Marine Heat Waves: A general overview and case studies in the Mediterranean and around Australia

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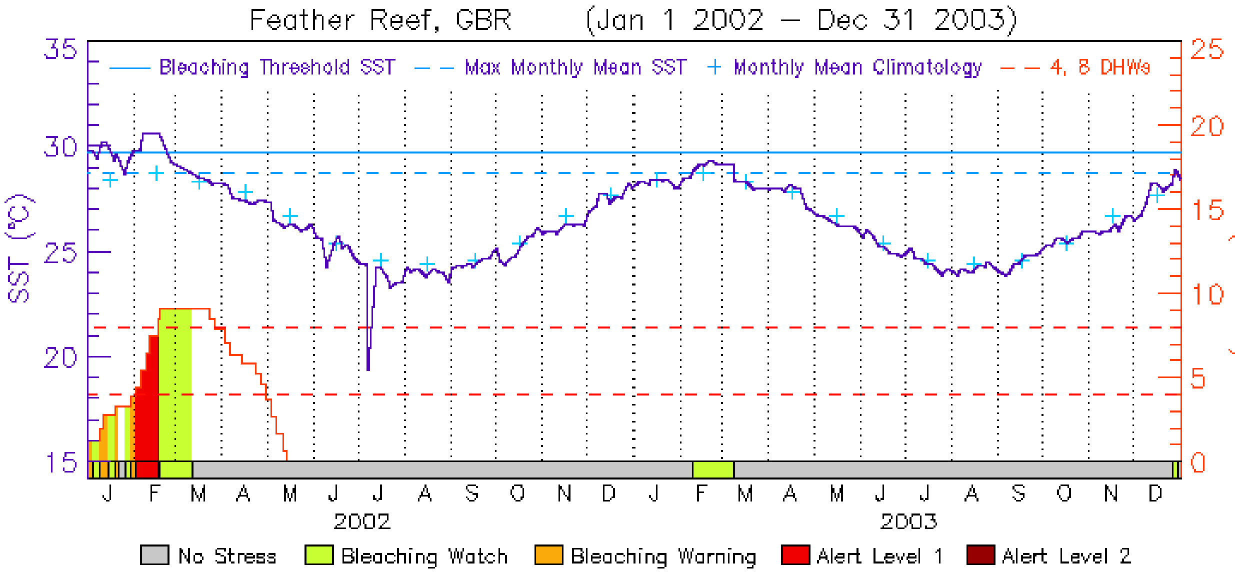
translatingnatureintoknowledge

Marine Heat Waves

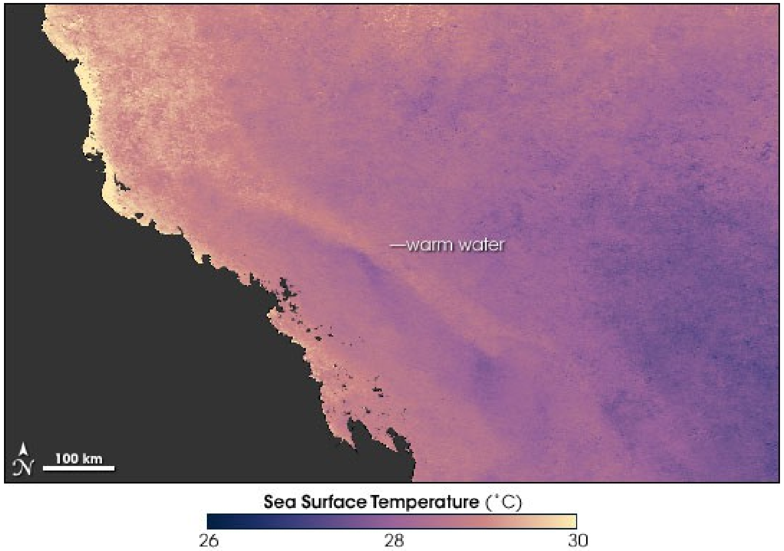
- While oceanic extremes have been studied for several decades, it has primarily focussed on a few key physical variables:
  - Most focus has been on extreme sea levels, which has a long history due to its relationship to hydrology,
  - And recently there has been interest in extreme wave height and current speeds
- However, extreme events in water properties (such as temperature, salinity, chlorophyll, etc...) have received relatively little attention
- These likely to be important for changes to species and ecosystem distribution

