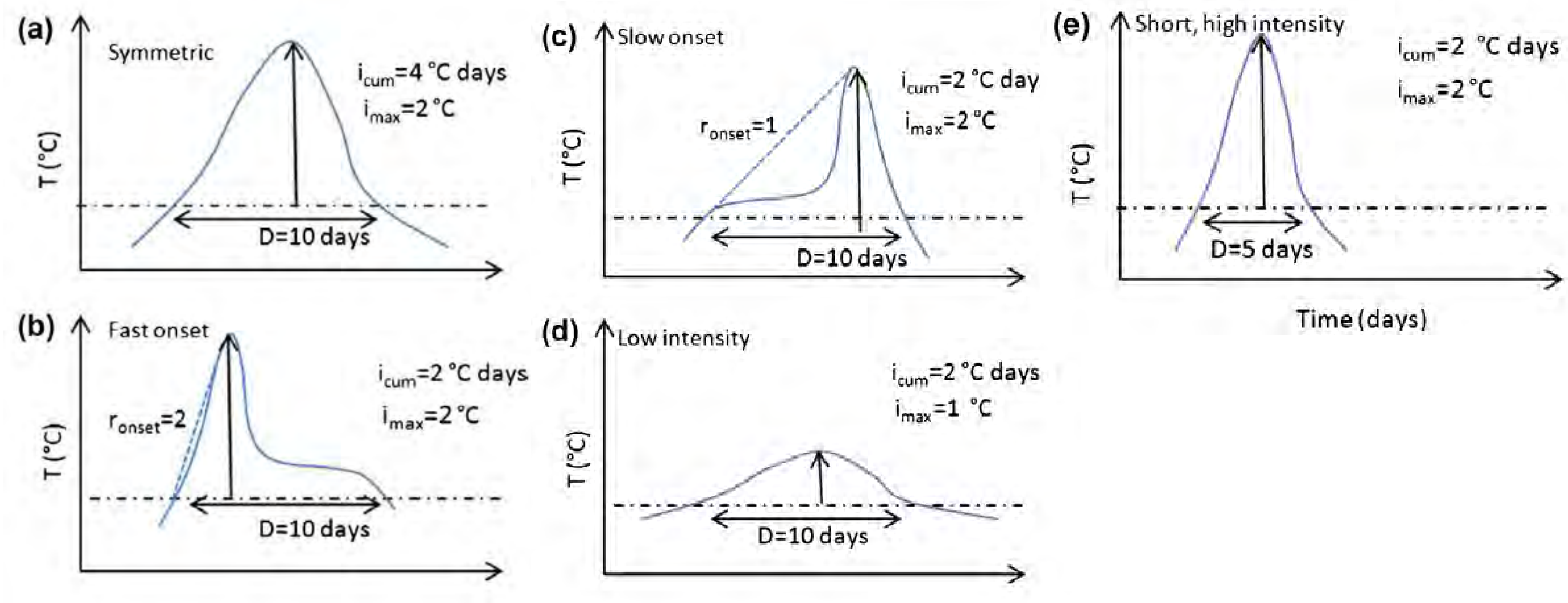
Step 3 – Create a set of metrics

- Duration
- Intensity – Maximum
- Intensity – Average
- Intensity – Cumulative
- Onset rate
- Decline rate



Hobday et al 2016

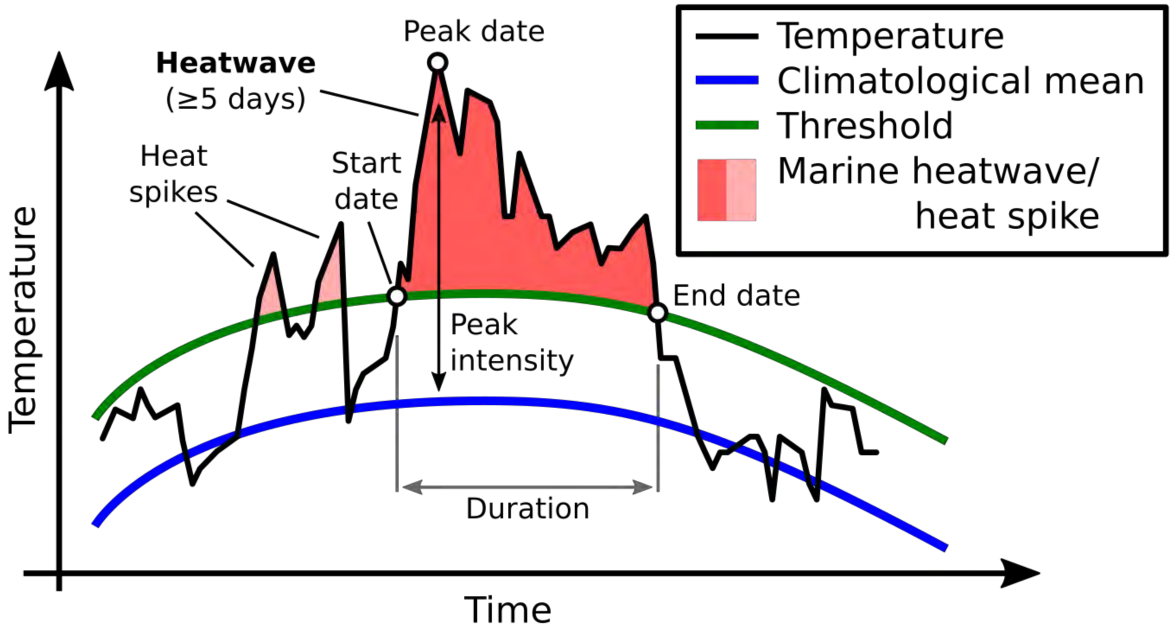
Distinguish different styles of MHW



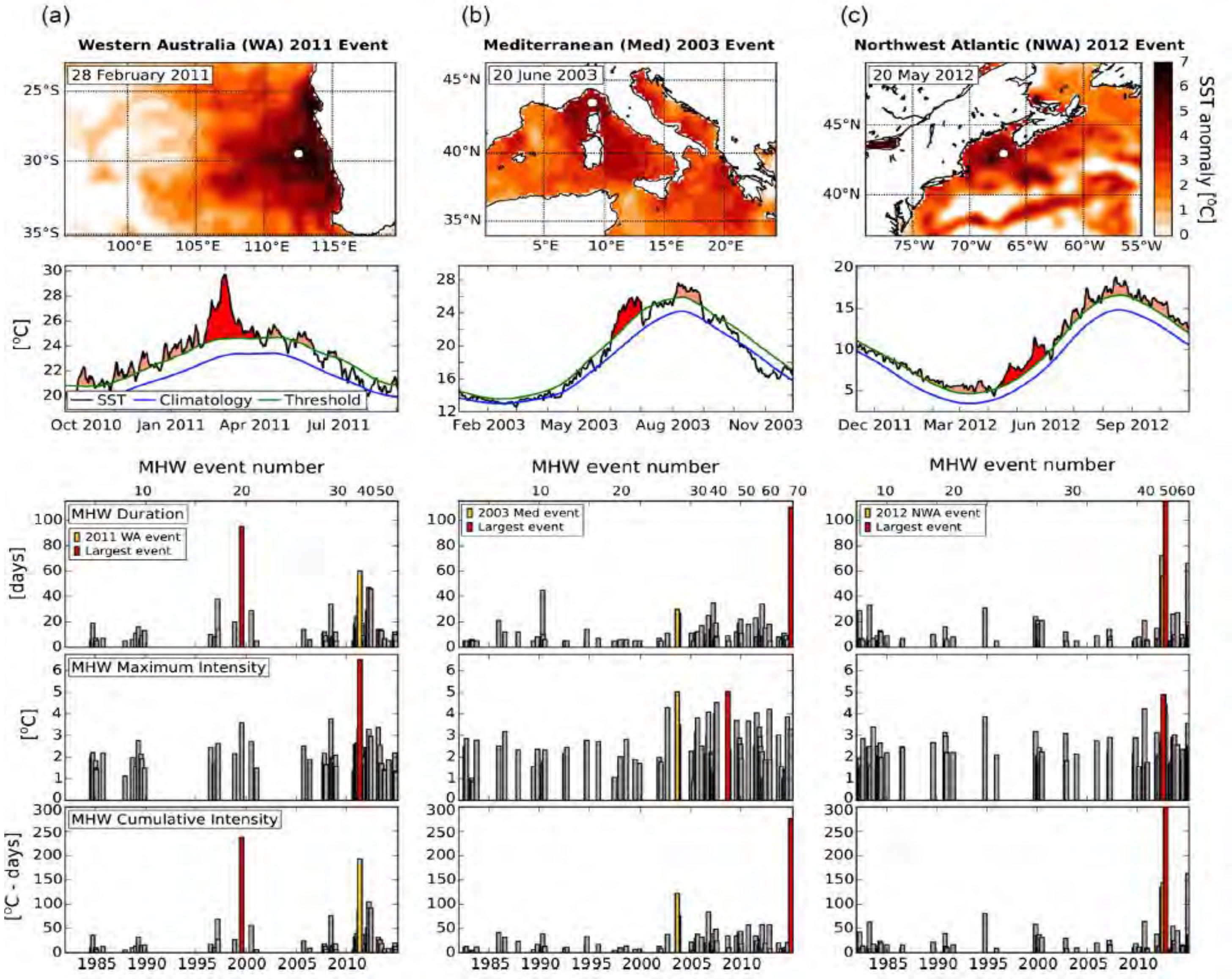
Hobday et al 2016

What does a MHW definition allow?

1. Comparison
2. Detailed description - atlas
3. Flavours
4. Drivers
5. Attribution
6. Trends – Historical
7. Projections
8. Communication
9. Predictions – short term

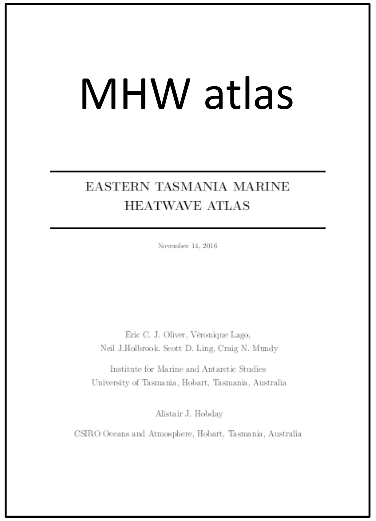


1. Comparison of MHWs across regions



Hobday et al. 2016

2. Detailed descriptions



MHW atlas

EASTERN TASMANIA MARINE
HEATWAVE ATLAS

November 14, 2016

Eric C. J. Oliver, Véronique Lago,
Neil J.Holbrook, Scott D. Ling, Craig N. Mundy

Institute for Marine and Antarctic Studies
University of Tasmania, Hobart, Tasmania, Australia

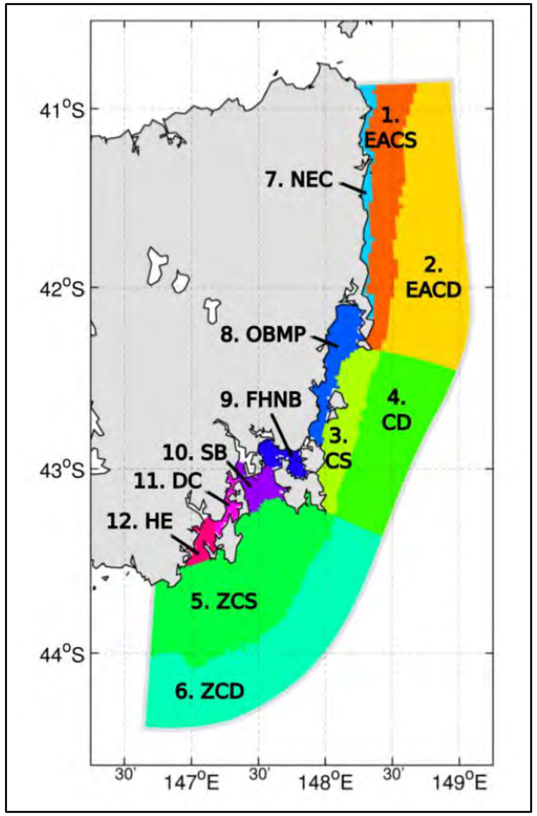
Alistair J. Hobday

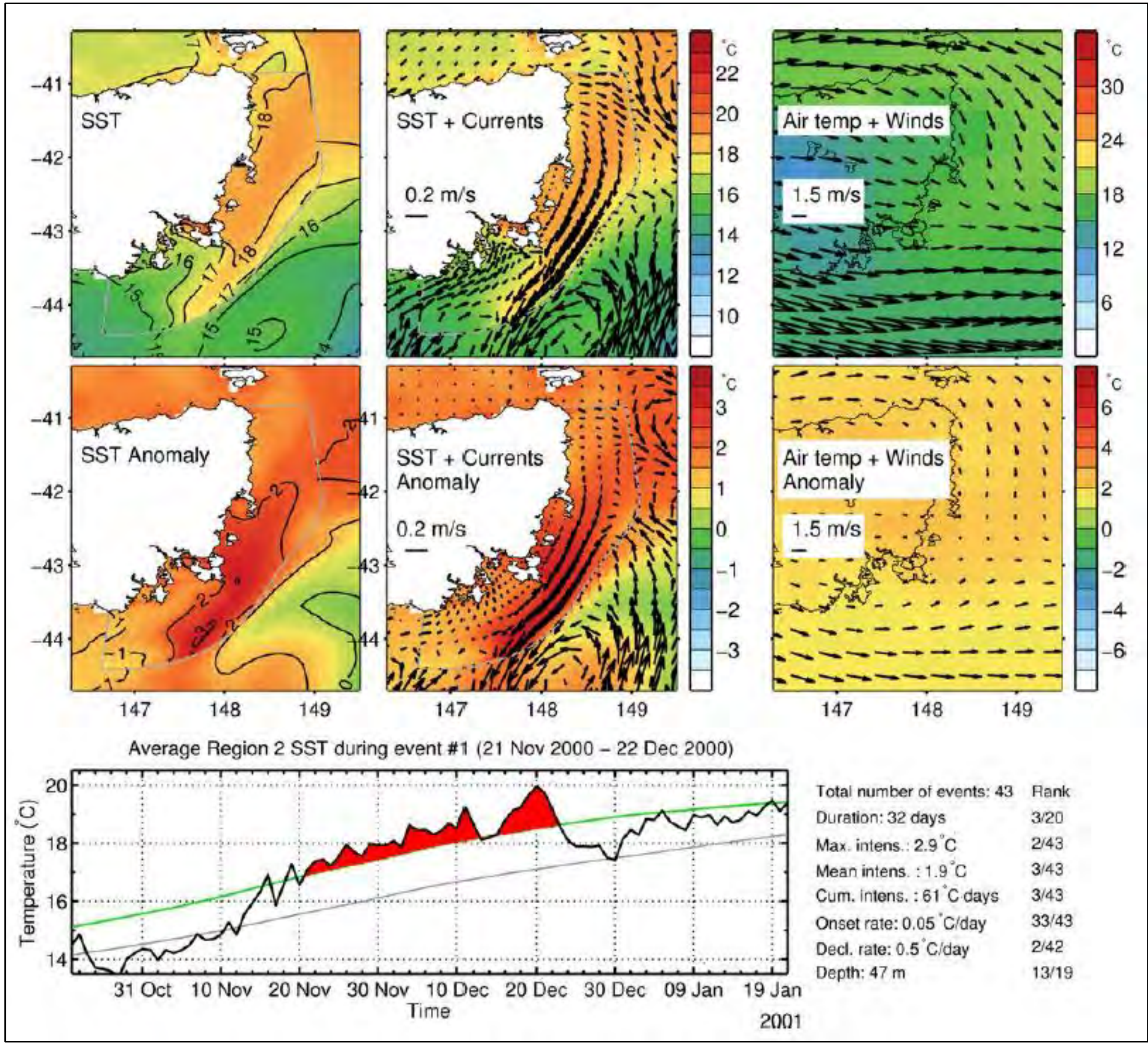
CSIRO Oceans and Atmosphere, Hobart, Tasmania, Australia

