Marine heatwaves – forecasting to enhance industry resilience

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"Because all decision making is ultimately based on what will happen in the future, either under the status quo or different decision alternatives, **environmental decision-making ultimately depends on forecasts**."

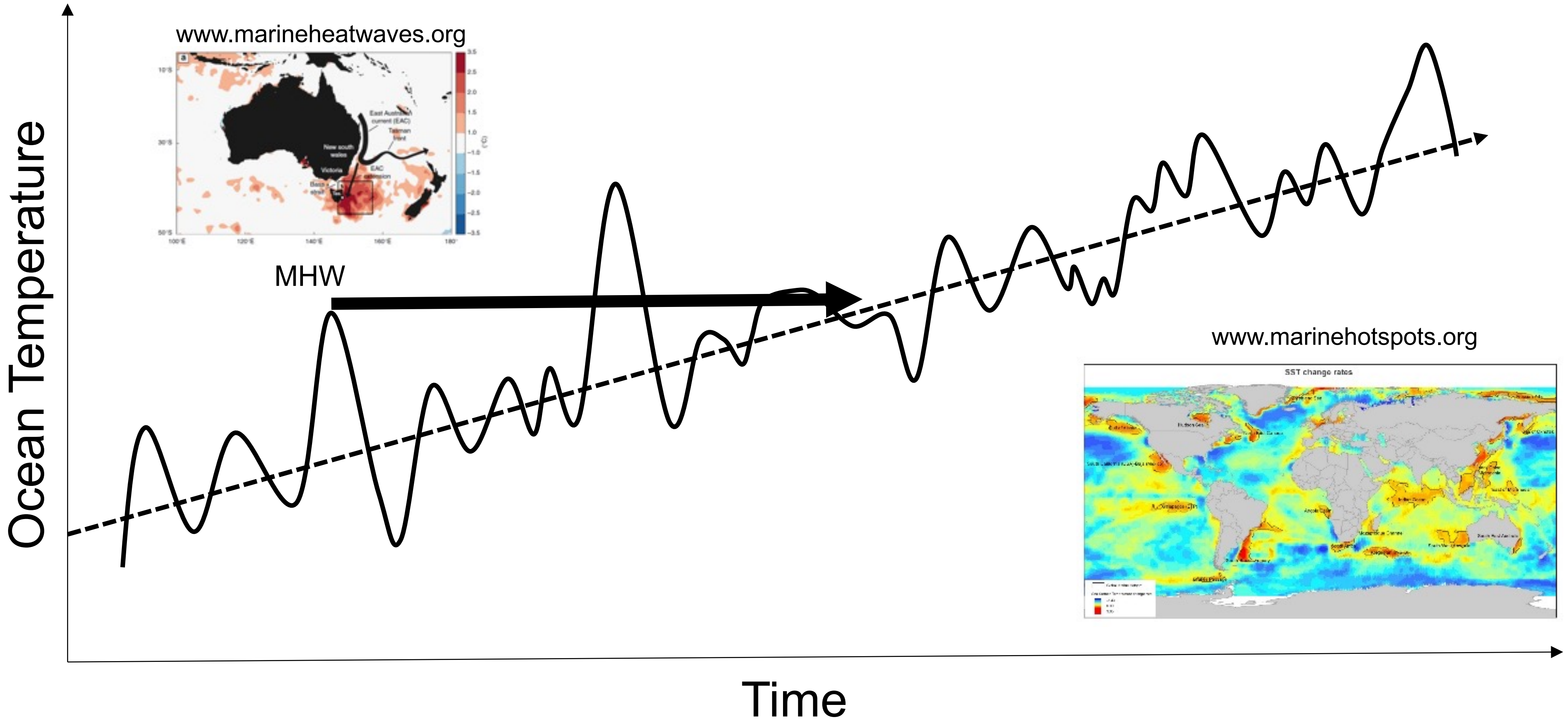
(Dietze et al. 2018)

Ability to use information about the future depends on industry agility

Hartog et al 2023

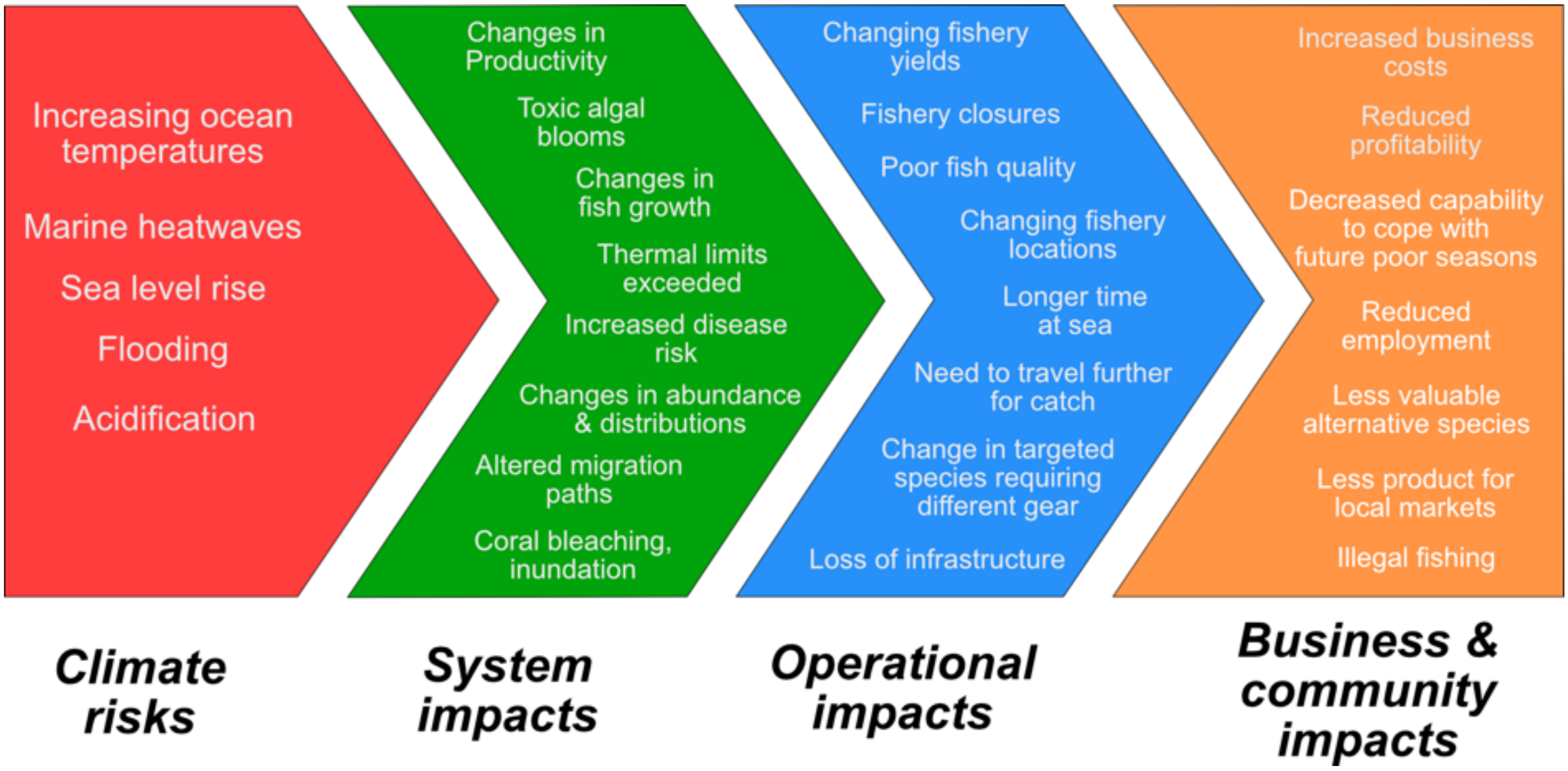
Future includes trends and variability (extremes)

Extreme events – a window to the future



Modified from Woehler & Hobday (2023)