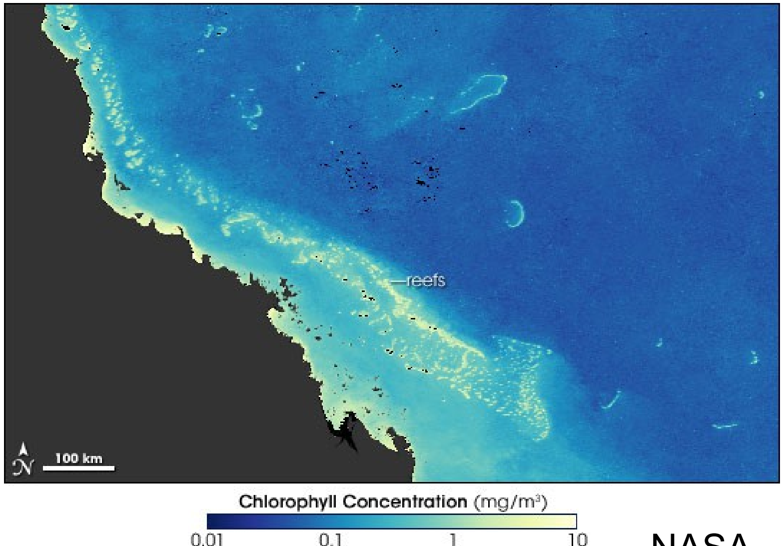
Impacts

- Coral bleaching is caused by exposure of coral reefs to elevated ocean temperatures and/or light levels
- Can be harmful to the coral reef ecosystem
- Reefs increasingly sensitive to bleaching in a warming ocean...