ETAS coastal ocean model

1993-2015

~400 events





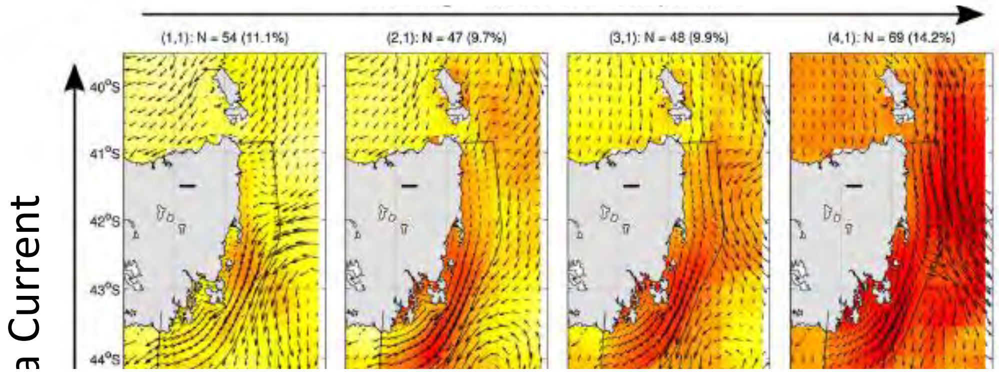
Total number of events: 43	Rank
Duration: 32 days	3/20
Max. intens.: 2.9 °C	2/43
Mean intens. : 1.9 °C	3/43
Cum. intens. : 61 °C days	3/43
Onset rate: 0.05 °C/day	33/43
Decl. rate: 0.5 °C/day	2/42
Depth: 47 m	13/19

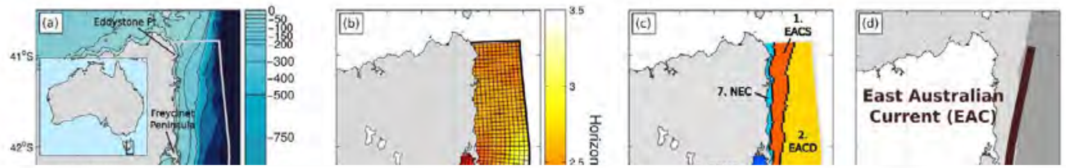
Oliver et al 2017 – IMAS publications

3. MHW flavours….

Atmosphere

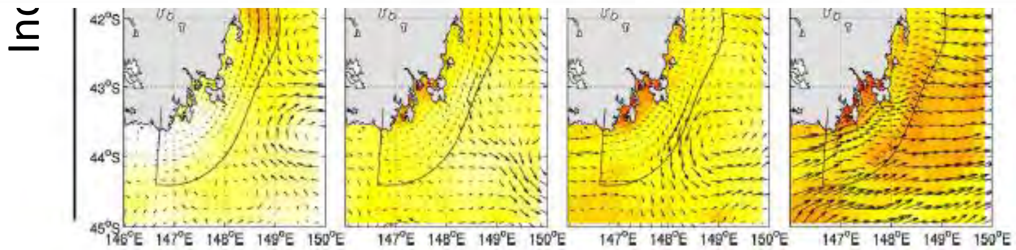
Increasing influence of air temperature





Node	Region	Season	MHW properties	Conditions
(1,1)	All	Autumn	Frequent, long, deep	Broad southward flow on and off the shelf, E-erly winds
(2,1)	All exc. SE coastal and NE offshore	Spring	Intense, deep	EAC flow over shelf, AC eddy off the SE, E-erly winds
(3,1)	All	Spring, Summer	Intense, fast onset and decline	EAC flow over shelf, AC eddy off the SE, NE-erly winds
(4,1)	All	Spring, Summer	Frequent, intense, short, fast onset	Strong EAC, large spatial scale, warm air, N-erly winds
(1,2)	ZCD, CD	Summer	Infrequent, long	EAC flow over shelf
(2,2)	ZCS, HE	Summer	Intense, fast decline	Broad southward flow over shelf, eddy off the SE
(3,2)	OBMP	All	Infrequent, intense, deep	Eddy train offshore
(4,2)	OBMP, northern, eastern offshore	Spring, Summer	Intense, deep	Eddy train offshore, warm air, N-erly winds
(1,3)	Northeast	Autumn, Winter	Frequent, weak, deep, slow onset and decline	Weak flow over shelf, eddy train offshore, weak atmosphere
(2,3)	EACD, OBMP, FHNB, DC	Winter	Weak, long, deep	Weak flow over shelf
(3,3)	Southeast coastal and OBMP	Winter	Shallow	Eddy off the SE, moderate strength Zeehan Current
(4,3)	Southeast coastal and ZCD	Autumn, Winter	Frequent, short, shallow	Strong Zeehan Current, warm air, NW-erly winds

8. OBMP	1.57	12.58	2.23	19.4	22.3	52.5
9. FHNB	1.83	10.65	2.62	21.2	21.1	28.8
10. SB	1.74	6.87	2.23	12.1	15.1	21.6
11. DC	2.00	6.78	2.67	14.8	21.9	22.4
12. HE	2.00	7.05	2.50	13.3	19.0	27.6

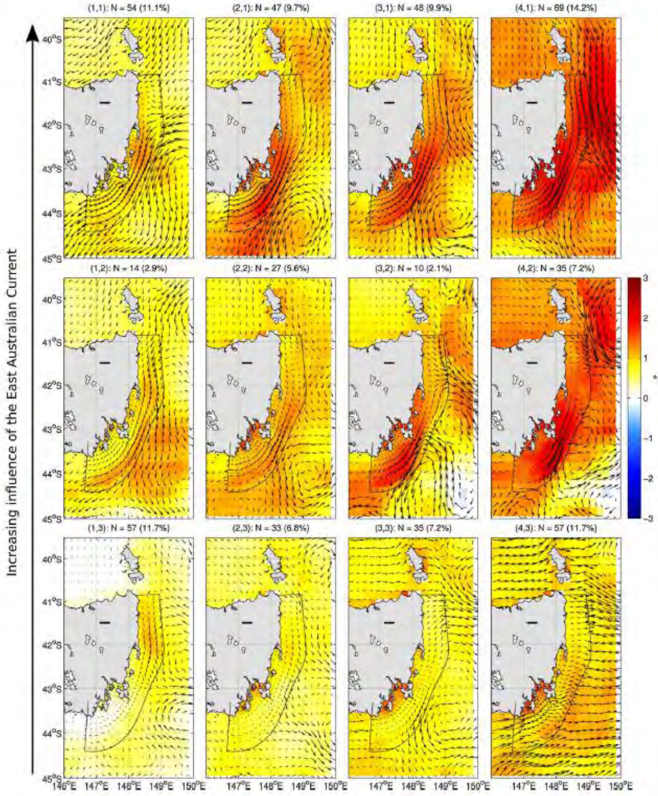


Oliver et al. 2018 PiO

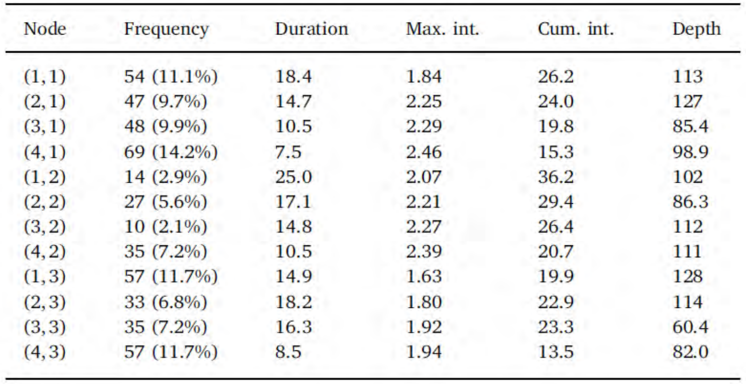
3. MHW flavours….

Atmosphere

Ocean

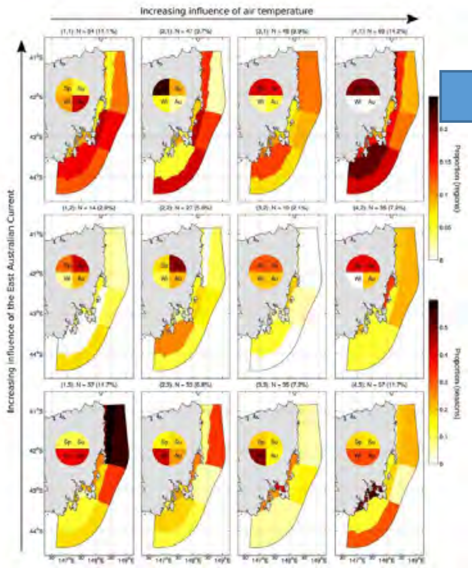


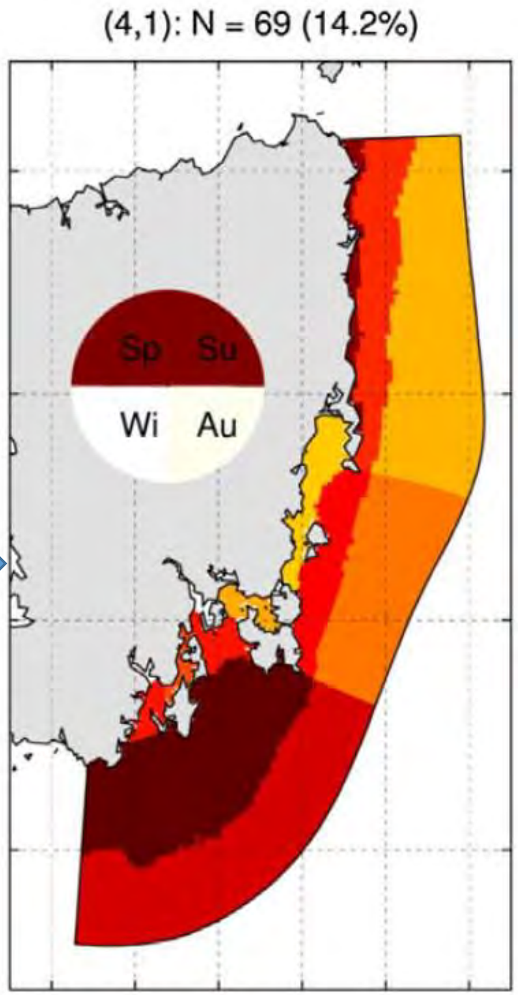
Summary statistics



Node	Frequency	Duration	Max. int.	Cum. int.	Depth
(1, 1)	54 (11.1%)	18.4	1.84	26.2	113
(2, 1)	47 (9.7%)	14.7	2.25	24.0	127
(3, 1)	48 (9.9%)	10.5	2.29	19.8	85.4
(4, 1)	69 (14.2%)	7.5	2.46	15.3	98.9
(1, 2)	14 (2.9%)	25.0	2.07	36.2	102
(2, 2)	27 (5.6%)	17.1	2.21	29.4	86.3
(3, 2)	10 (2.1%)	14.8	2.27	26.4	112
(4, 2)	35 (7.2%)	10.5	2.39	20.7	111
(1, 3)	57 (11.7%)	14.9	1.63	19.9	128
(2, 3)	33 (6.8%)	18.2	1.80	22.9	114
(3, 3)	35 (7.2%)	16.3	1.92	23.3	60.4
(4, 3)	57 (11.7%)	8.5	1.94	13.5	82.0

Summary statistics





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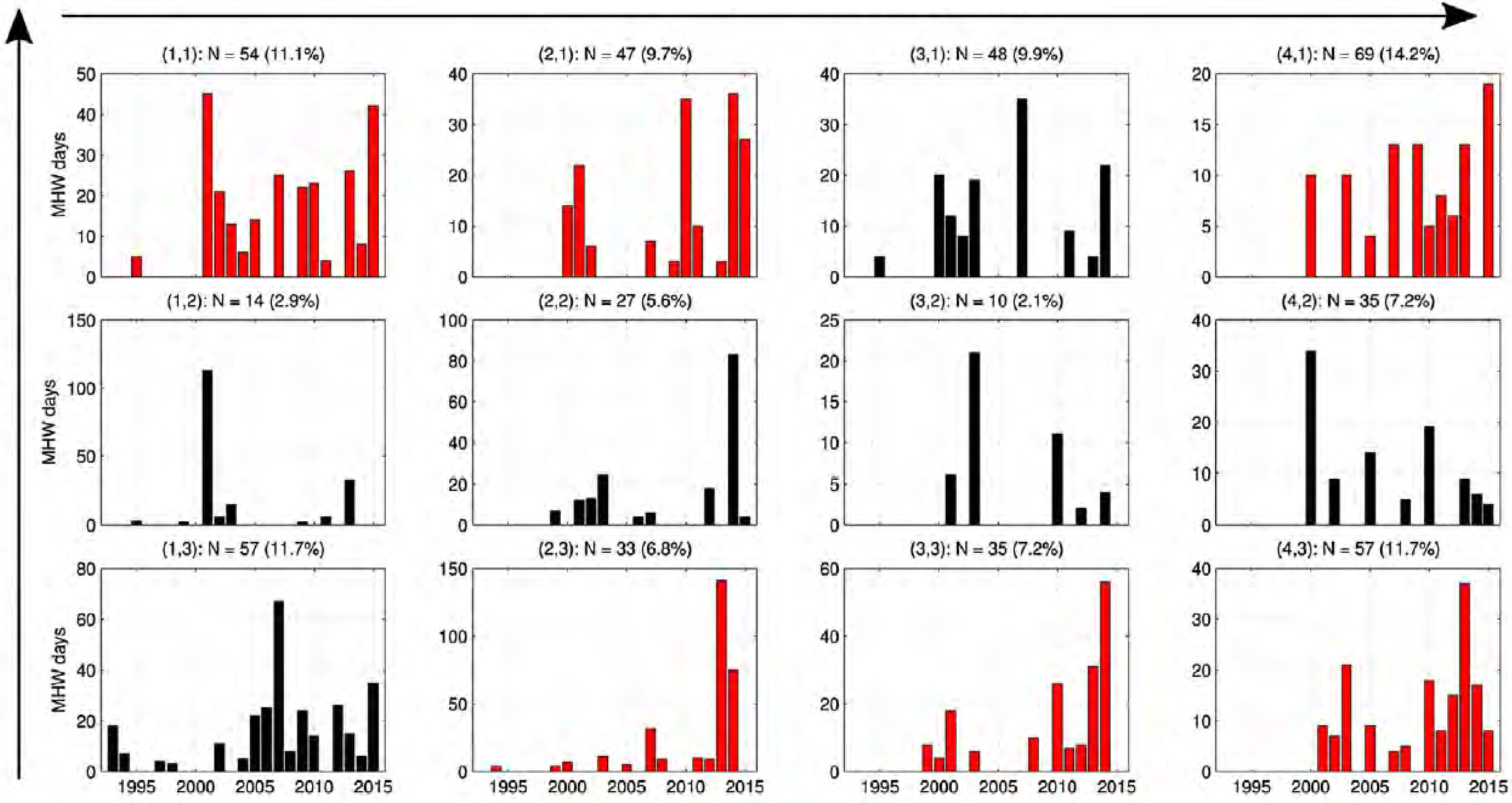
Trends in MHW flavours....(e.g. total annual days)

Atmosphere
Increasing influence of air temperature

Ocean
Increasing influence of East Australia Current

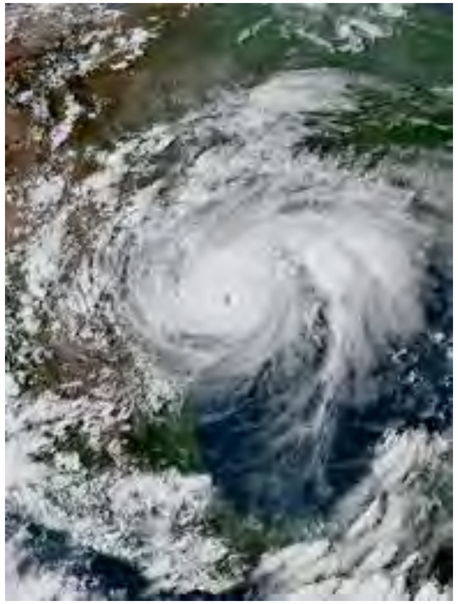


Red = Sig trend

Oliver et al. 2018 PiO

What’s in a name…

- Cyclones and hurricanes
  - Cyclone Tracey
  - Hurricane Katrina
  - Hurricane Harvey



Bushfires (Australia)

Black Monday
Black Wednesday (not the 1992 collapse in the pound)
Black Friday
Black Saturday
Black Sunday

Naming conventions*….