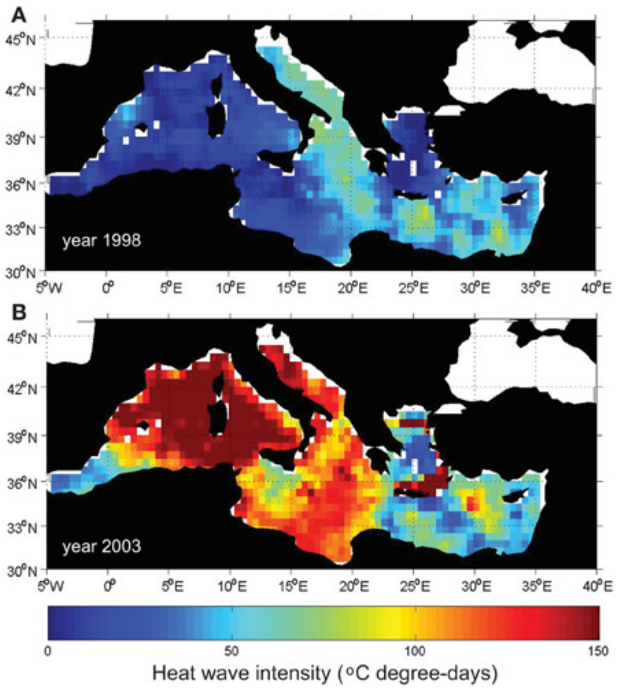
Impacts of climate extremes



Hartog et al 2023

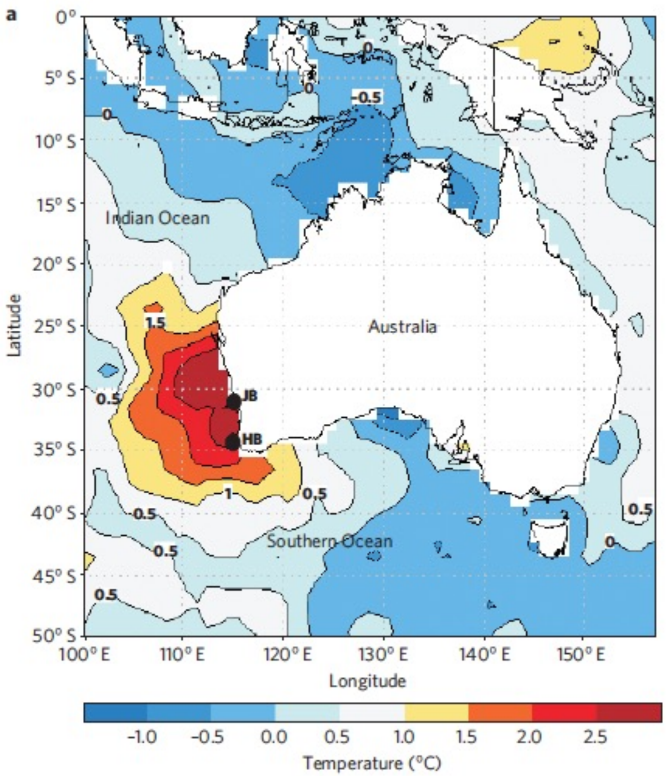
Marine heatwaves – extreme events

Mediterranean 2003



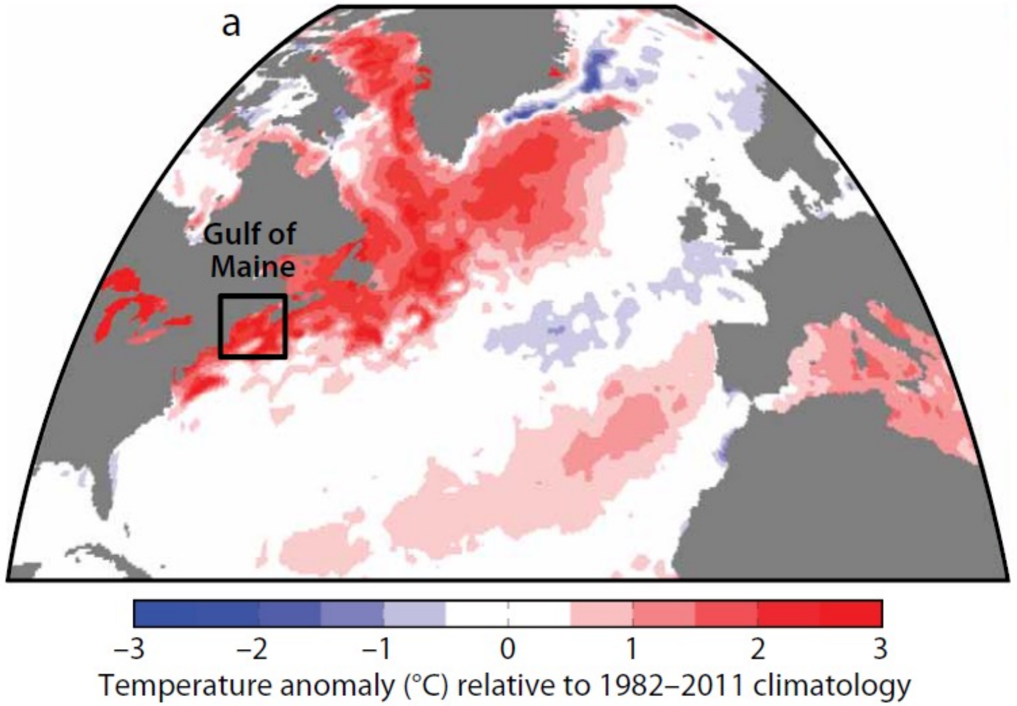
Garrabou et al 2009

Western Australia – 2011



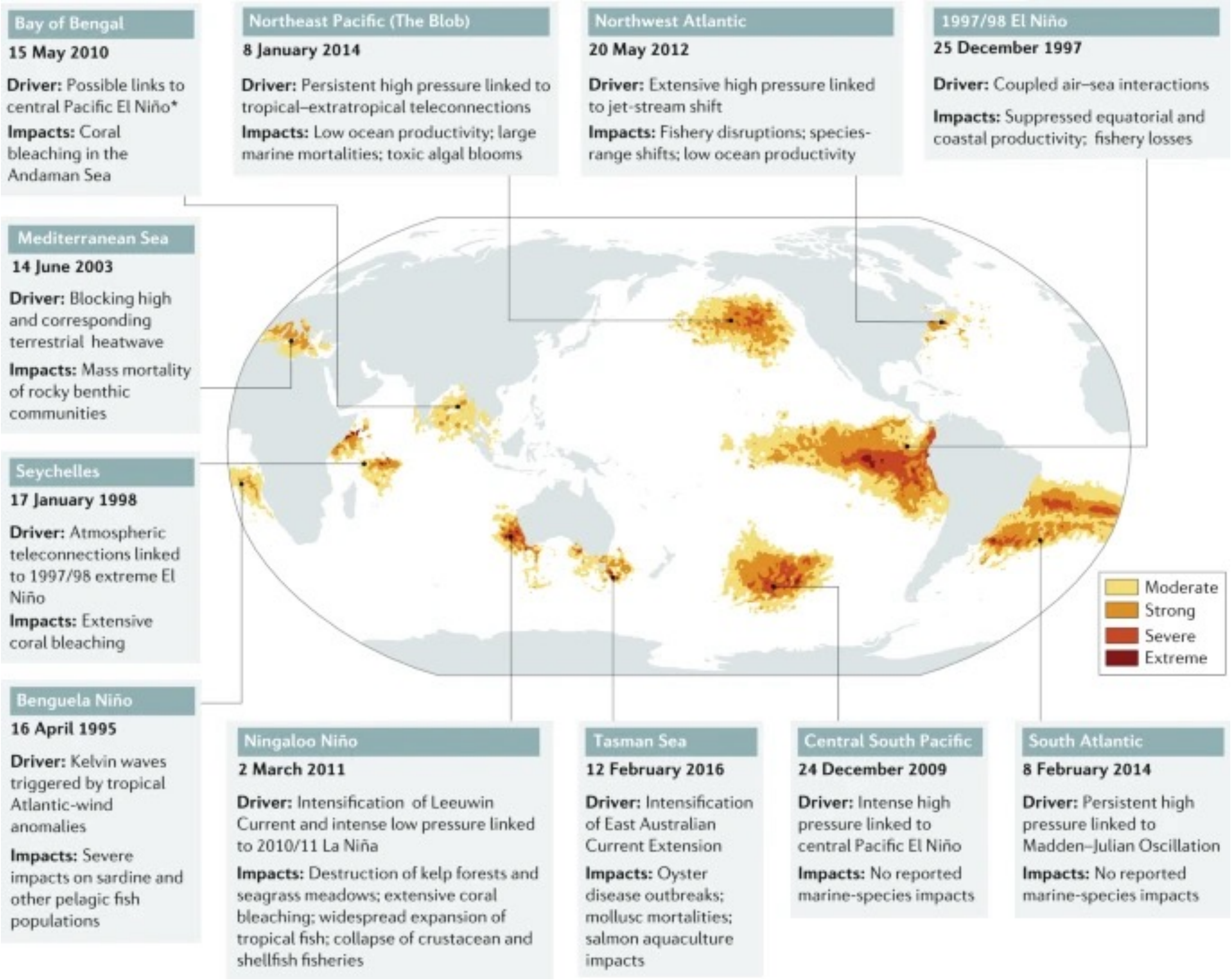