coralreefwatch.noaa.gov





NASA

Impacts

- Spiny sea urchins are displacing giant kelp along Tasmania's coastline

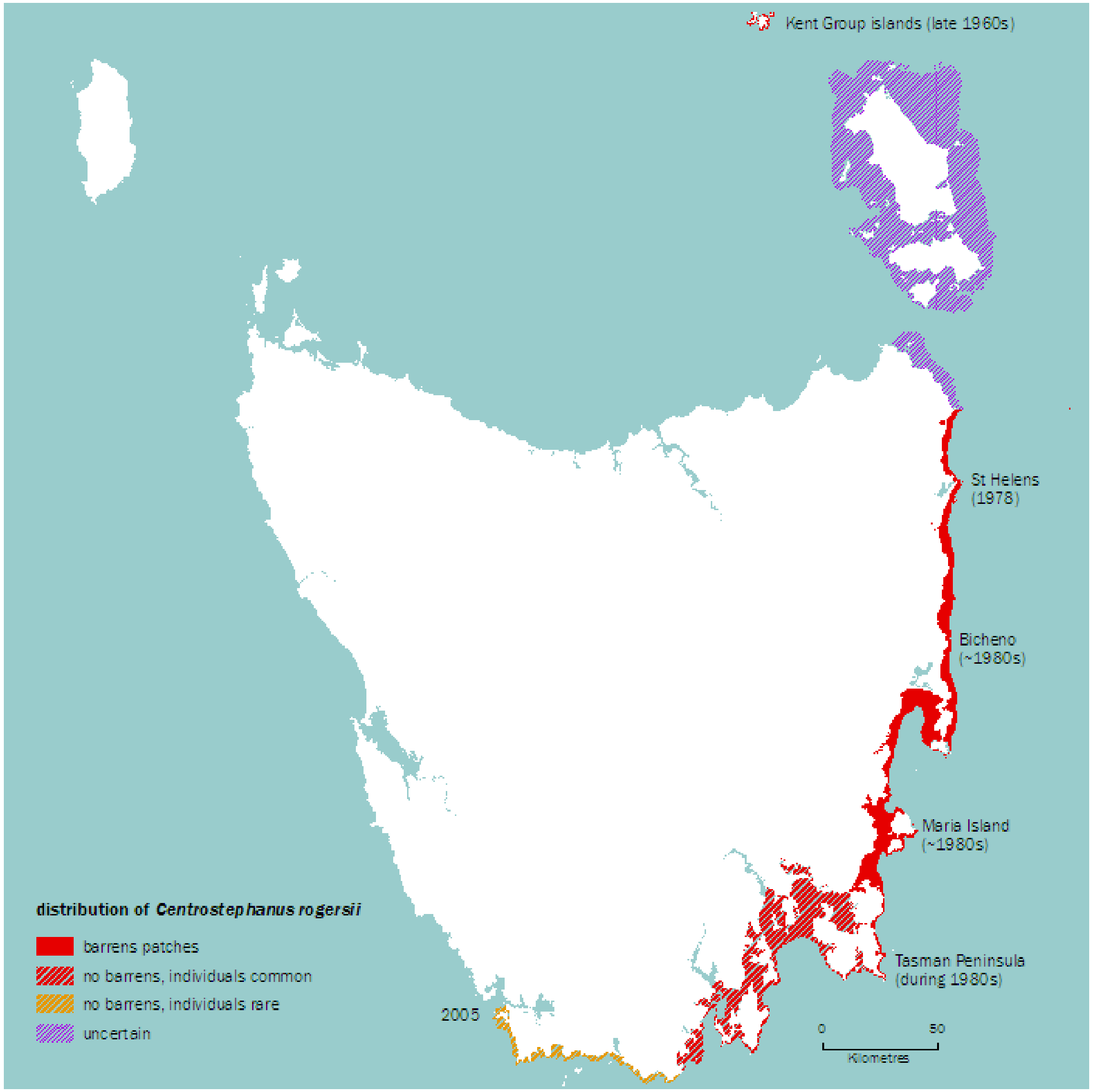
Kelp forests (Macrocystis pyrifera) off Tasmania

Neville Barrett

Spiny sea urchin
(C. rodgersii)

kelp become → urchin barrens

Impacts



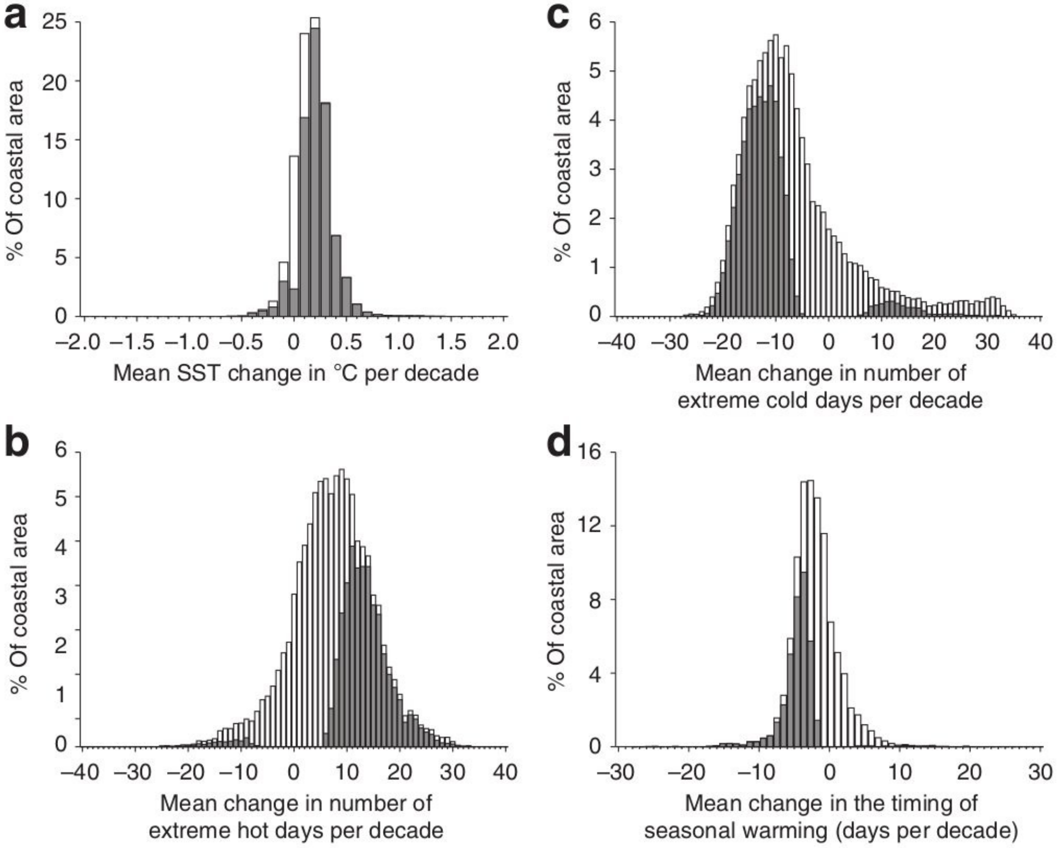
State of the Environment, Government of Tasmania