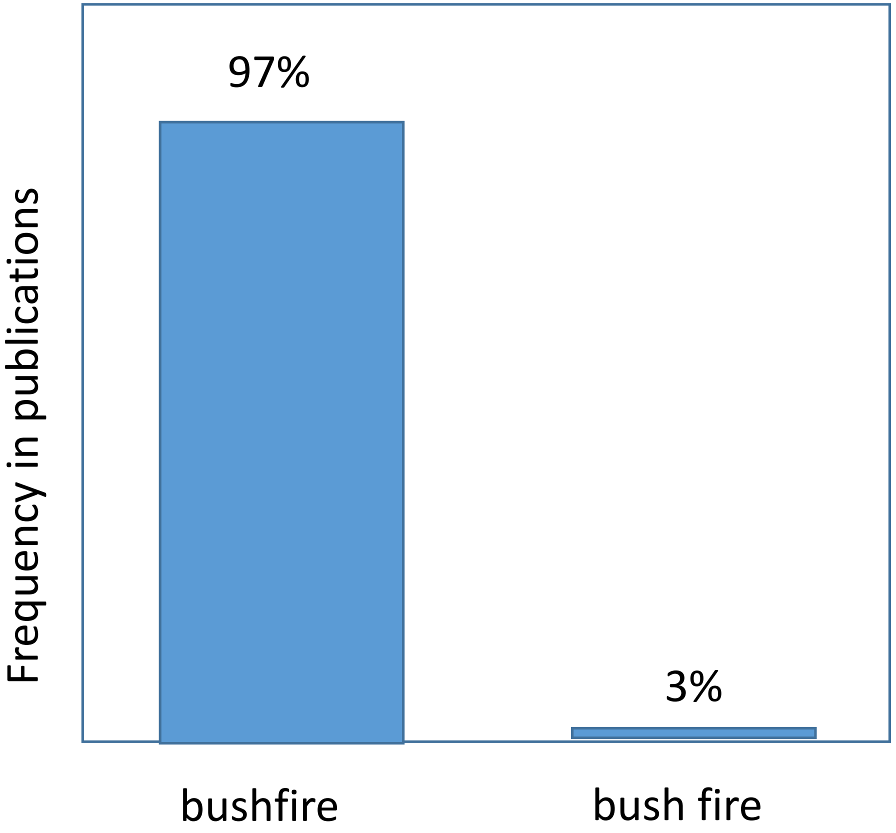
This conference – Extremes session: 26 oral presentations

- Marine heatwave: 5 abstracts
- Marine heat wave: 2 abstracts
- Marine heat-wave: 1 abstract

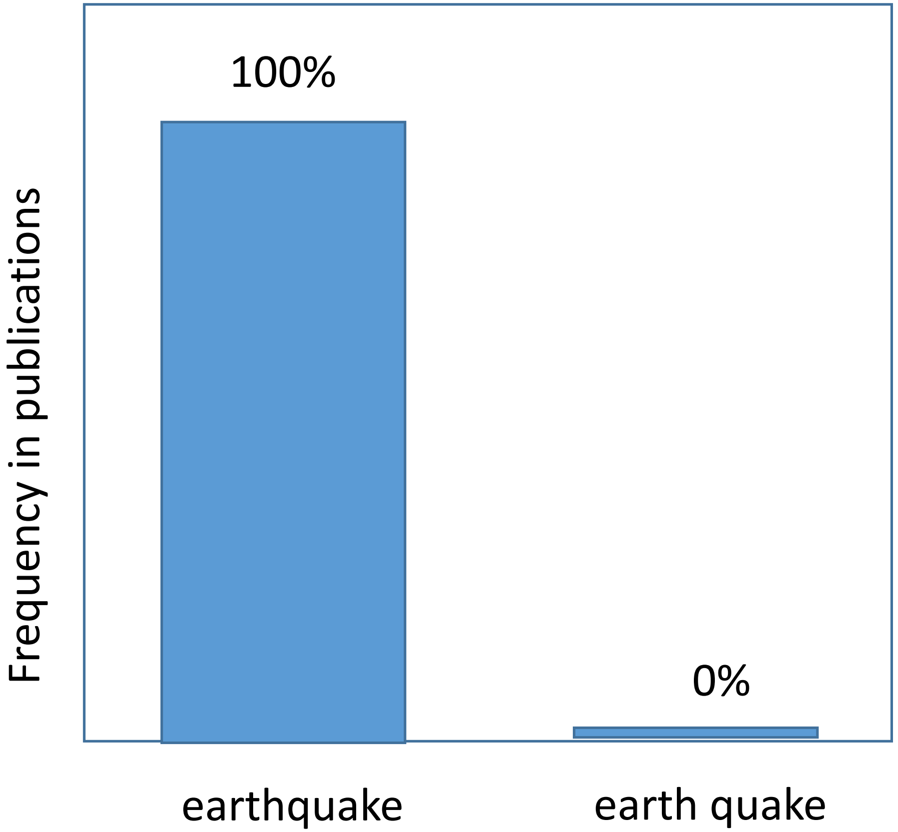
We should get consistent…of course it's marine "heatwave"

*Don't think I won't follow up on that late night discussion on semantics!

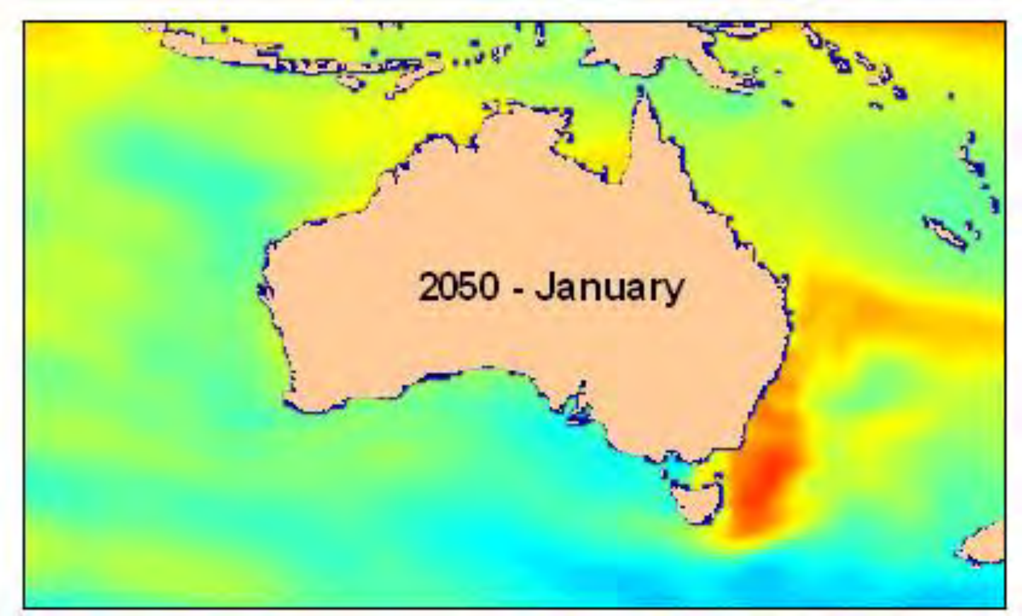
“Bushfire” or “bush fire”?

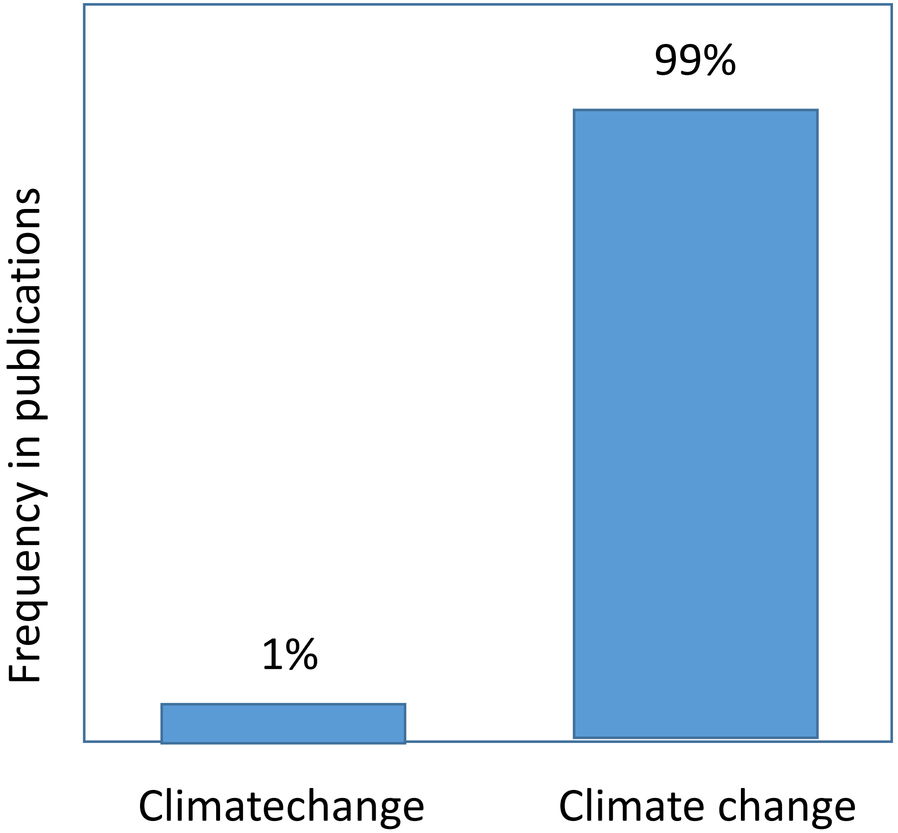


“Earthquake” or “earth quake”?

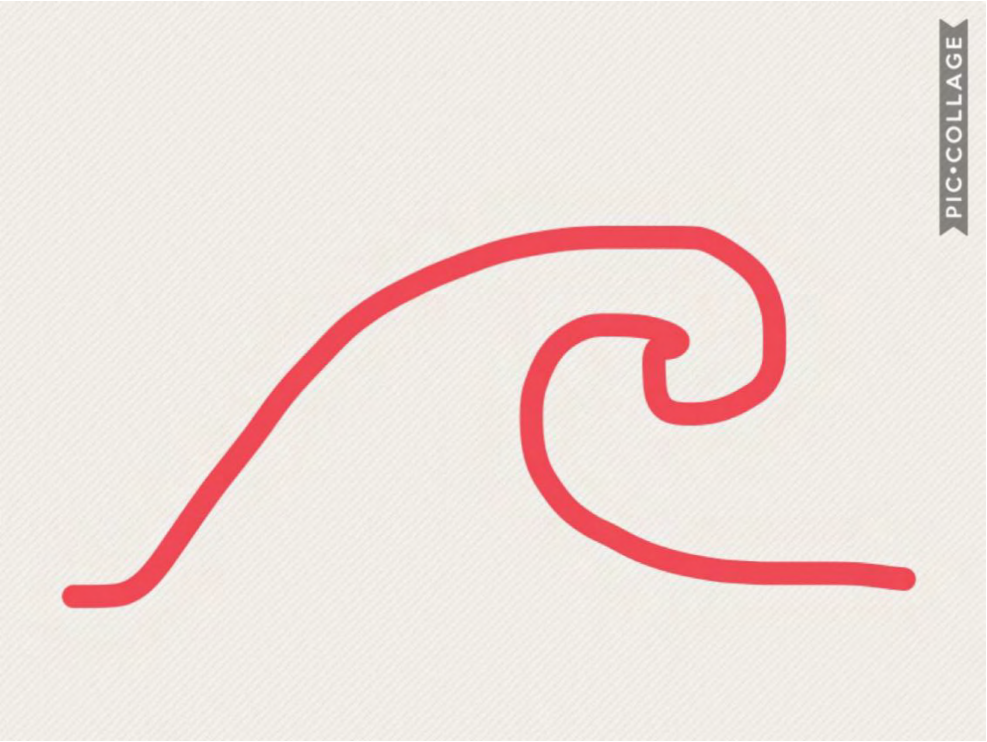


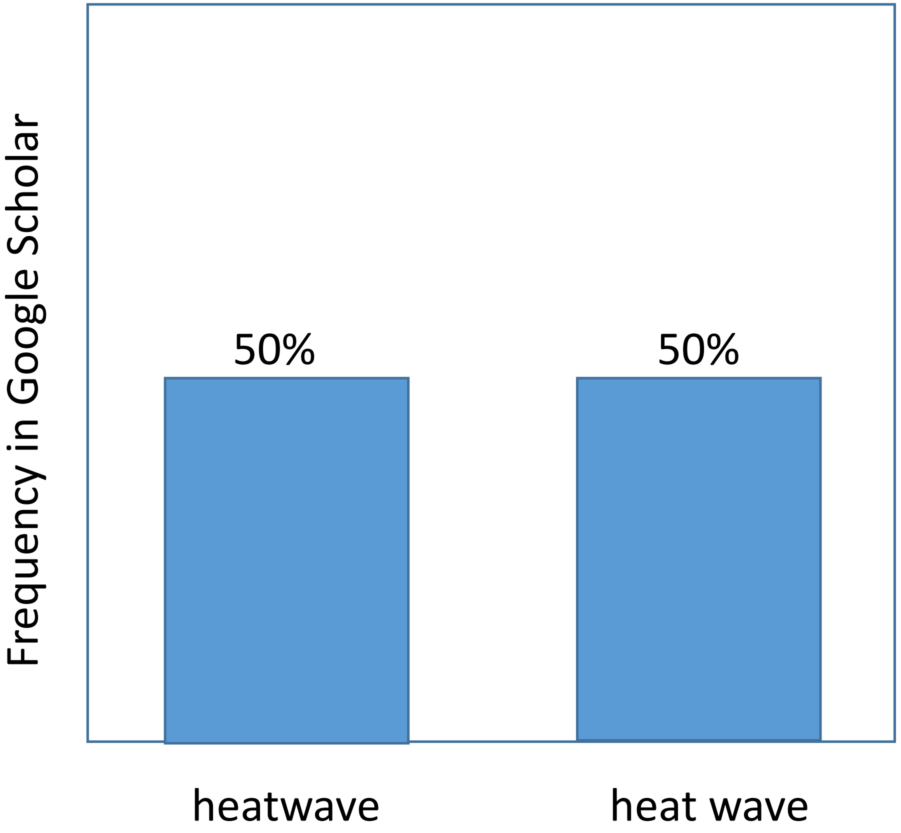
“climate change” or “climatechange”?