Wernberg et al 2011

NW Atlantic 2012



Mills et al. 2013

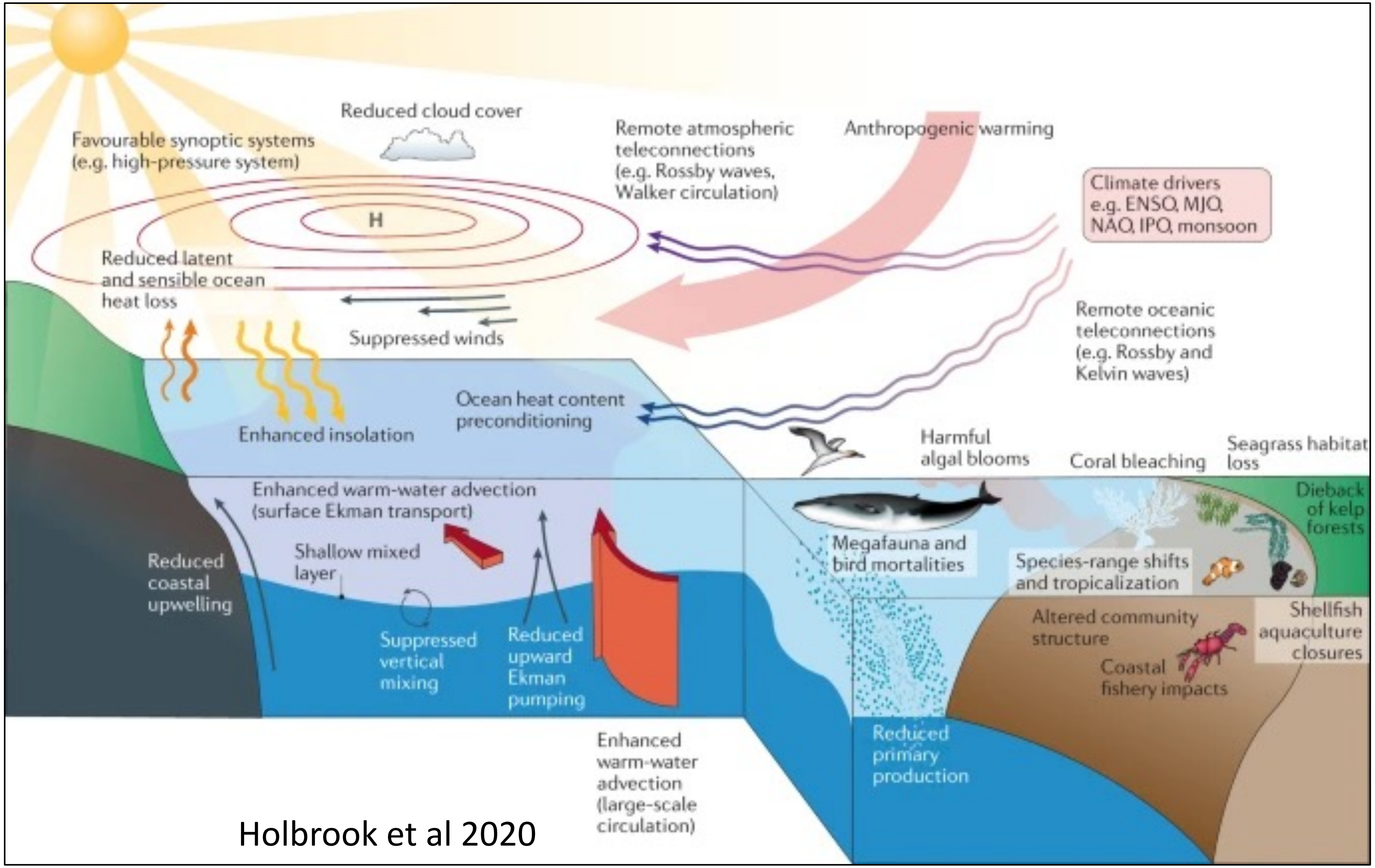
Significant MHWs have caused $B's in damages



Holbrook et al 2020
Smith et al 2021

How do MHWs form?

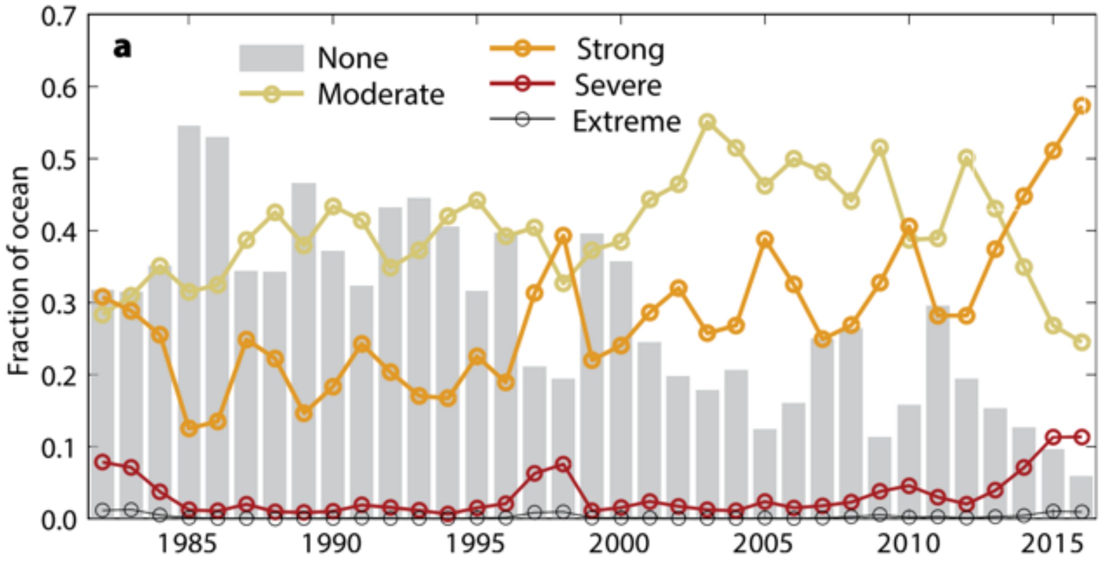
- Advection of warm water
- Atmospheric heat input