Marine Heat Waves

- Recently extreme ocean temperatures, or what may be loosely called "marine heat waves" have received some attention in the literature
- I will discuss four main "focus areas":
  - The global context
  - The 2003 European heat wave (influence on Mediterranean)
  - The 2011 Western Australia marine heat wave
  - Extreme surface temperatures off southeastern Australia

The Global Context

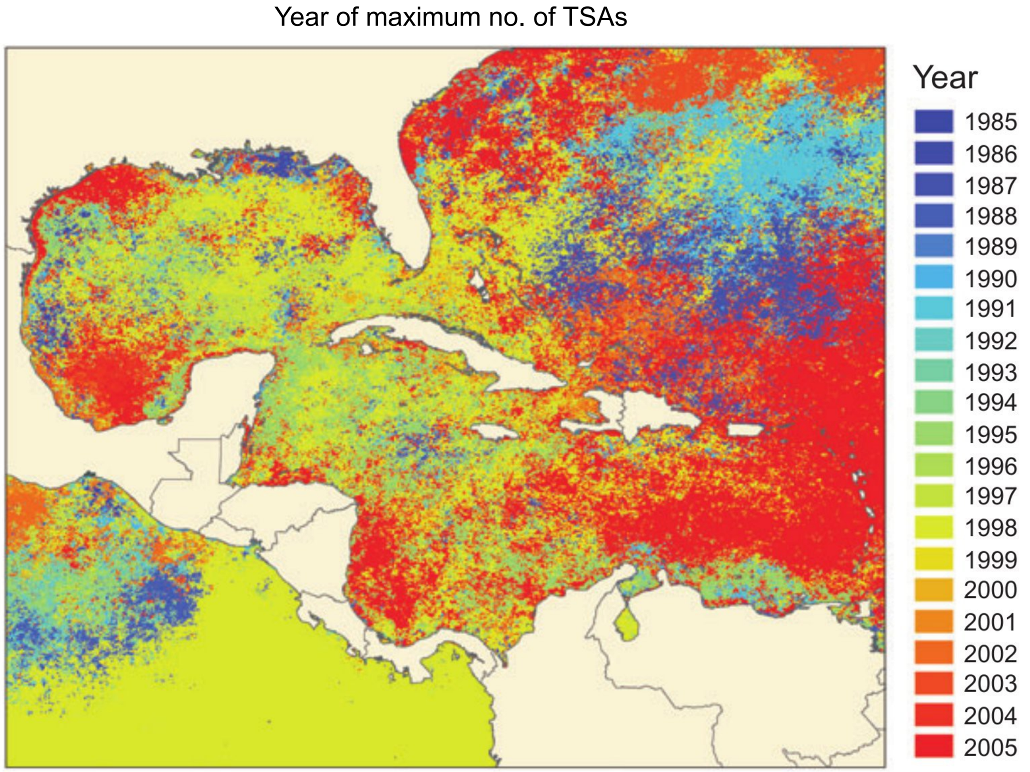
- Lima and Wethey (2012) performed an analysis of coastal marine temperatures around the globe notes that
  - linear trends vary regionally and seasonally,
  - frequencies of extremely warm and cold days vary seasonally but are generally increasing and decreasing respectively, and
  - the timing of seasonal warming is generally occurring earlier in the year.