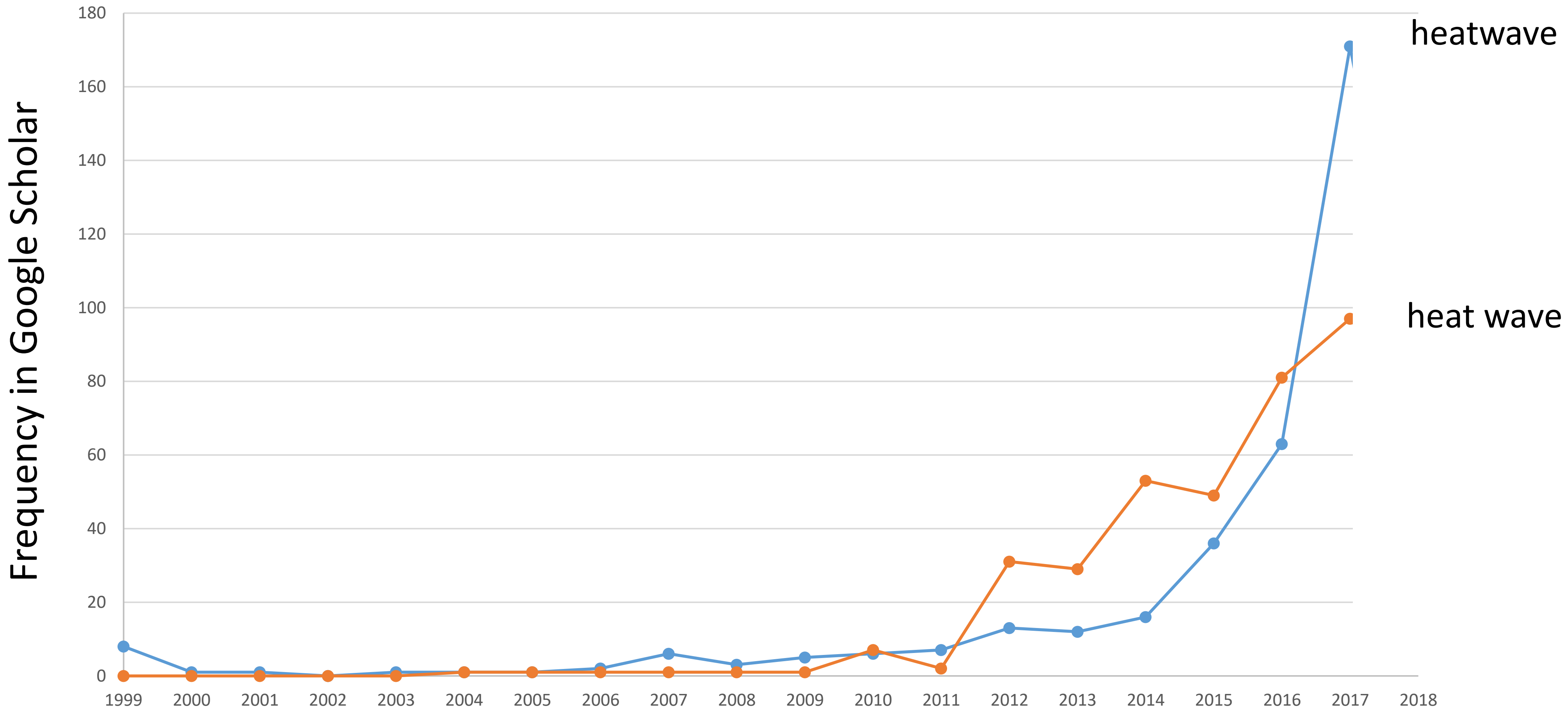


marine “heatwave” or “heat wave”?

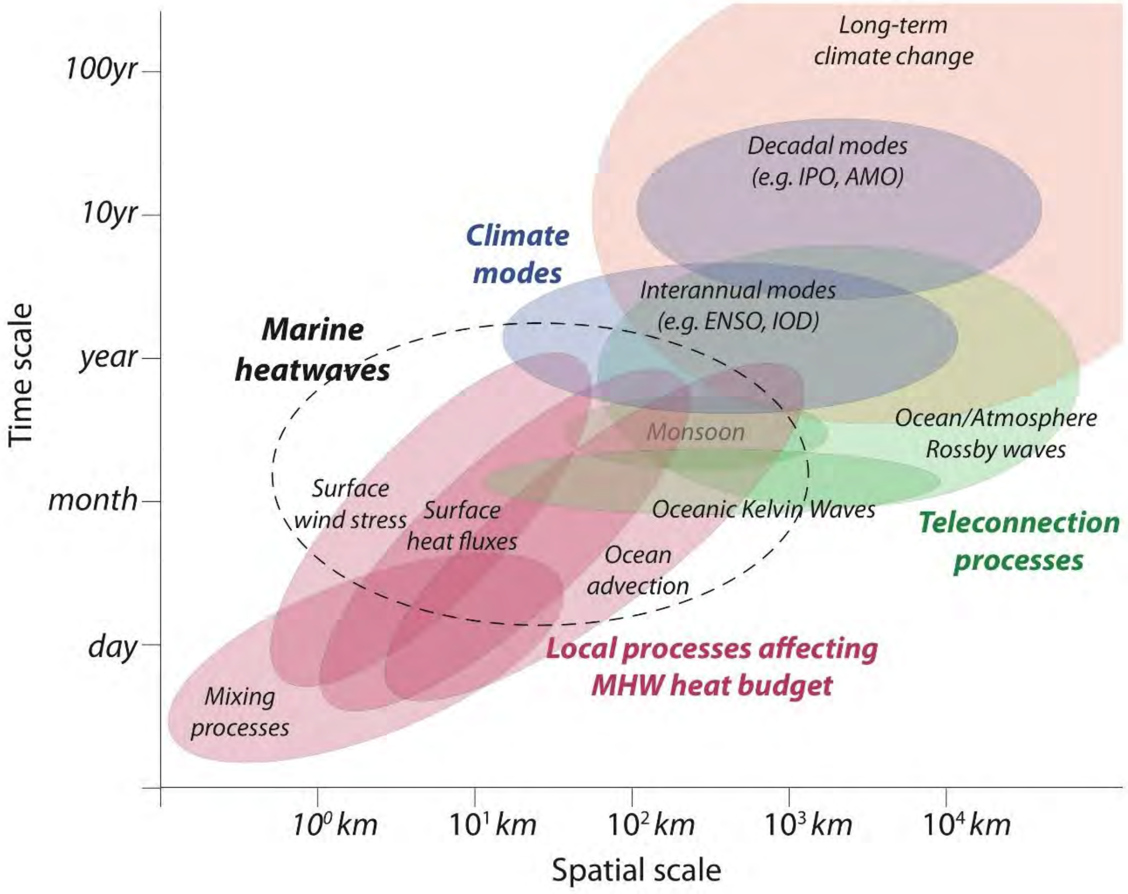


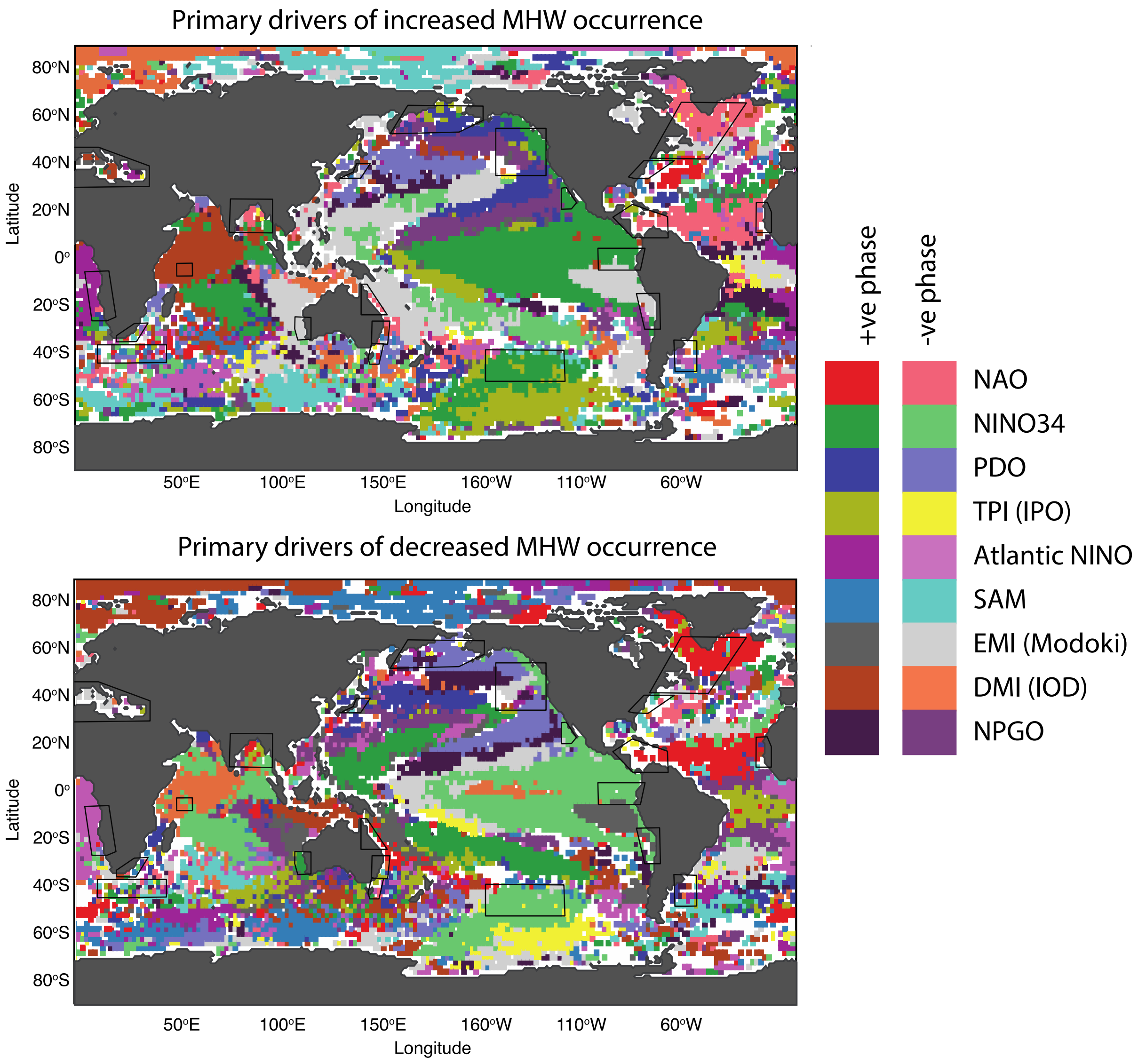


Marine “heatwave” is winning over time….



4. Drivers of MHWs





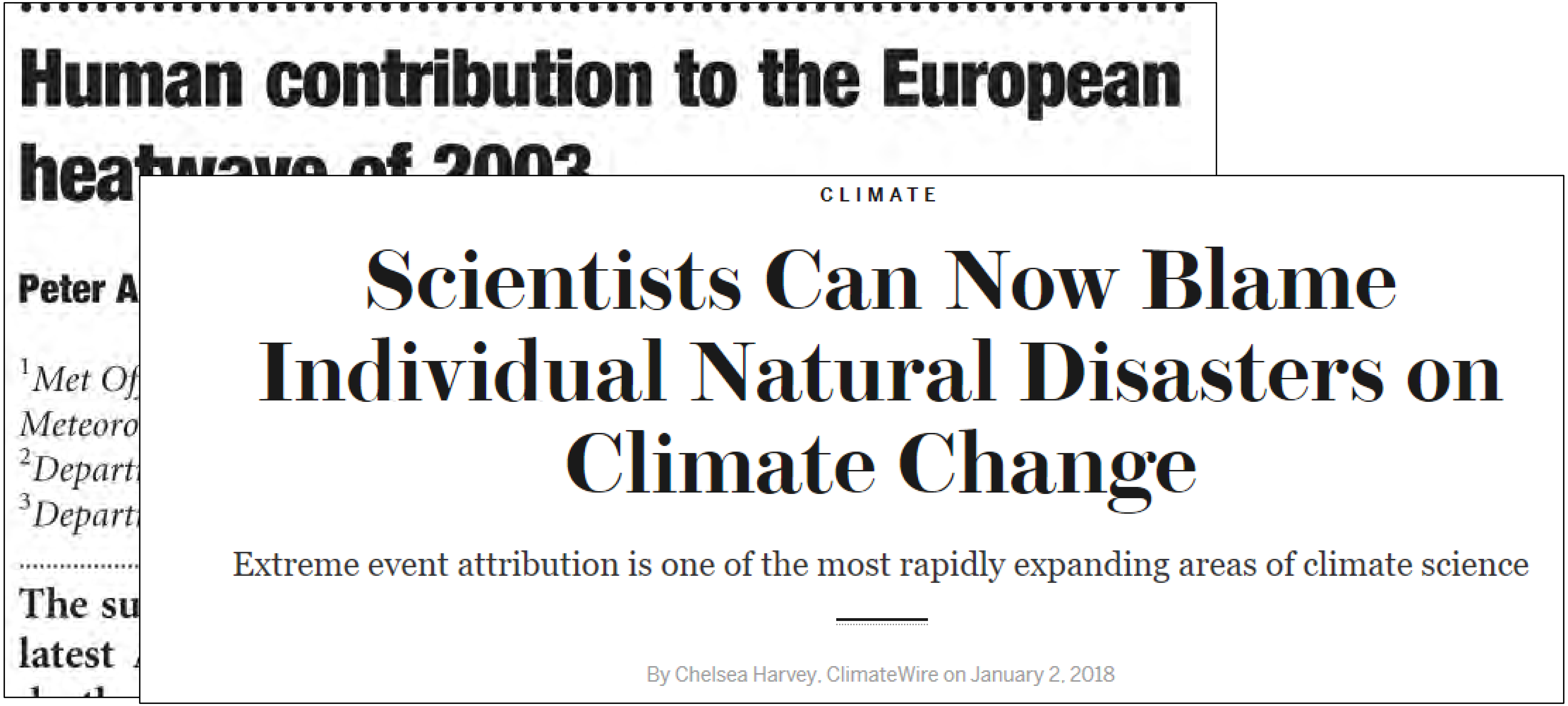
Holbrook et al. in review

Extremes not linked to climate change

Pre ~2004 or so….(even past 2015)

- Journalist: “…..was this flood due to climate change?”
- Scientist: “…no individual event is caused by climate change, however, this *type* of event is likely to be more frequent under global warming….”
- Journalist: “…thank you, very helpful”.