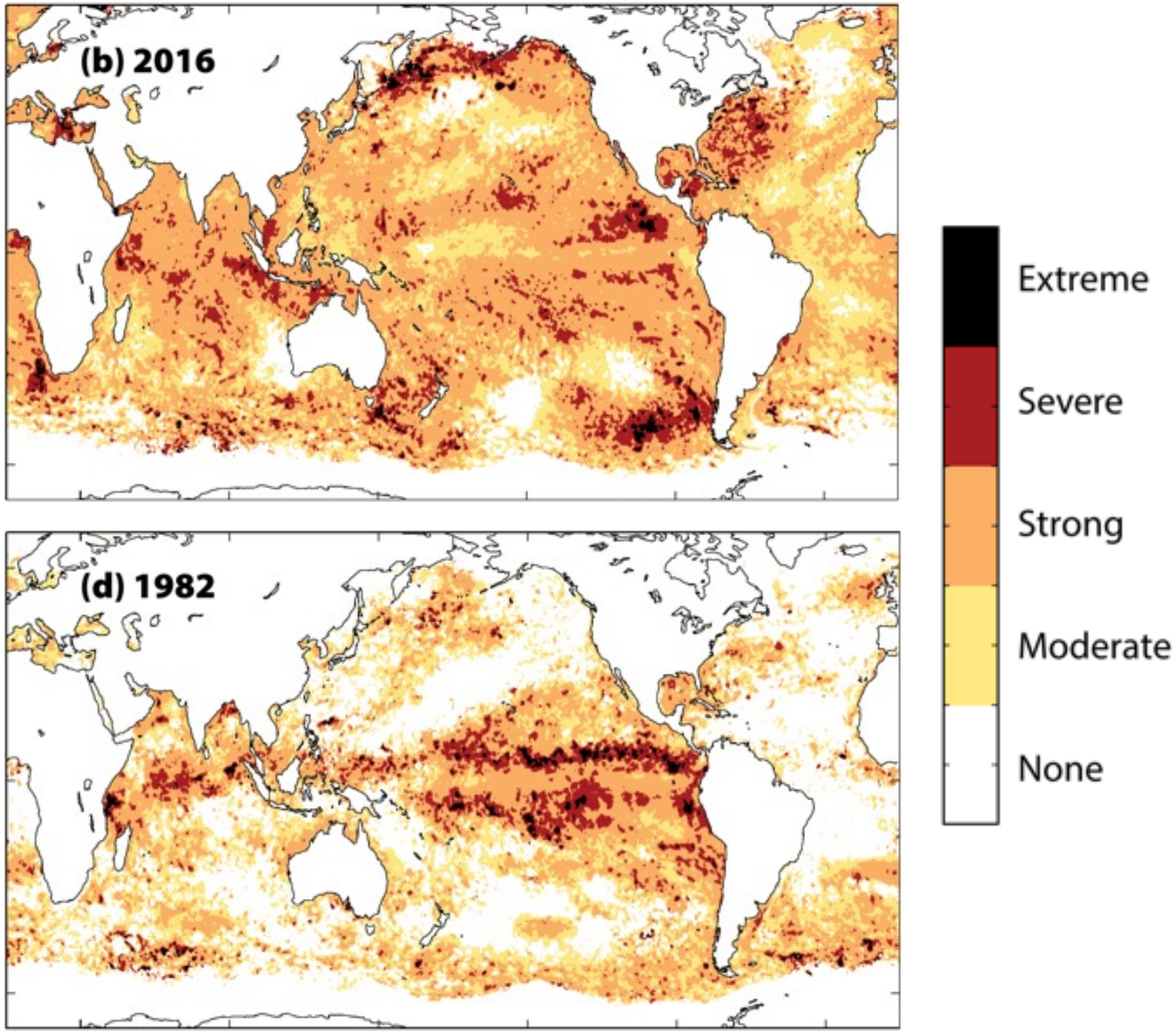


Holbrook et al 2020

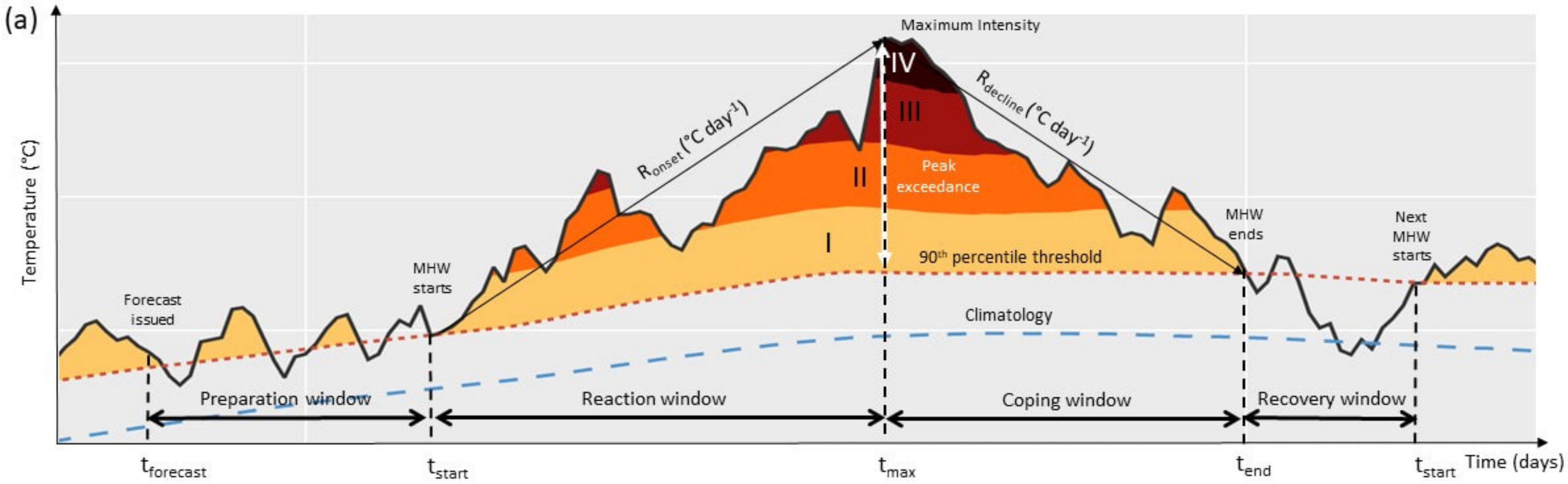
MHW trends – more, longer, stronger

- 24% increase in Strong (Cat 2)





Forecasting: increases preparation window



Preparation window

Spillman et al 2021

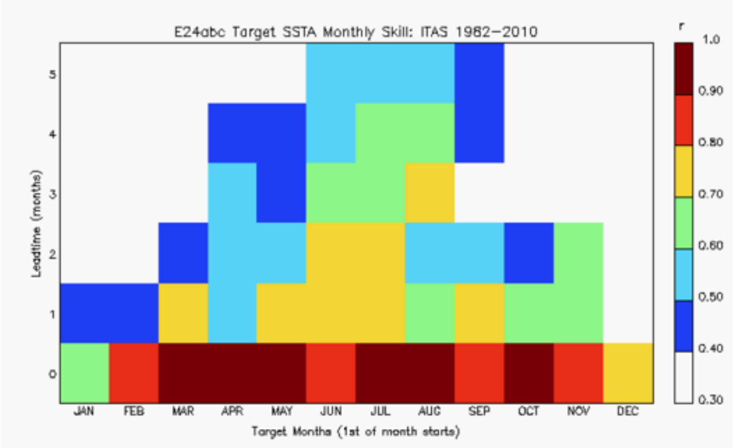
Forecasting of MHWs – how we do it

1. Forecasting techniques

- Expert model (experiential data)
  - This year is El Nino – we expect "X"
- Statistical model (historical data)
  - GAM/GLM
  - Machine learning
- Dynamical model (has the future in it)
  - Ocean model
  - Coupled models

Plus

2. Skill assessment of forecast



3. Uncertainty

1. Expert models – climate drivers such as ENSO

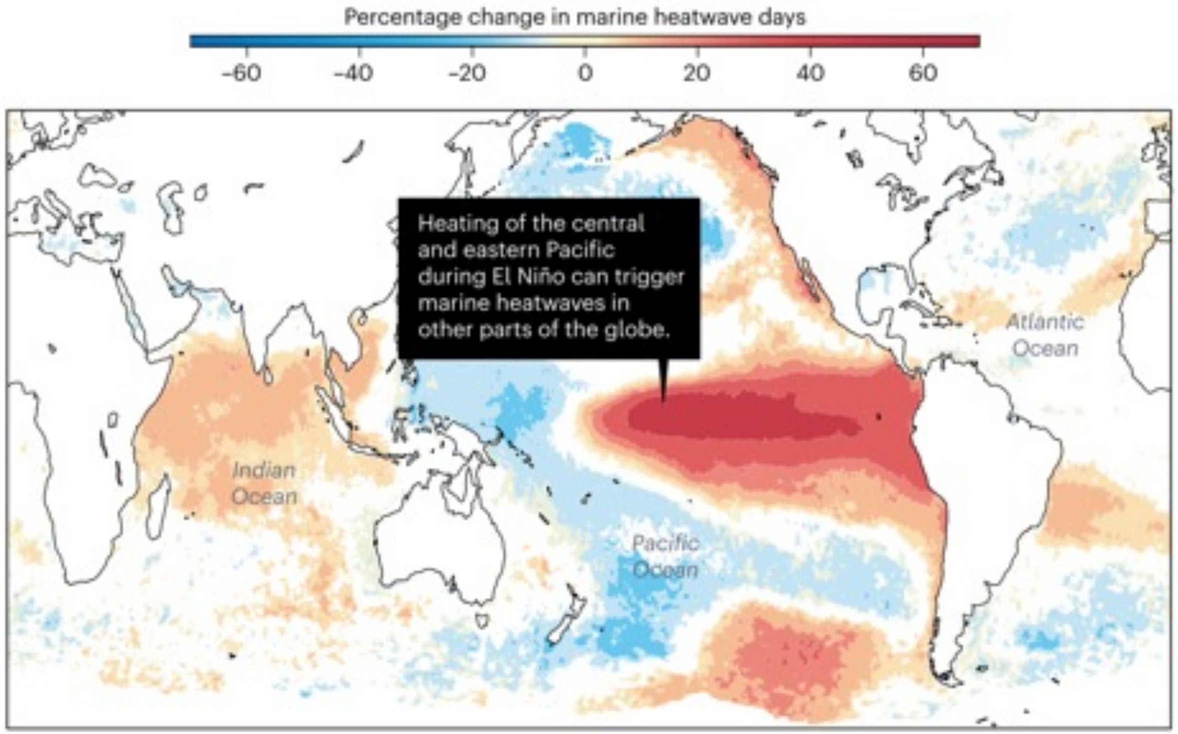
With the arrival of El Niño, prepare for stronger marine heatwaves

Alistair J. Hobday, Michael T. Burrows, Karen Filbee-Dexter, Neil J. Holbrook, Alex Sen Gupta, Dan A. Smale, Kathryn E. Smith, Mads S. Thomsen & Thomas Wernberg

- February to June, 2023

EL NIÑO AND MARINE HEATWAVES

El Niño is associated with an increased likelihood of marine heatwaves. This map shows where that risk is strongest, by comparing the number of marine-heatwave days during past El Niños with the number occurring during neither an El Niño nor the cooler La Niña phase.