Lima, F. P. and D. S. Wethey (2012), Three decades of high-resolution coastal sea surface temperatures reveal more than warming, *Nature Communications*, 3, 704

The Global Context

- Selig et al. (2010) examined global SST anomalies over a 21-year period and represented the data set in terms of magnitude, timing, and frequency of thermal stress anomalies (TSAs).
- TSAs are defined for each grid cell as temperatures that exceed the climatological warmest week of the year (in that grid cell).
- They showed significant regional variation in extreme ocean temperatures (as characterised by the TSAs)



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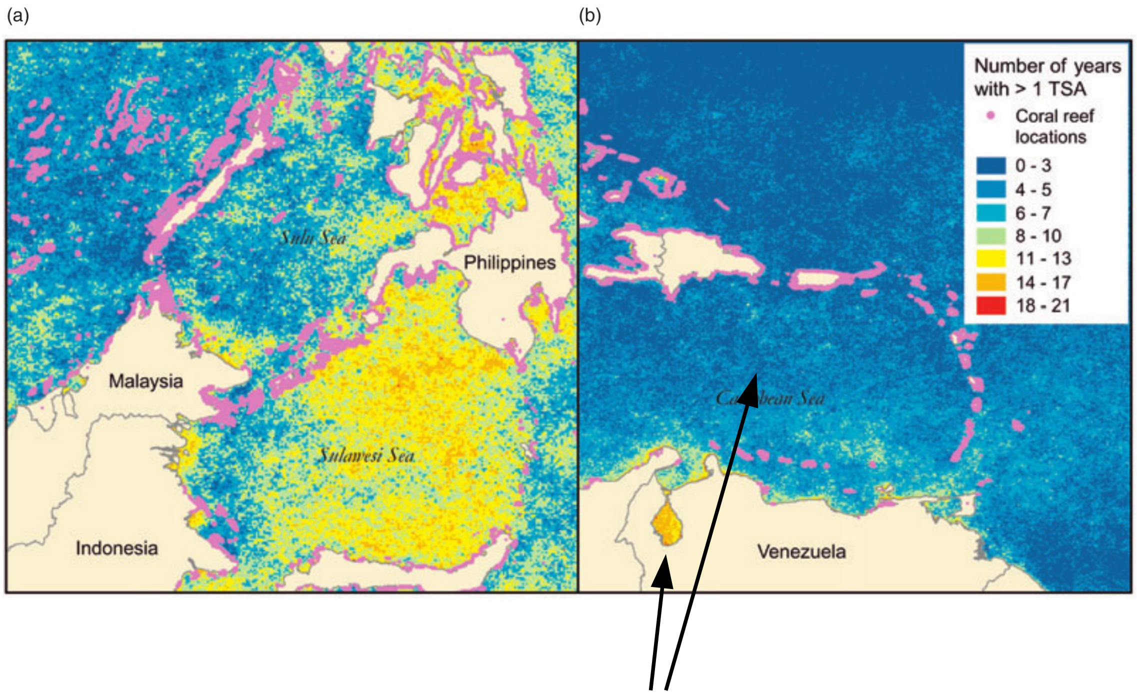

Non-homogeneous response (coastal vs. offshore)