Attribution now possible



Human contribution to the European heatwave of 2003

Peter A

[1]Met Of
Meteoro
[2]Depart
[3]Depart

The su
latest

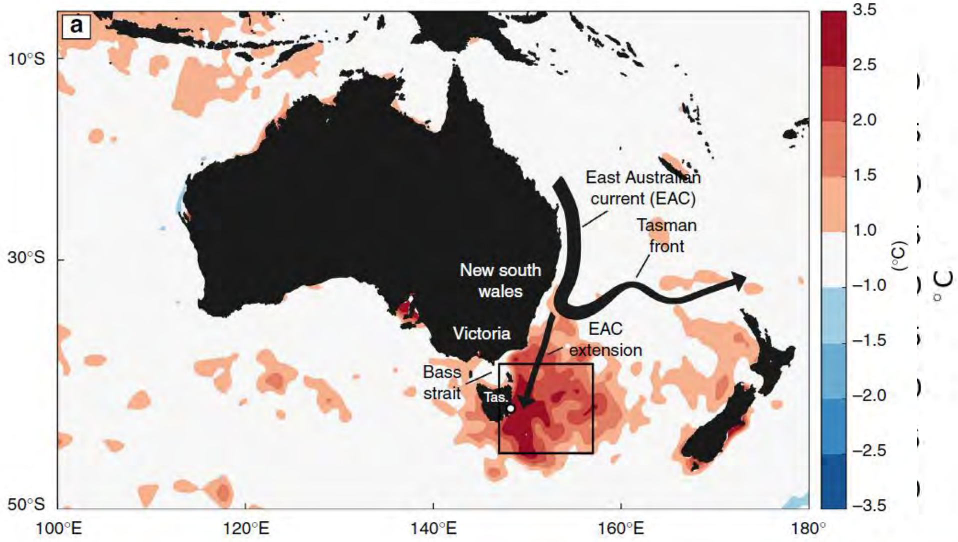
CLIMATE

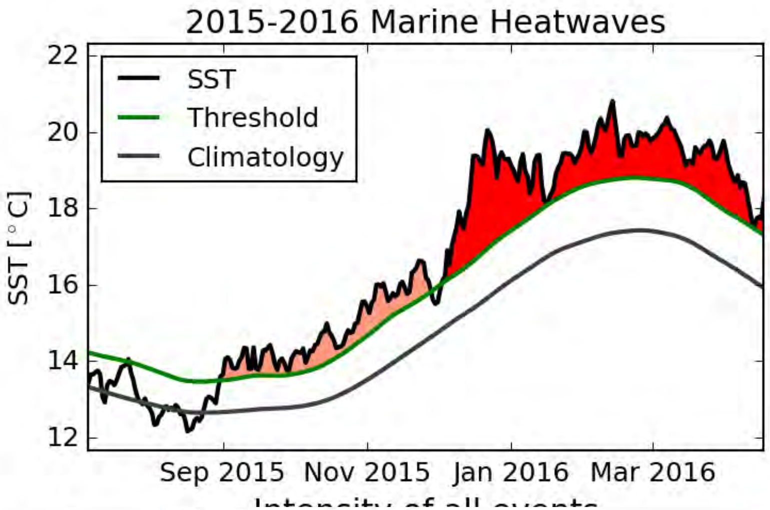
Scientists Can Now Blame Individual Natural Disasters on Climate Change

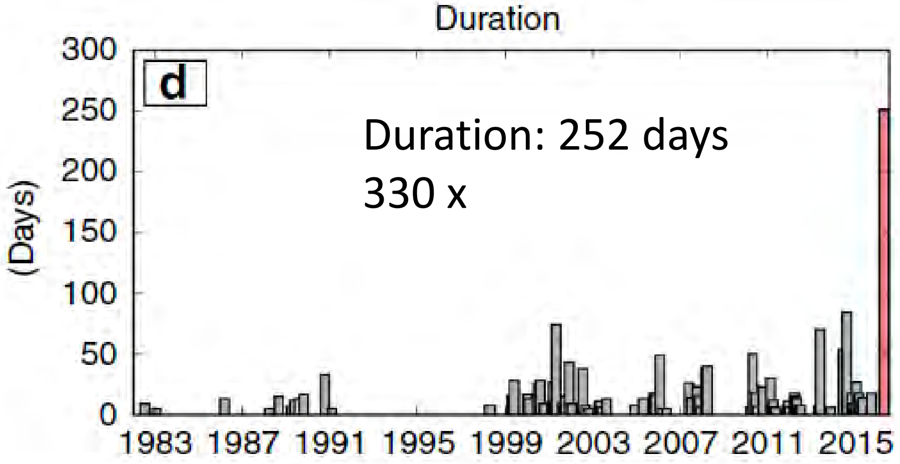
Extreme event attribution is one of the most rapidly expanding areas of climate science

By Chelsea Harvey, ClimateWire on January 2, 2018

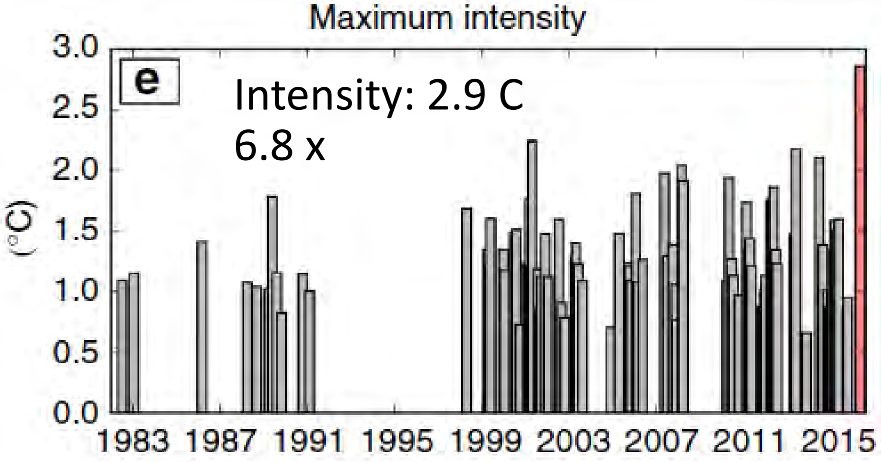
5. Attribution of marine heatwaves







Duration: 252 days
330 x

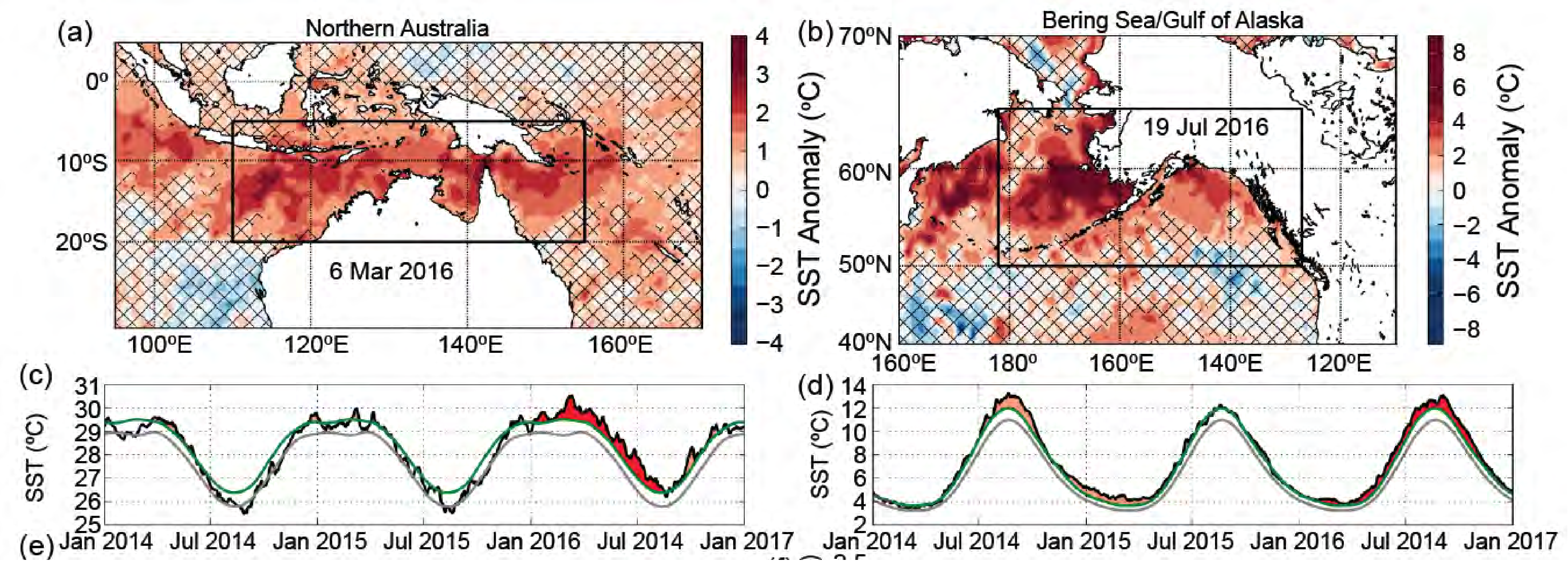


Intensity: 2.9 C
6.8 x

Oliver et al. 2017

5. Attribution of marine heatwaves

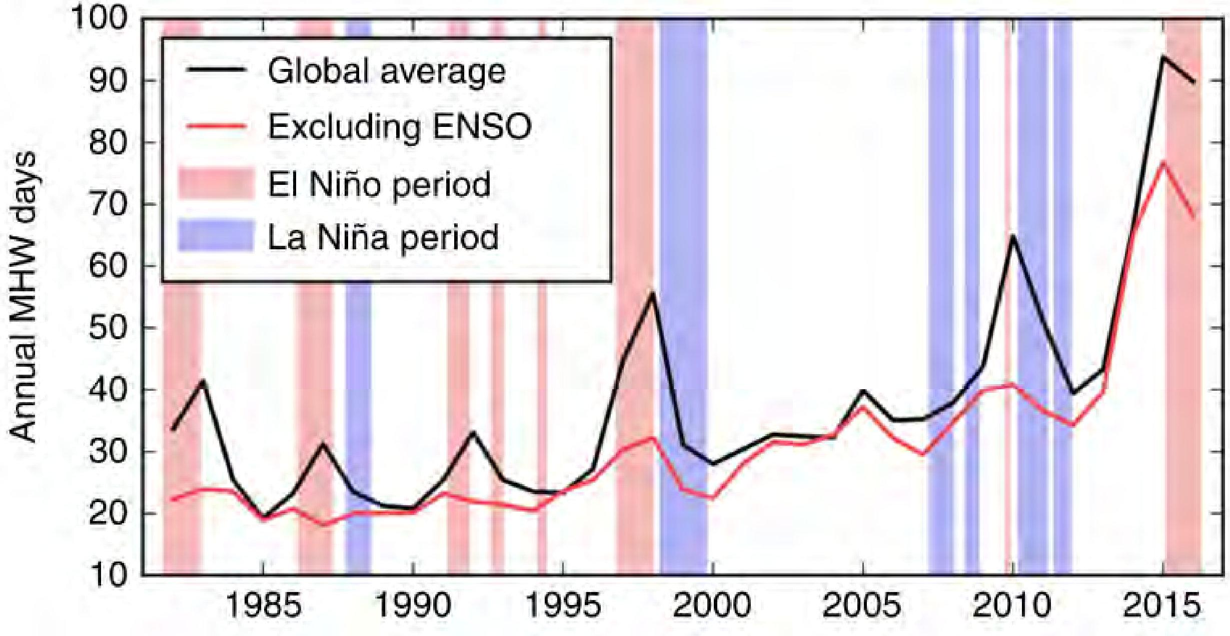
	Northern Australia 2016	Bering Sea 2016
Intensity	8.5 x	7.3x
Duration	53 x	7.4x