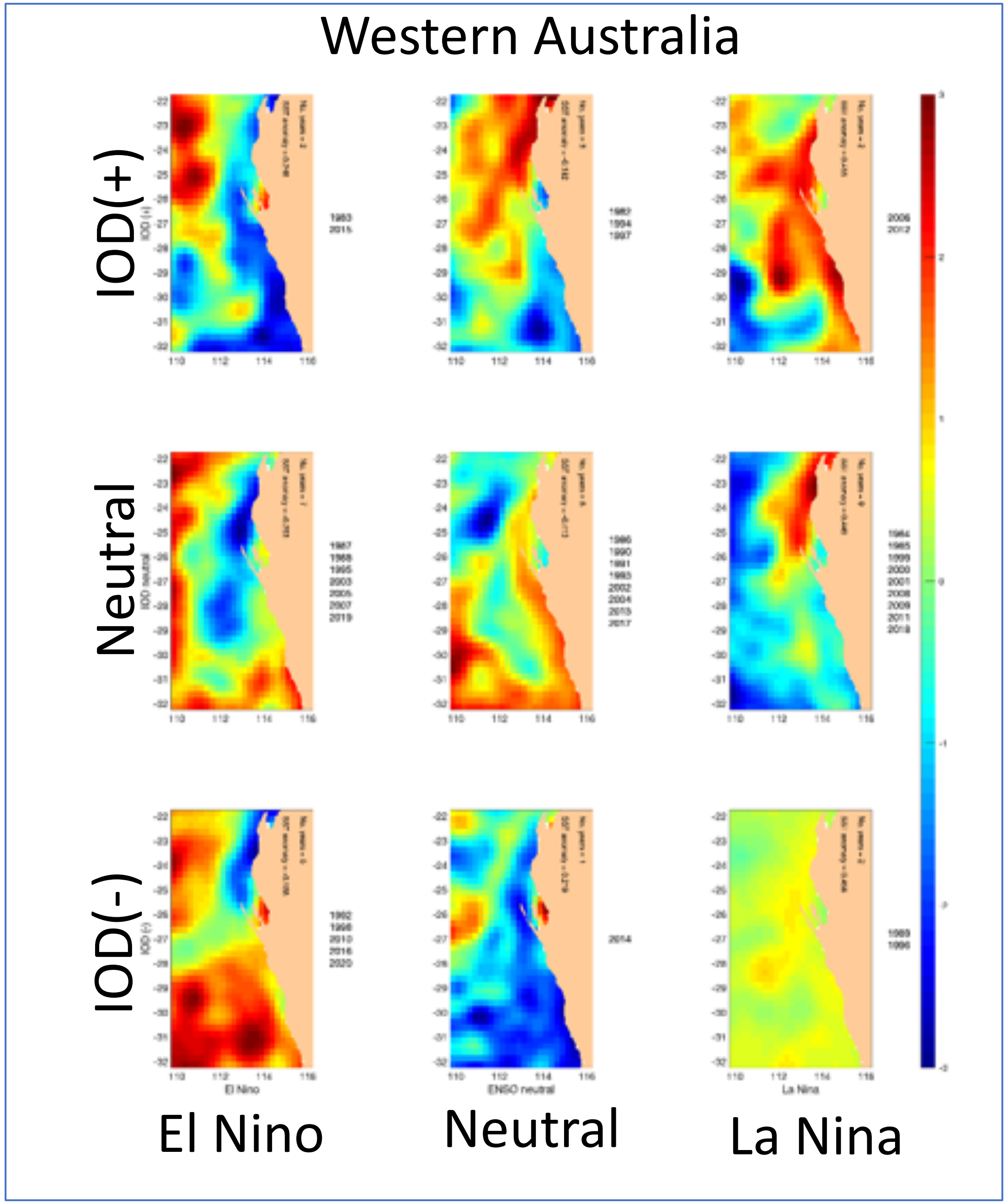


1. Expert models

Analogue forecasts

Use combinations of past conditions to suggest the future

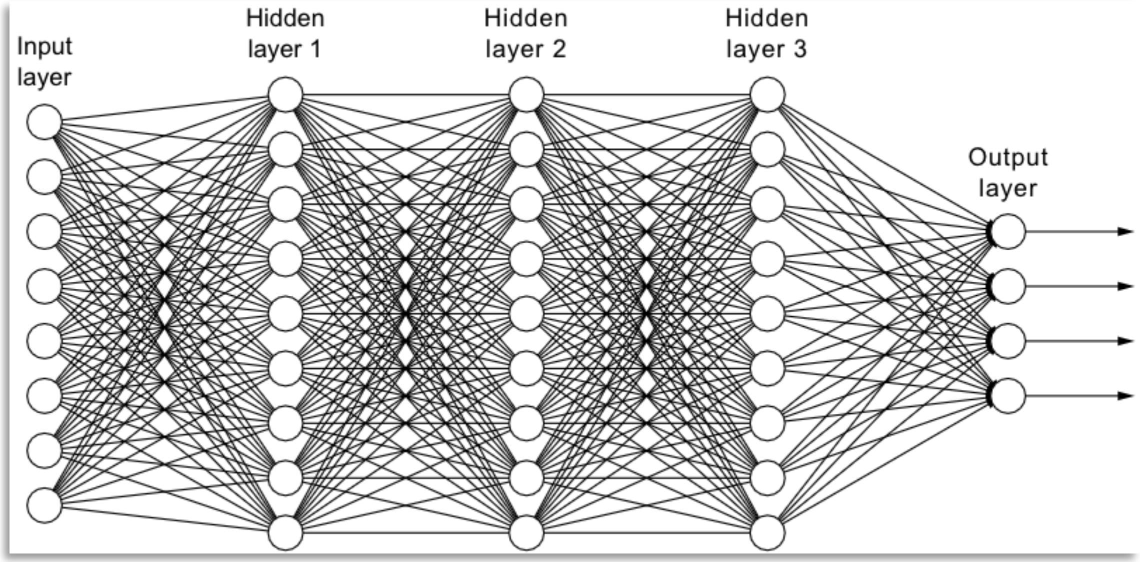
Temperature patterns - summer



2. Statistical forecast models (machine learning)

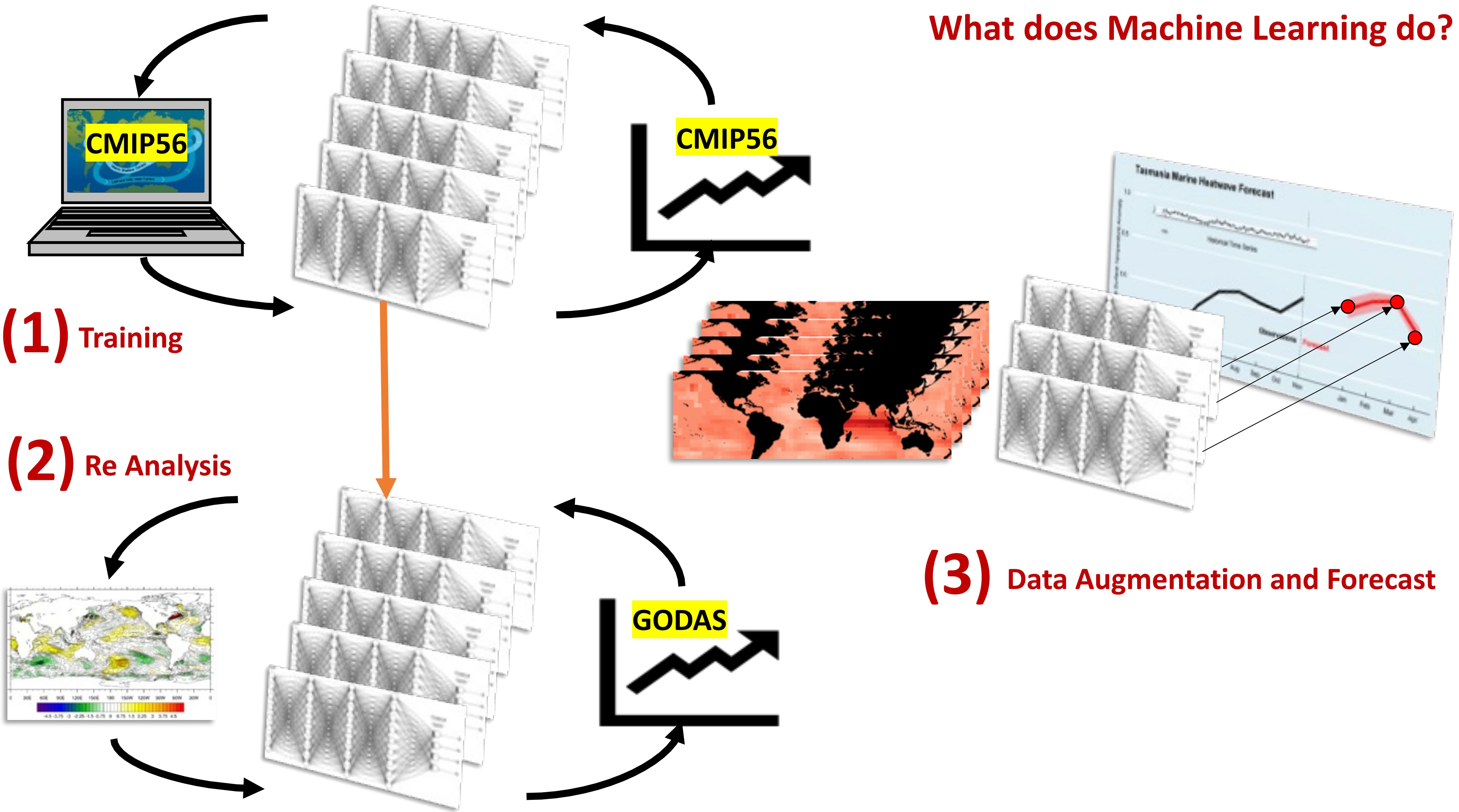
Why Machine Learning?