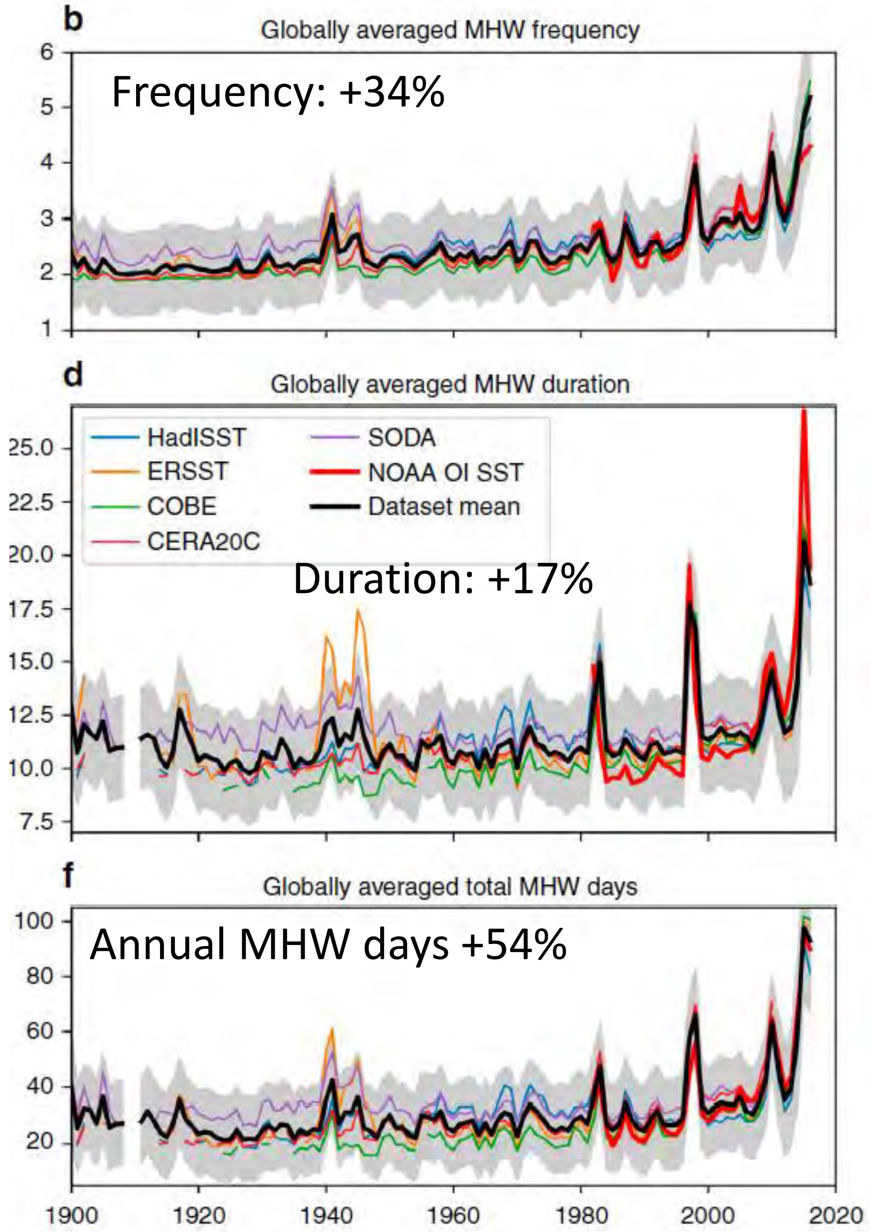
Oliver et al 2017. BAMS

6. Trends in MHWs

- Satellite record



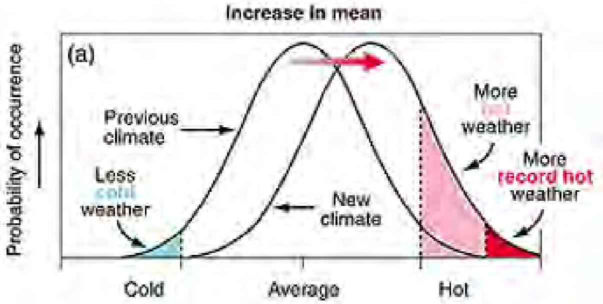
Oliver et al. 2018


Frequency: +34%

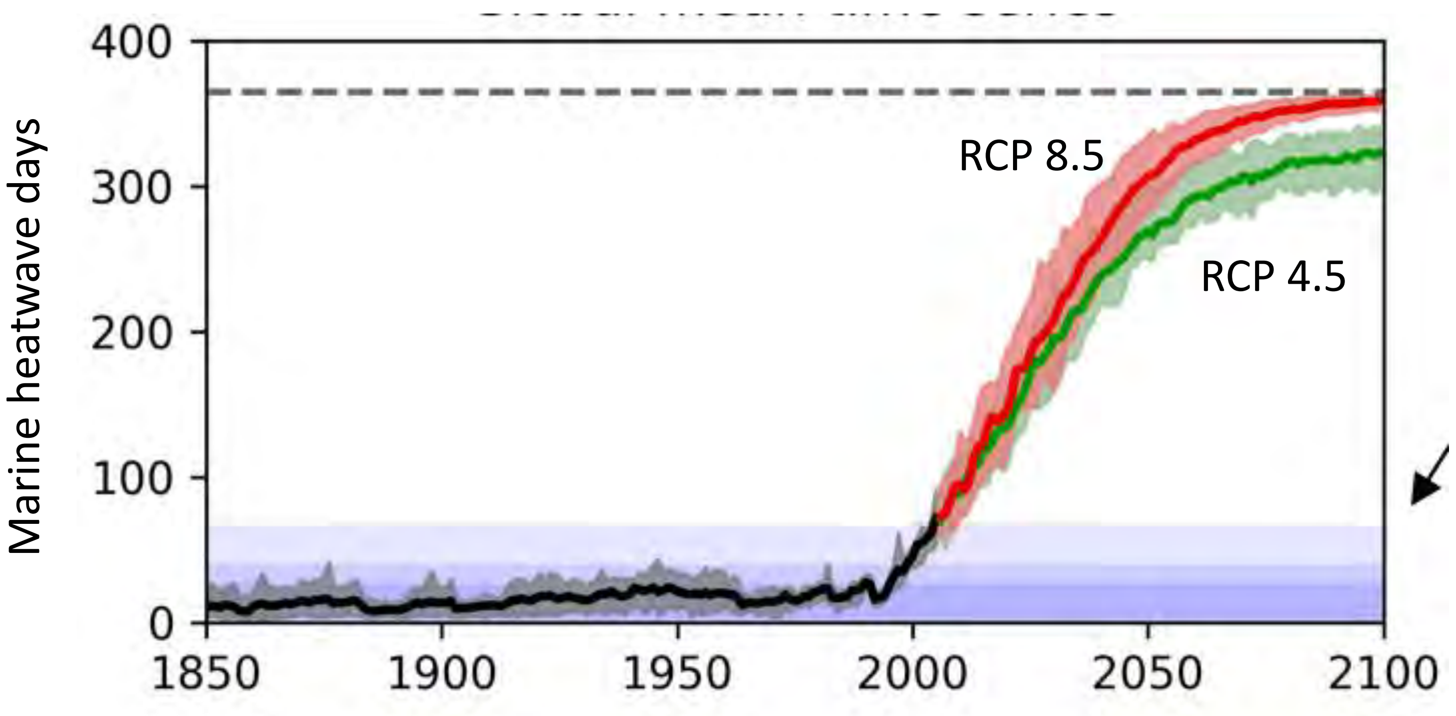
Duration: +17%

Annual MHW days +54%

But if we are getting more MHW's....



- Soon every day will be a MHW day based on a present baseline

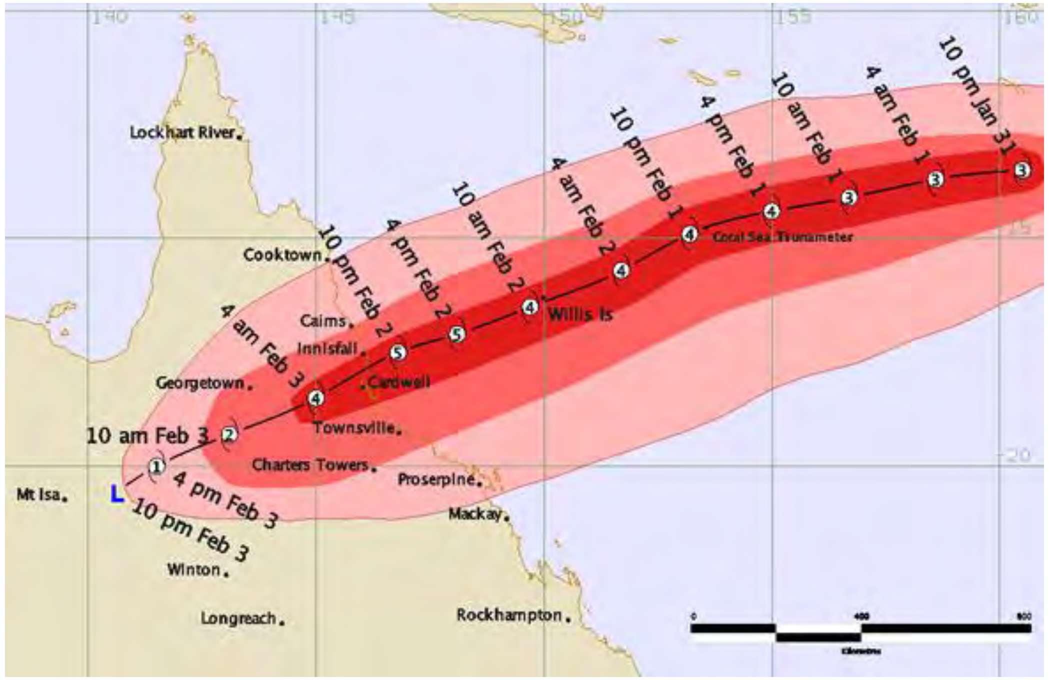


<u>Options</u>

- Change the definition
    - e.g. 99%....not a fix
- Change the baseline period
    - i.e., a new normal
- Create a category system...

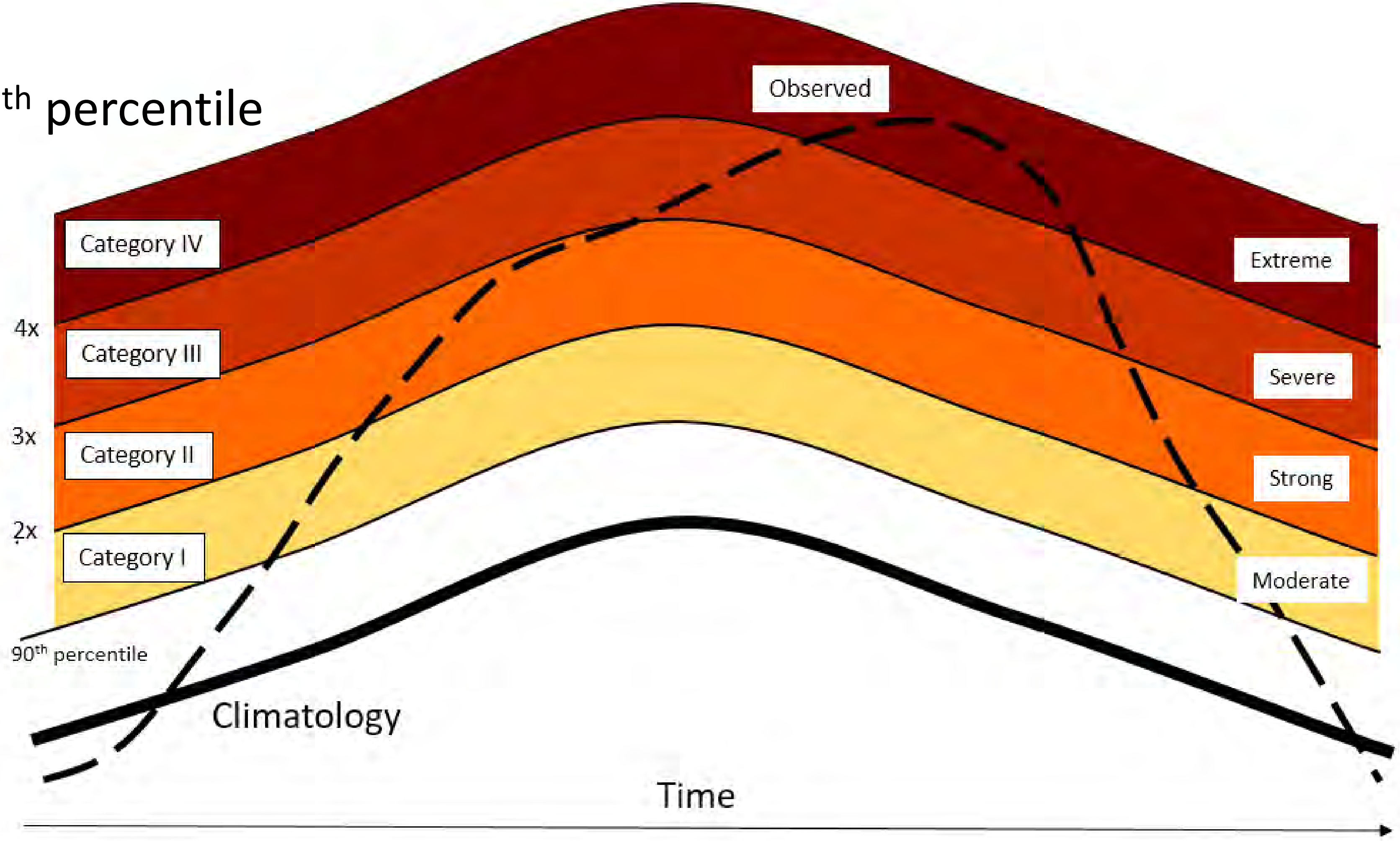
Design criteria for a categorisation scheme

1. Describe and update the category as MHW progresses.
2. Reflect local thermal impact
3. It should be possible to change the category in time as events strengthen and weaken
4. The metric should not be overly complicated in order to facilitate simplicity of communication and wide adoption.



Categories of Marine Heatwaves

- Based on intensity
  - Multiples of the 90th percentile
- Instantaneous
- Expandable

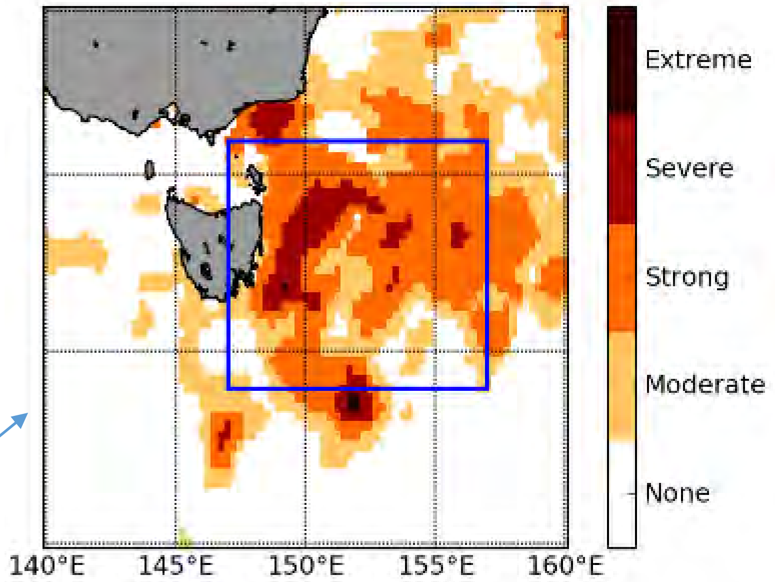


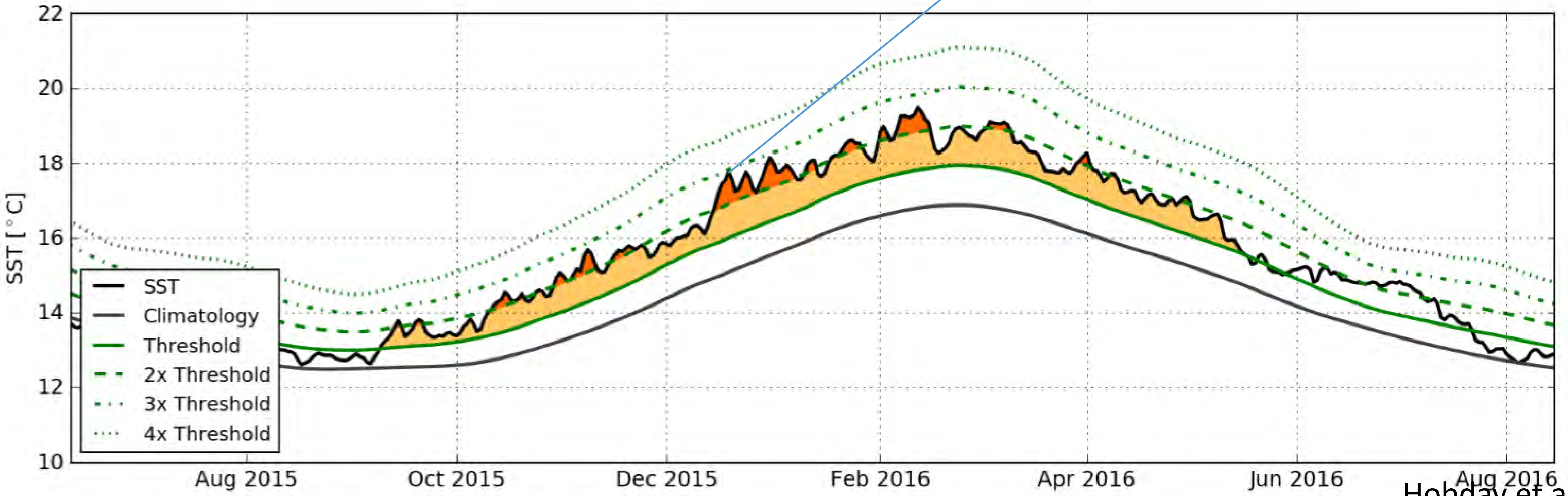
Hobday et al. 2018

Tasman Sea 2015

Category II (Strong)

Event	Peak Date	I_{max}	Duration	$p_{moderate}$	p_{strong}	p_{severe}	$p_{extreme}$
Tasman Sea 2015	Dec 19, 2015	2.70	252	59 %	41 %	–	–