1) Good at detecting predictive, informative patterns (especially on images)
2) Can outperform physical models, even in some chaotic processes
3) Machine learning and traditional modelling can be successfully integrated

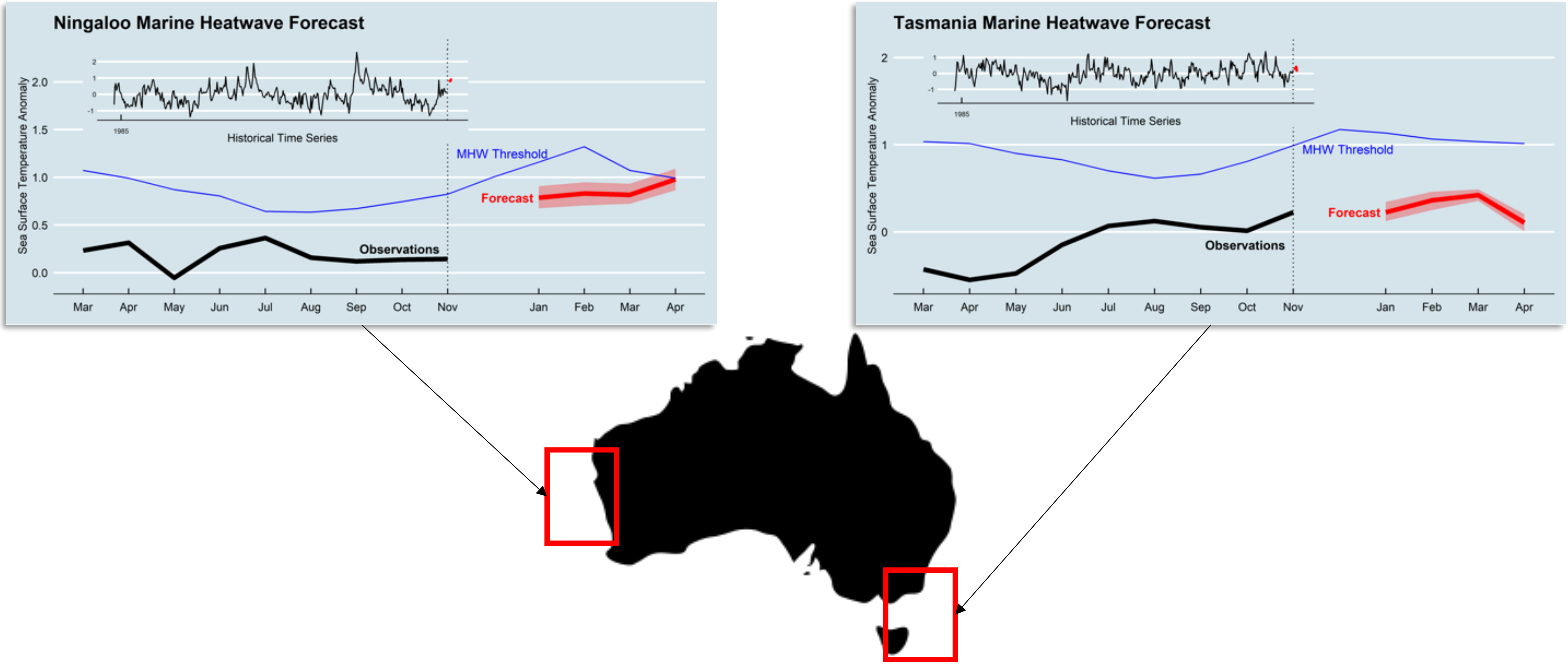


Boschetti et al (2023)

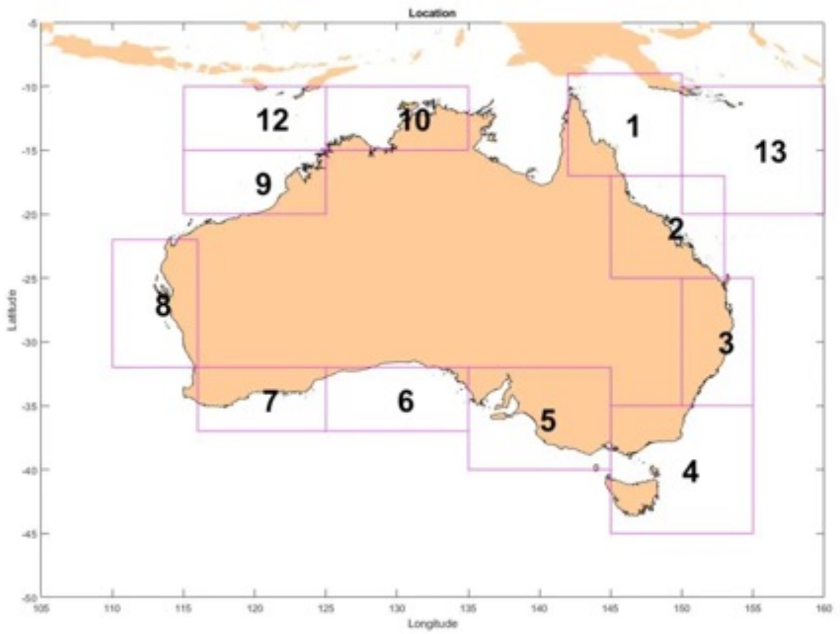
What does Machine Learning do?

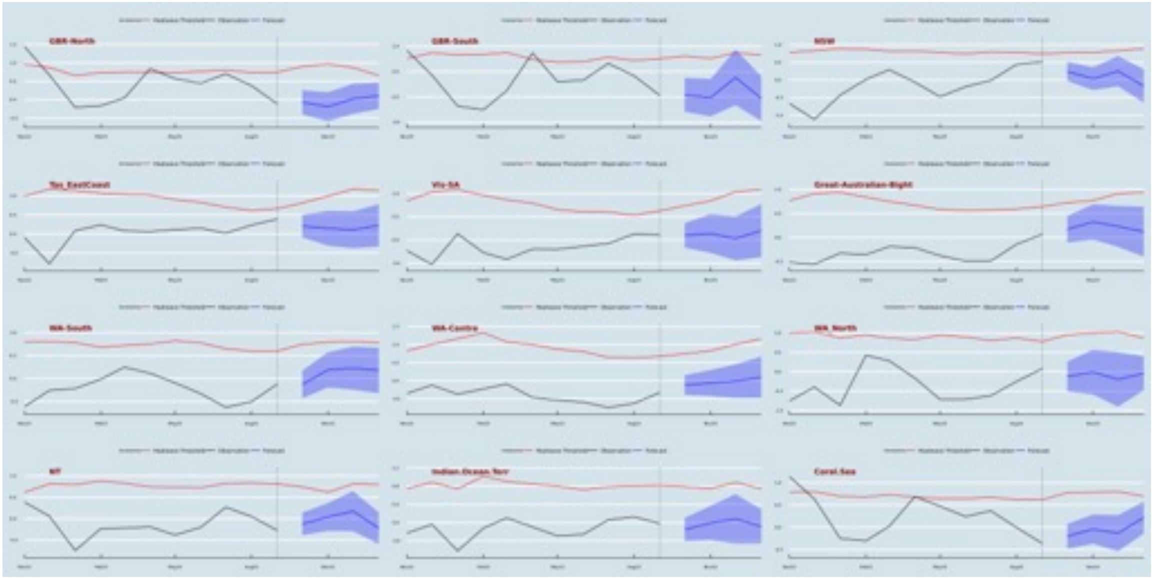


Experimental forecasts – 2021



Experimental forecasts – machine learning





https://research.csiro.au/cor/research-domains/climate-impacts-adaptation/marine-heatwaves/forecasting-marine-heatwaves/australian-mhw-forecasts/