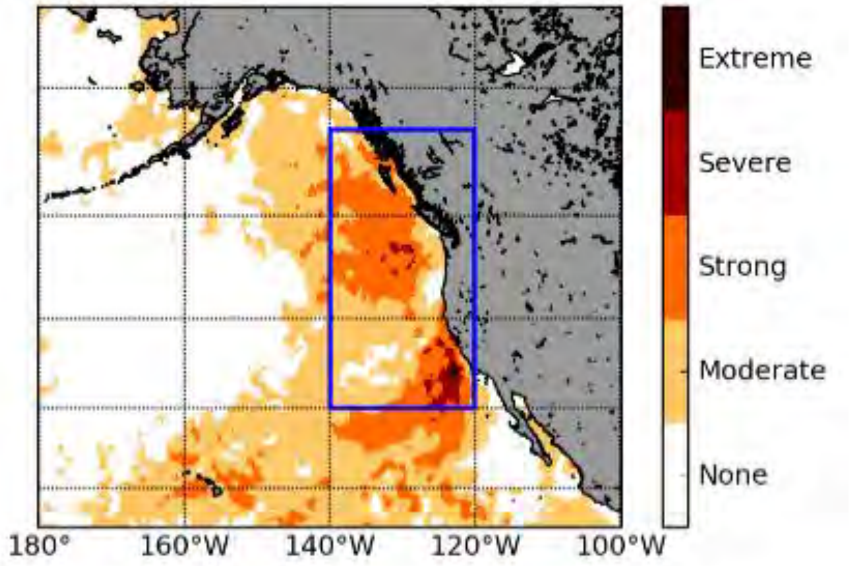


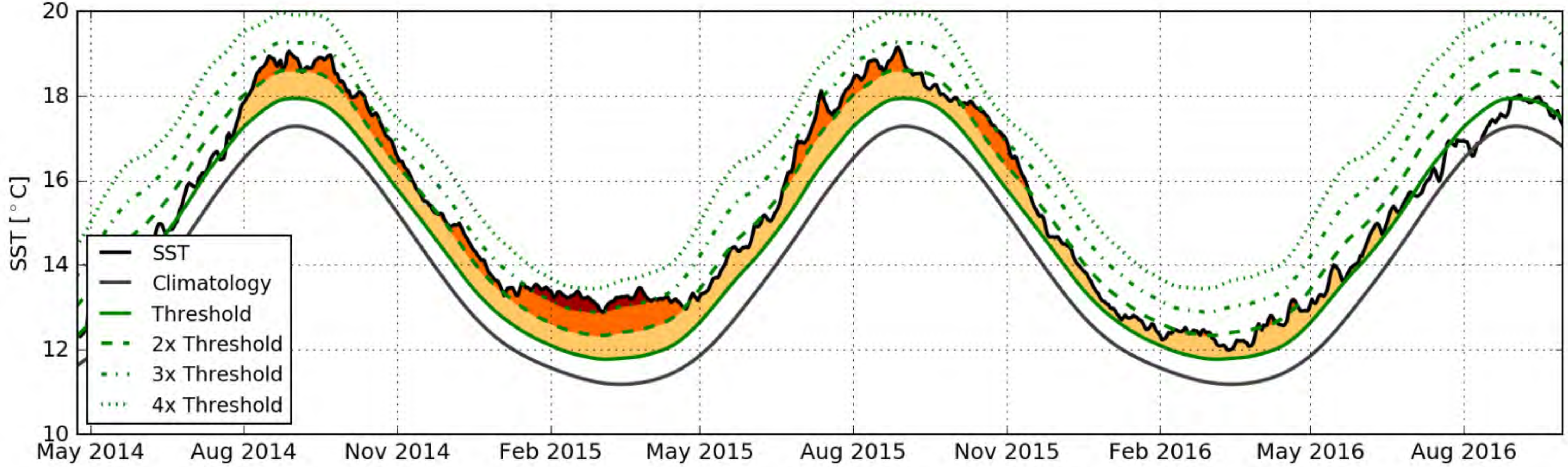
Hobday et al. 2018

NE Pacific 2015 (BLOB)

Category III (Severe)

Event	Peak Date	I_{max}	Duration	$p_{moderate}$	p_{strong}	p_{severe}	$p_{extreme}$
Northeast Pacific Blob 2015	Jul 13, 2015	2.56	711	44 %	43 %	13 %	–



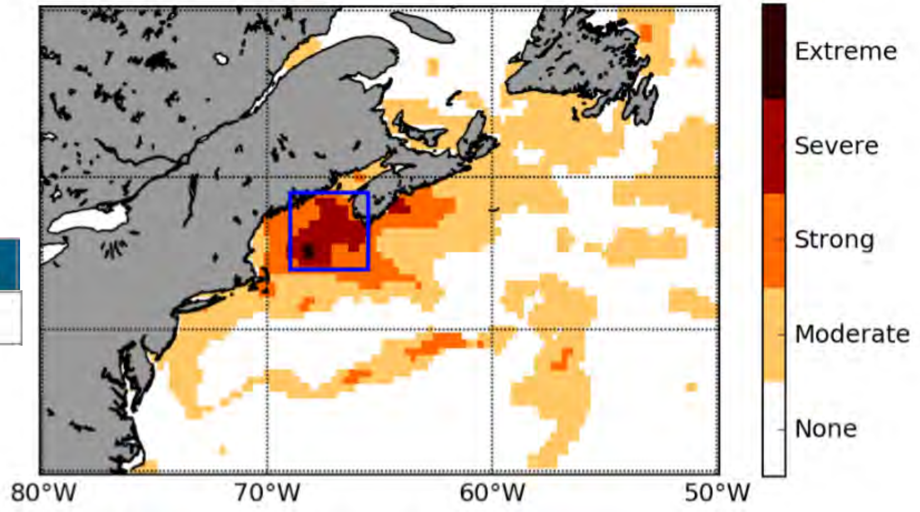


Hobday et al. 2018

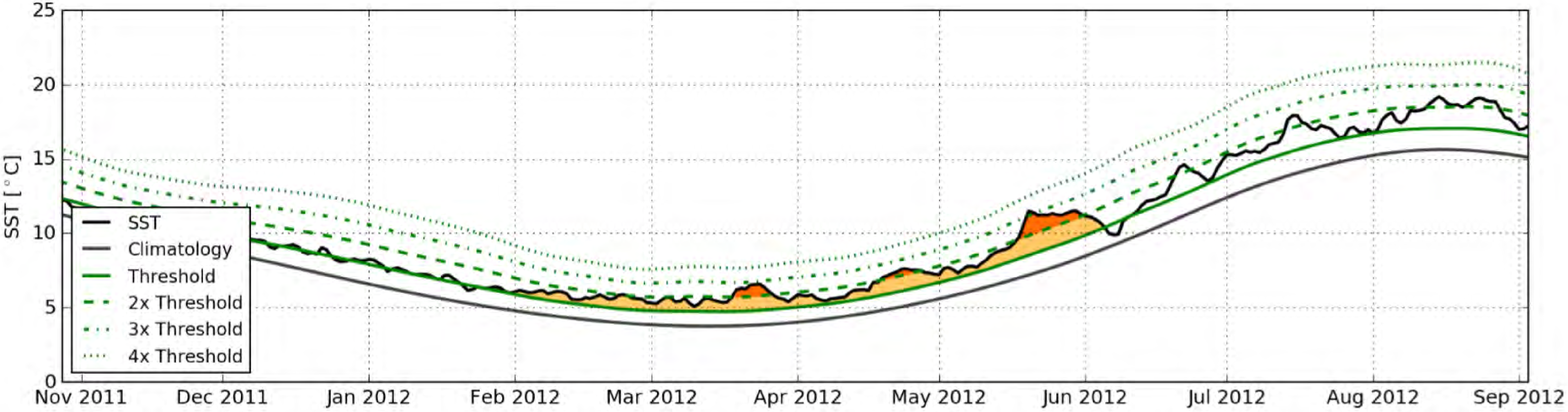
NW Atlantic 2012

Category III (Severe)

Event	Peak Date	I_{max}	Duration	$p_{moderate}$	p_{strong}	p_{severe}	$p_{extreme}$
Northwest Atlantic 2012	May 20, 2012	4.30	132	76 %	23 %	2 %	–



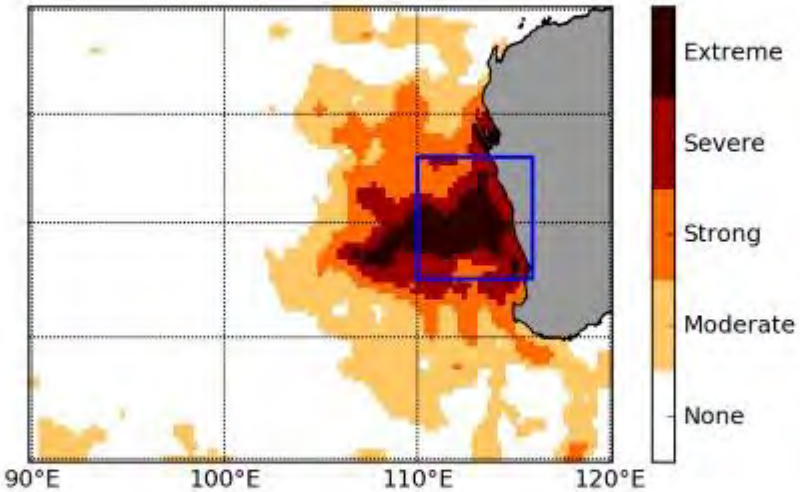
- Communication and engagement

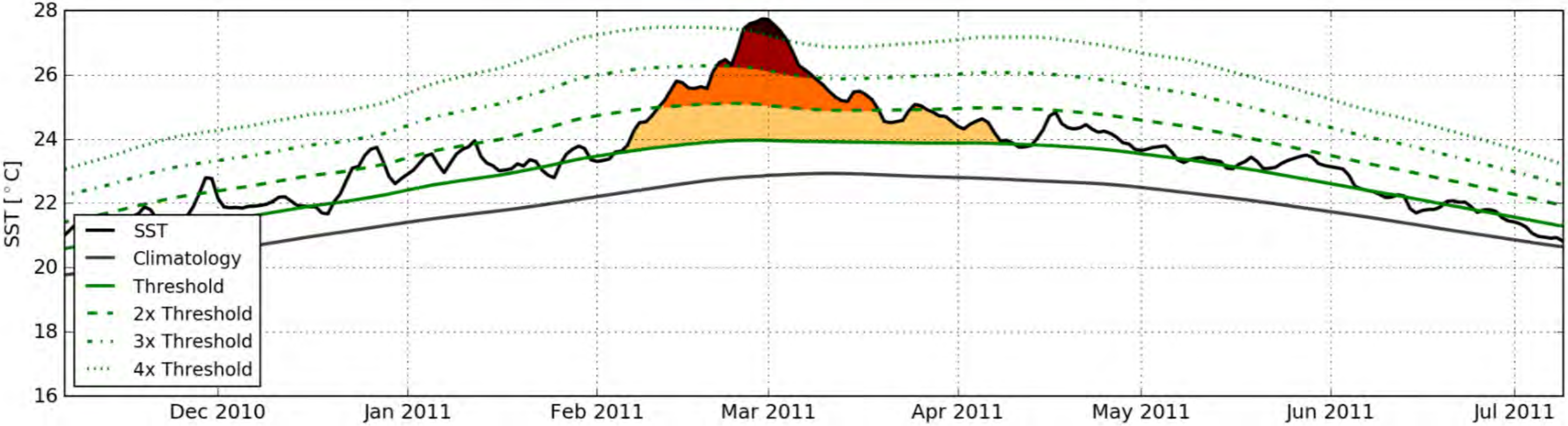


Hobday et al. 2018

Western Australia 2011

	Event	Peak Date	I_{max}	Duration	$p_{moderate}$	p_{strong}	p_{severe}	$p_{extreme}$
Category IV (Extreme)	Western Australia 2011	May 20, 2011	4.89	66	42 %	33 %	12 %	12 %