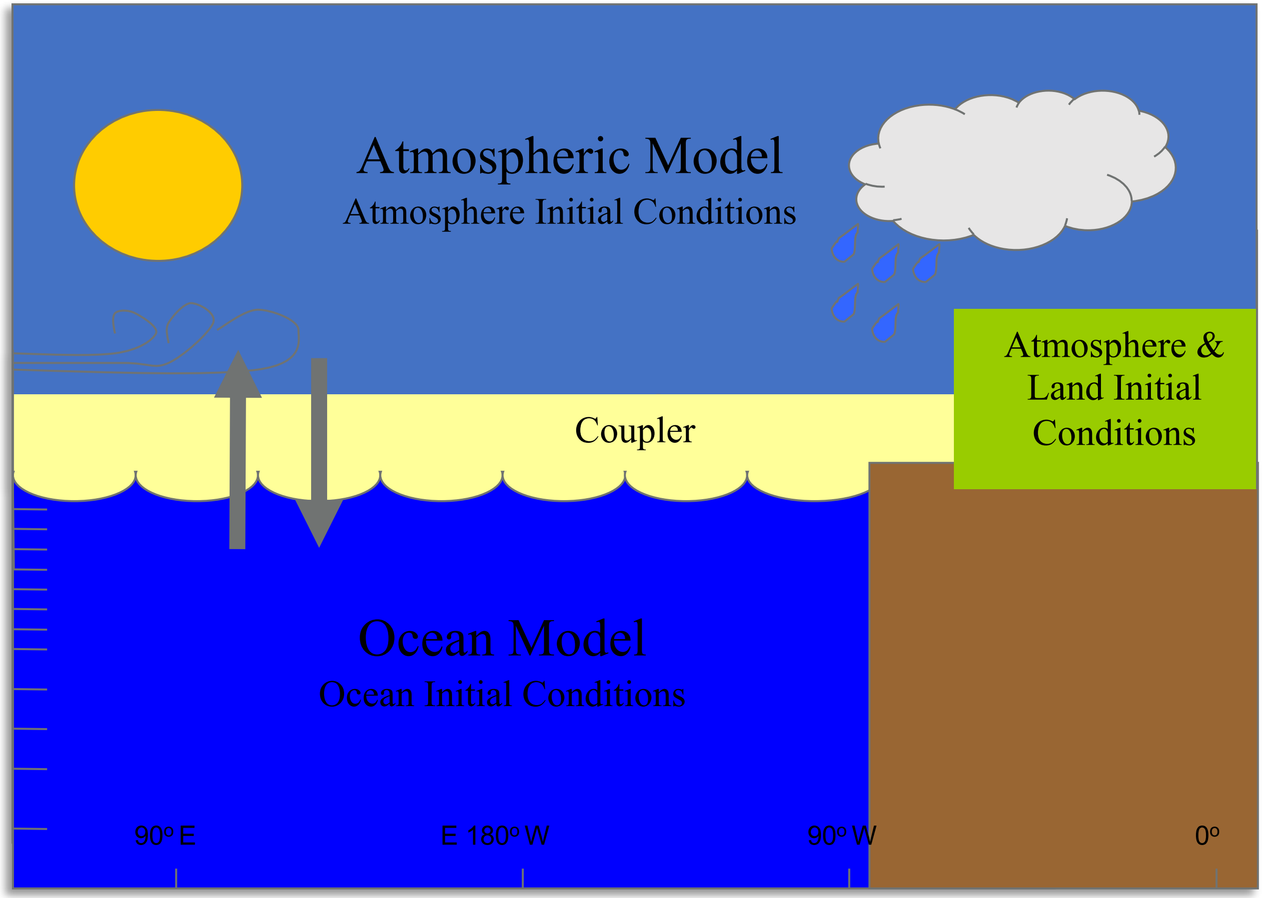
Boschetti, Hobday, Hartog, Feng, Zhang

3. Dynamical Forecasts

- **Use ACCESS-S2** - BOM's seasonal prediction system

- Computer models that predict future ocean, land & atmospheric conditions in 3D out to 6 months
- Includes winds, currents, rain, clouds, radiation, sea ice & more
- Use latest observations

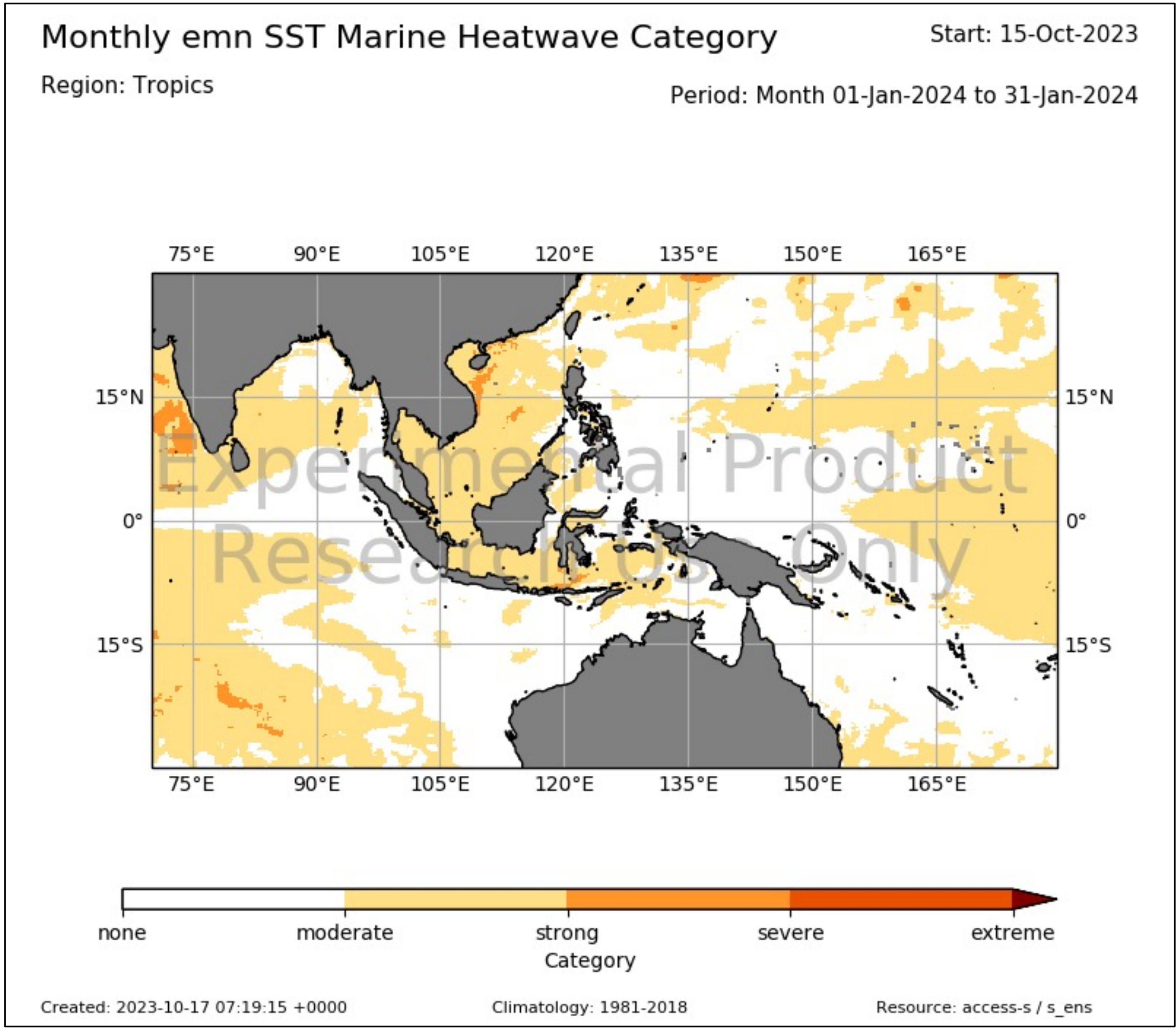
- Run 40 years of hindcasts to test how well past events were predicted



Dynamical MHW Forecasts

- Leadtime – 3 months

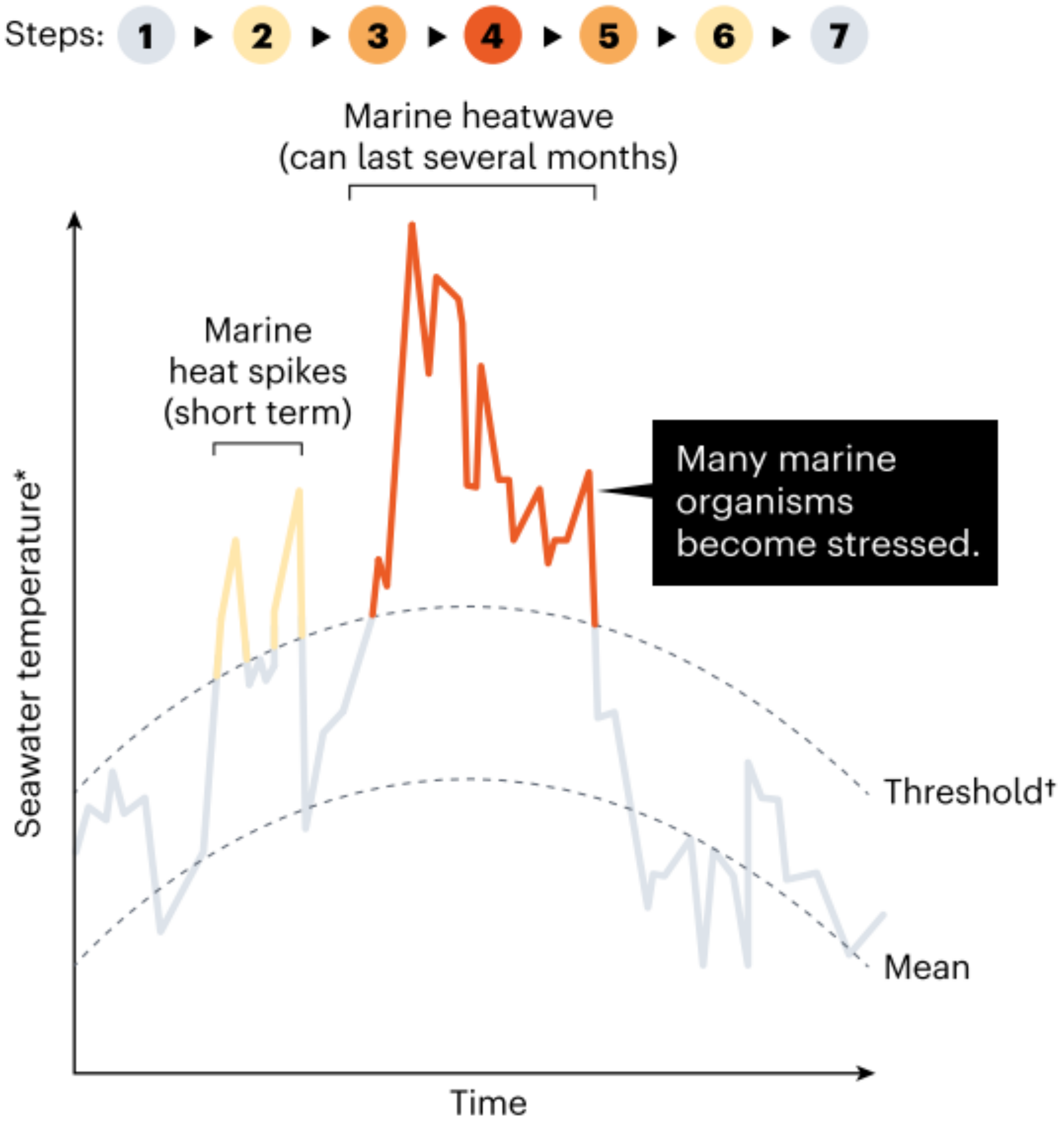
  - https://research.csiro.au/cor/climate-impacts-adaptation/marine-heatwaves/dynamical-forecasting-of-marine-heatwaves/



Claire Spillman, Grant Smith, Jason Hartog, Alistair Hobday

MANAGING MARINE HEATWAVES

Periods of anomalously warm marine waters that can last from five days to more than a year require appropriate preparation and response, involving researchers and coastal communities alike.



*Temperature and time illustrated schematically. †Usually the 90th percentile.

1. **Establish baseline**
   Researchers can use historical records and long-term monitoring.
2. **Assess risk and plan responses**
   Identify vulnerable ecosystems, species and industries and ways to protect them.
3. **Respond to forecasts**
   Shift aquaculture species to cooler sites, for example.
4. **Adjust to cope**
   Close fisheries, reduce quotas, cull pests.
5. **Evaluate impacts**
   Assess recovery time post-heatwave.
6. **Collect new baseline data**
   On temperature, salinity, acidity, oxygen and nutrients.
7. **Reset quotas and activities**
   Targets must be adjusted for any change in baseline.

Climate change, variability and extremes will challenge Australia this summer

June	August-September	November-February	
Events predicted	Events forecast	During events	Recovery phase

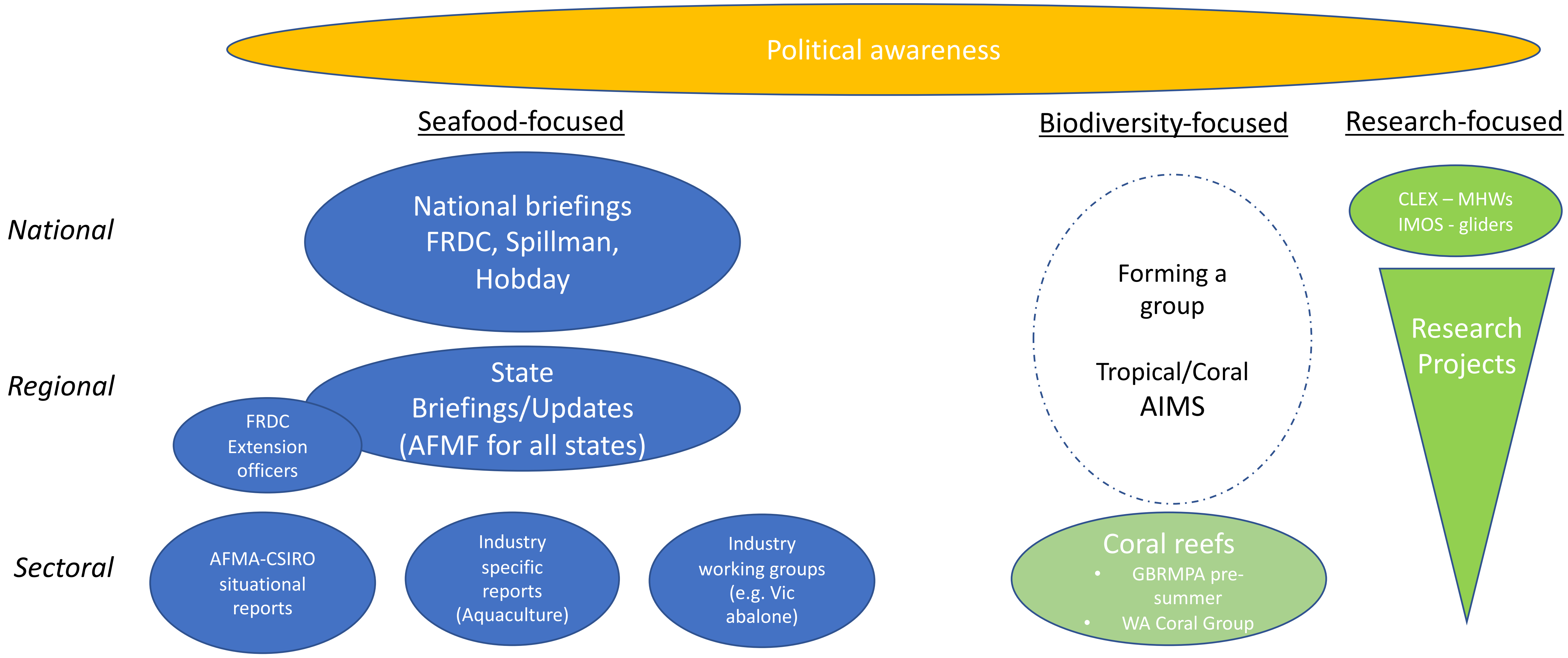
And we have never had such early-warning and preparation capability

Improving awareness

National Briefings for seafood industry hosted by FRDC

- **Briefing 1 - 23 June:** https://www.youtube.com/watch?v=EhqaIioYD4c
- **Briefing 2 - 25 August:** https://www.youtube.com/watch?v=-Fp9g35KbNw
- **Briefing 3 -** Friday 8 December 2-3pm (requests to Jamie.Alnutt@frdc.com)

Marine Environmental Awareness Landscape



Step 1: Preparation: Assess the risk

Action	Example
Obtain baseline data using long-term monitoring programs and historical studies (R, I) Revisit past marine heatwave effects in region of interest (I) Estimate risk, intensity and duration of marine heatwaves during El Niño in region of interest (R)	Marine heatwave historical analyses — for example www.marineheatwaves.org. In eastern Tasmania, an atlas of marine heatwaves can be used to revisit past events and understand the frequency, intensity, duration and impacts of past events
Identify vulnerable ecological areas and populations, using vulnerability assessment approaches (R)	Determine population susceptibility for different species (for example shallow or sessile). Measure thermal thresholds for species/populations survival. Knowledge from past events can inform expected impacts and improve responses, as occurred for lobster fisheries in Maine, USA.
Identify vulnerable marine industries using vulnerability approaches (R, I)	Determine commercial species and strains at risk under different marine heatwave scenarios Undertake supply chain analysis to identify weak links
Identify vulnerable human populations (such as subsistence fishers, communities reliant on single marine industry) using socio-ecological vulnerability assessment (R, M)	Communities that have high exposure to loss of income from fishery closures, tourism downturns, or opportunities for new businesses (such as iconic species located in new areas) should contribute to risk planning.

Code - researchers (R), industry (I), managers (M) and policy-makers in local or national governments (P).

Step 2: If risk exists, continue preparation –> Plan responses

Action	Example
Undertake consensus-building approaches to enable fast action when needed, and included stakeholders with special knowledge, such as Indigenous communities (I, M, P)	Explore different scenarios and possible actions such as relocation, fisheries closures, and livelihood alternatives using participatory approaches.
Formulate response plan, using decision support tools, and think about adaptive responses that do not have unwanted side effects (I, M).	Responses include changing marine resource use, building ecological resilience, and reducing other stressors. Fisheries that have closed in the past due to marine heatwaves — for example Western Australia — should develop response plans.
Prioritize high-risk areas and populations for response using vulnerability mapping (R, I, P)	Based on mapping, aquaculture companies can prepare to shift populations to cooler parts of their lease sites and fallow the warmer sites. Harvest before the forecast event.
Develop early warning systems based on ecosystem monitoring, ocean forecasting and available real-time information. (R)	Develop skills in using existing ocean information websites, such as provided by observing programs — for example Australia's integrated marine observing system (IMOS) or www.marineheatwaves.org Deploy monitoring equipment around area of activity, such as gliders

Code - researchers (R), industry (I), managers (M) and policy-makers in local or national governments (P).

Summary

1. MHWs cause stress to the ocean and resource management
2. Prediction…seasonal MHW forecasting is now possible
3. Many ways to respond and prepare to MHWs
4. Other extreme events will also be challenging – also need to prepare