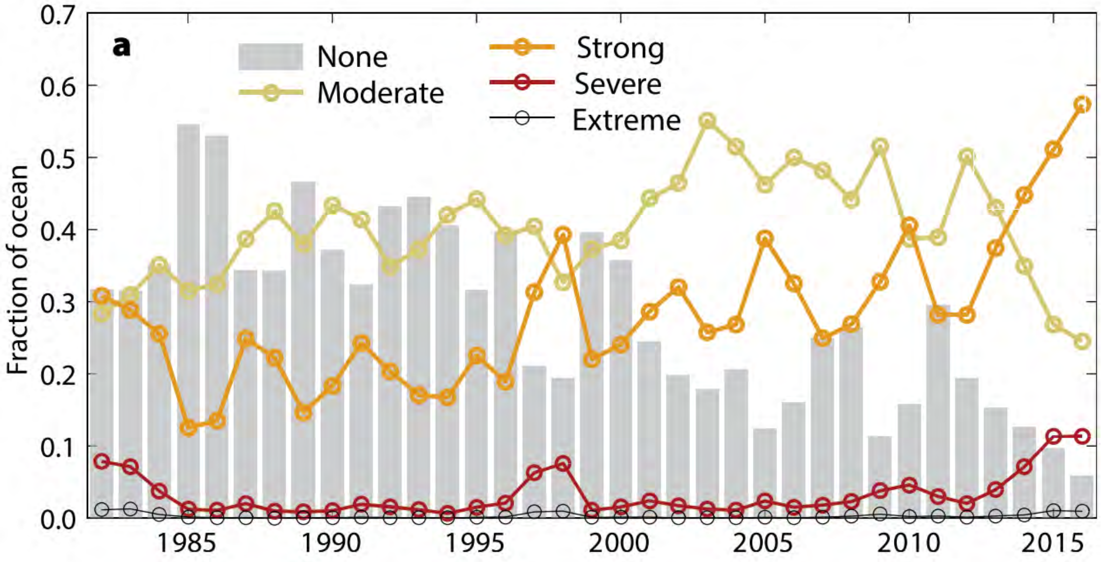


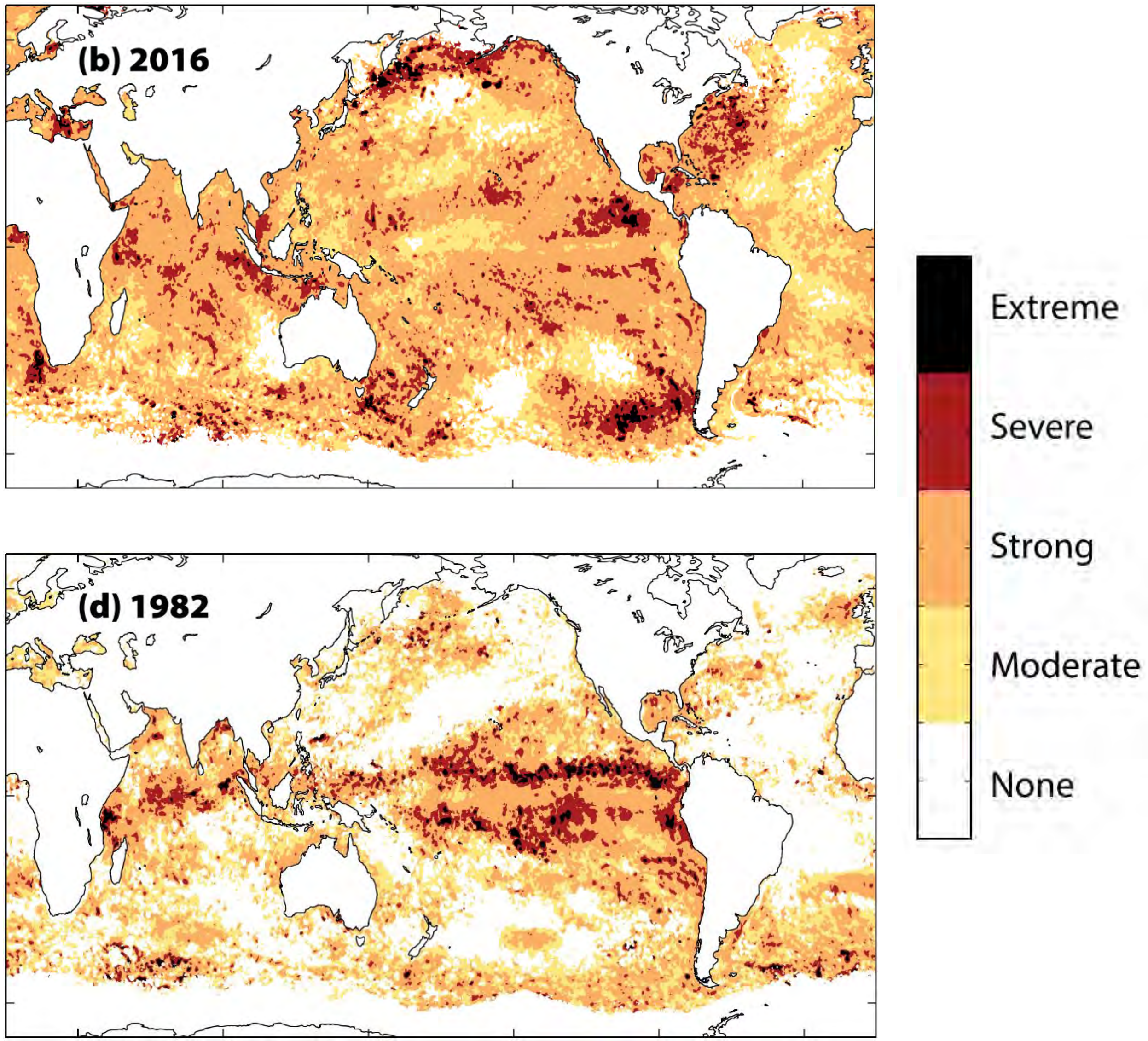


Hobday et al. 2018

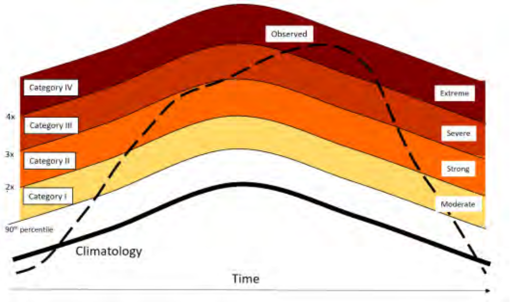
Trends (categories)

- 24% increase in Strong (Cat 2)

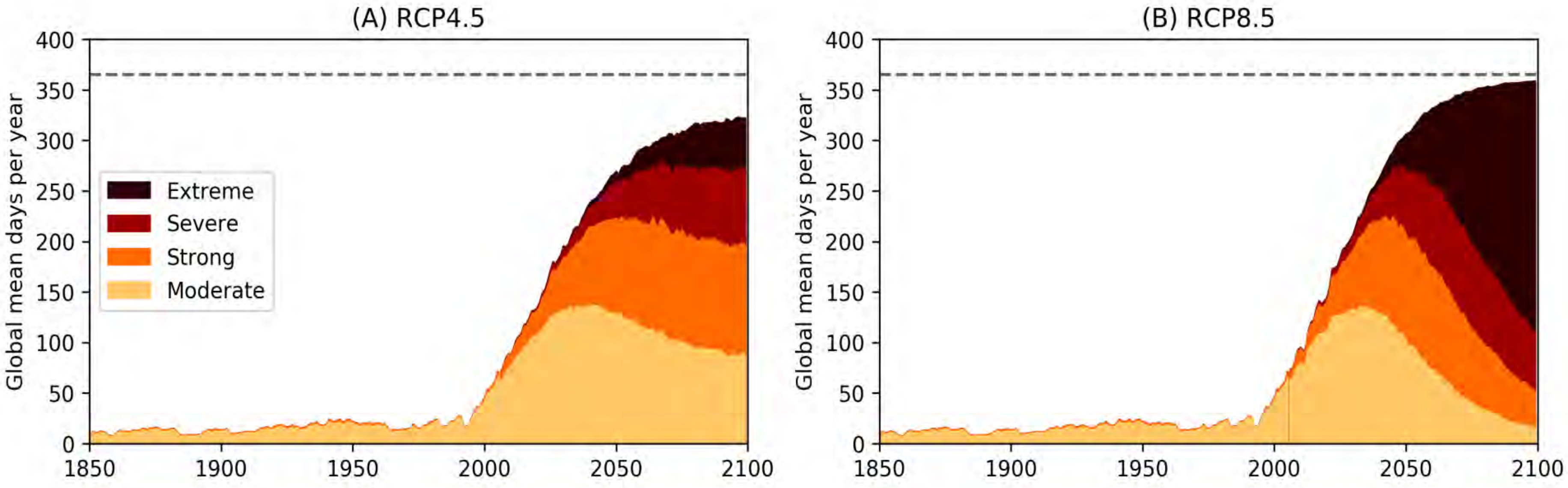




7. Projections of marine heatwaves



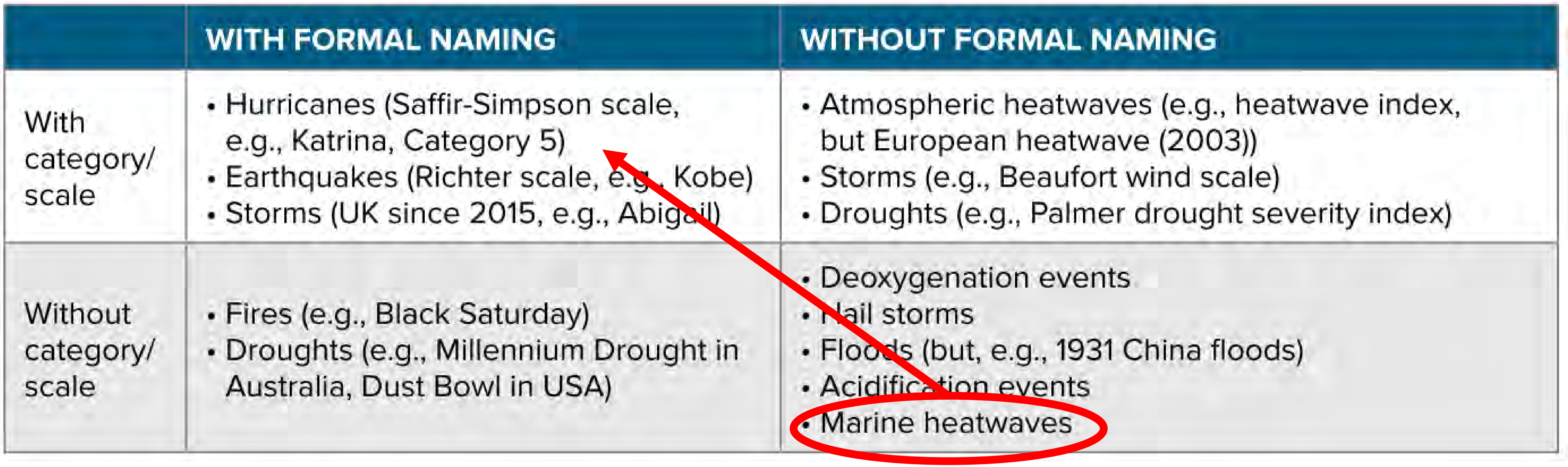
- **Both RCP4.5 and RCP8.5** lead to >300 MHWs days (global average) by 2100….
  - **RCP4.5: still mostly moderate or strong events** **RCP8.5 mostly extreme!!!**



We are going to need a bigger category….living in a category 5+ world….

Oliver et al. in prep

8. Communicating extremes – scales & names



	WITH FORMAL NAMING	WITHOUT FORMAL NAMING
With category/ scale	• Hurricanes (Saffir-Simpson scale, e.g., Katrina, Category 5) • Earthquakes (Richter scale, e.g., Kobe) • Storms (UK since 2015, e.g., Abigail)	• Atmospheric heatwaves (e.g., heatwave index, but European heatwave (2003)) • Storms (e.g., Beaufort wind scale) • Droughts (e.g., Palmer drought severity index)
Without category/ scale	• Fires (e.g., Black Saturday) • Droughts (e.g., Millennium Drought in Australia, Dust Bowl in USA)	• Deoxygenation events • Hail storms • Floods (but, e.g., 1931 China floods) • Acidification events • Marine heatwaves

<u>Naming marine heatwaves</u>

- Recommend: Area & peak year, for <u>strong</u> MHWs (Cat 2)

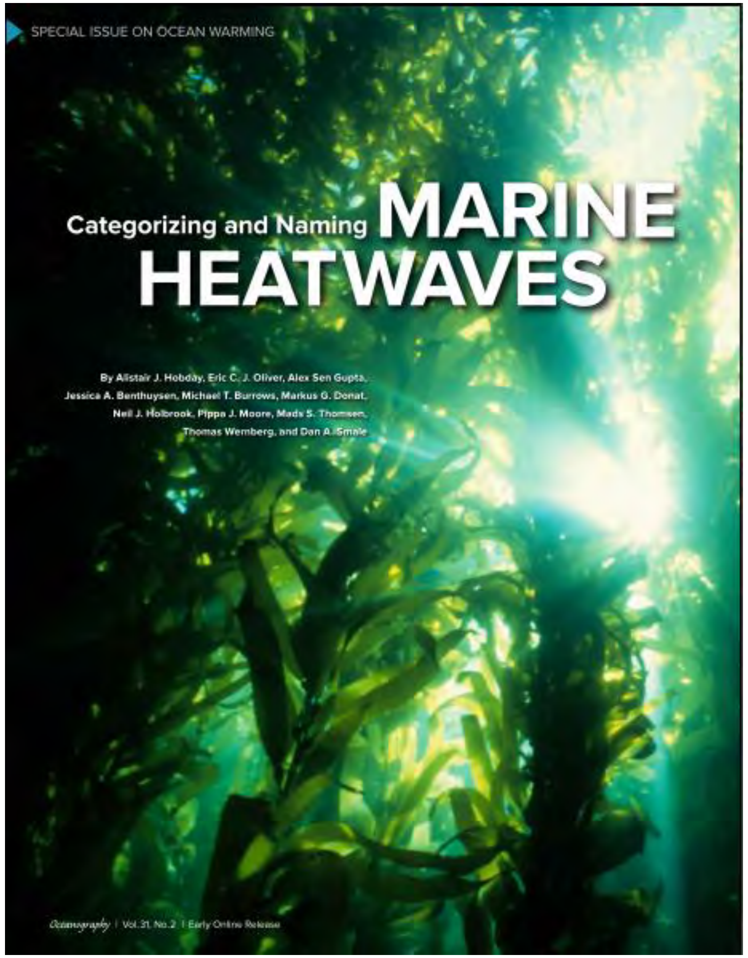
  e.g. Tasman Sea 2015 MHW

Next steps in marine heatwaves

9. Prediction – seasonal forecasting of MHWs

10. Biological impacts
    - How is MHW duration, intensity, and other metrics, related to impact?
        - Smale et al (in review)

11. More regional studies – as they happen!



SPECIAL ISSUE ON OCEAN WARMING

Categorizing and Naming MARINE HEATWAVES

By Alistair J. Hobday, Eric C. J. Oliver, Alex Sen Gupta,
Jessica A. Benthuysen, Michael T. Burrows, Markus G. Donat,
Neil J. Holbrook, Pippa J. Moore, Mads S. Thomsen,
Thomas Wernberg, and Dan A. Smale

Oceanography | Vol. 31, No. 2 | Early Online Release

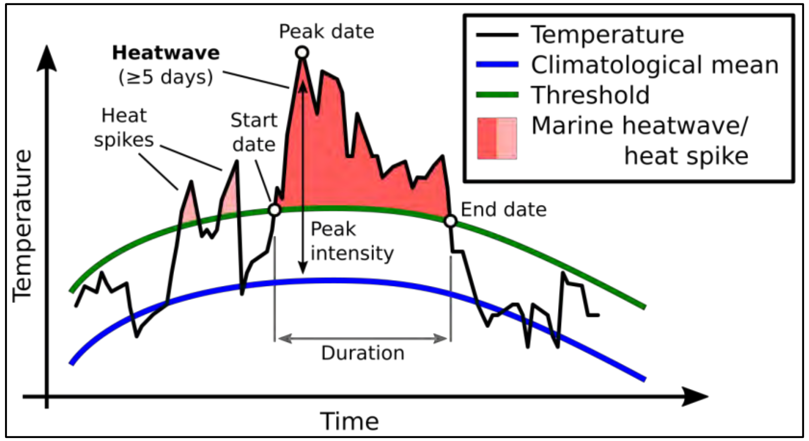
MHW code – publicly available

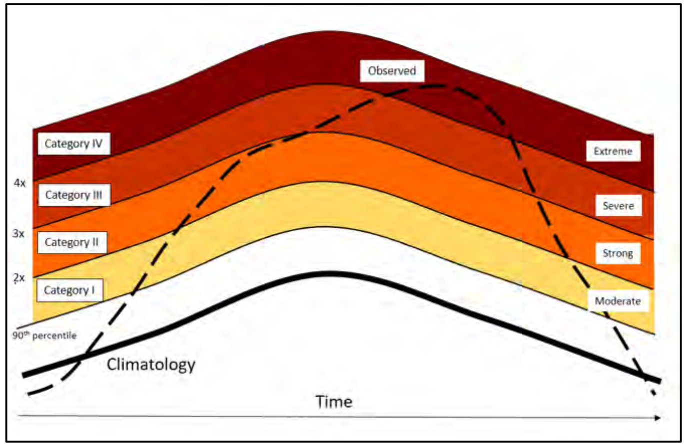
- Code to do all this is freely available at **Marineheatwaves.org**
  - R package - Robert Schlegel, University of the Western Cape, South Africa
  - Python package – Eric Oliver, Dalhousie, Canada

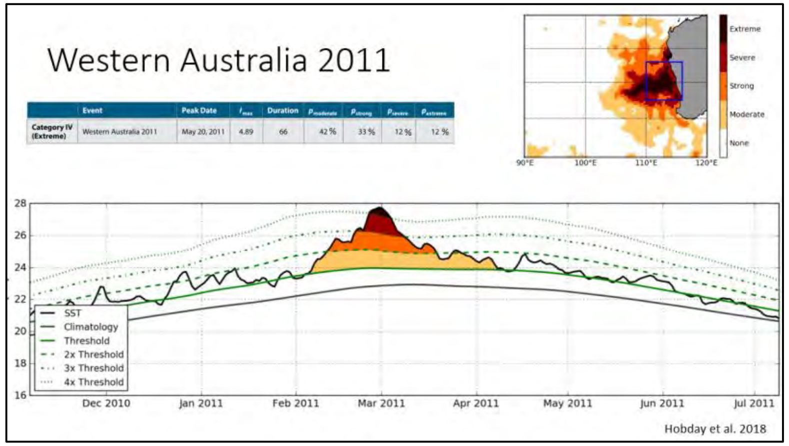
- Potential to be applied to data other than ocean temperatures (does cold spells)

www.marineheatwaves.org

1. Extremes (MHWs) represent a chance for fast learning – stress test
2. A comparative MHW approach is possible with consistent description
3. Continued research to address the relationship with impacts
4. Prediction is the next frontier…seasonal forecasting!



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Hobday et al. 2018