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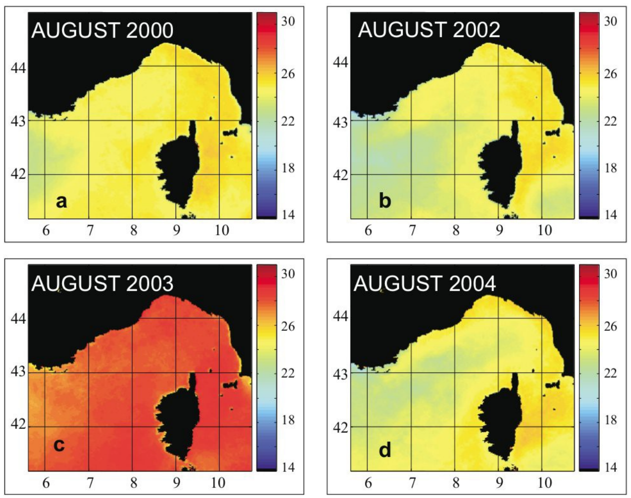
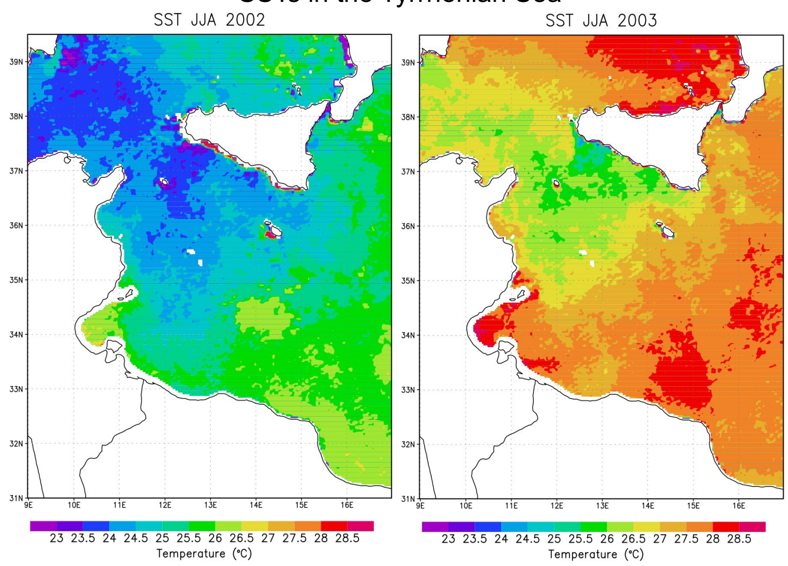
Mediterranean 2003

- In **summer 2003 a record heatwave** was experienced in Europe (particularly in France)
- Sparnocchia et al. (2006) observed that august surface temperatures in the Ligurian Sea were as high as 28-28.5^{O}C in 2003 (2-3^{O}C higher than previous summers) and homogeneous in both the central and coastal zones.
- Olita et al. (2007) noted that sea surface temperatures in the Tyrrhenian Sea were affected significantly with anomalous June SSTs of up to 2.5^{O}C (absolute SSTs over 29.5^{O}C).
- Warming was confined to the upper layers (above 20 m depth) and was in fact anomalously cold below this depth.
- This was found to be caused by anomalous heat flux: partially due to high air temperatures (the atmospheric heatwave) and partially due to low wind speeds.
- This marine heat wave as likely linked to the mass mortality in local rocky reef communities that occurred at that time (Garrabou et al., 2009).

SSTs in the Ligurian Sea



SSTs in the Tyrrhenian Sea



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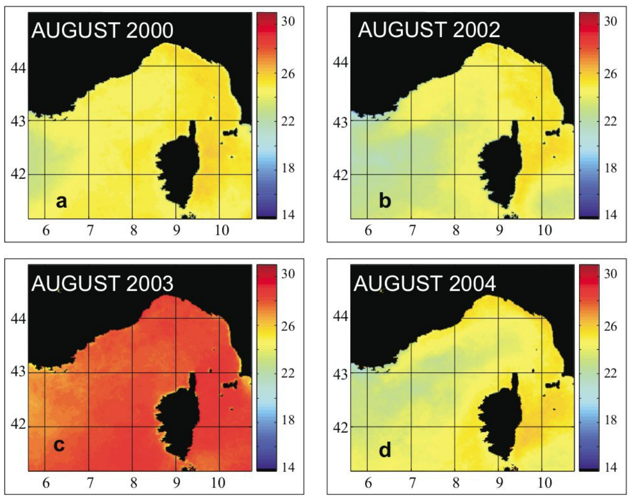

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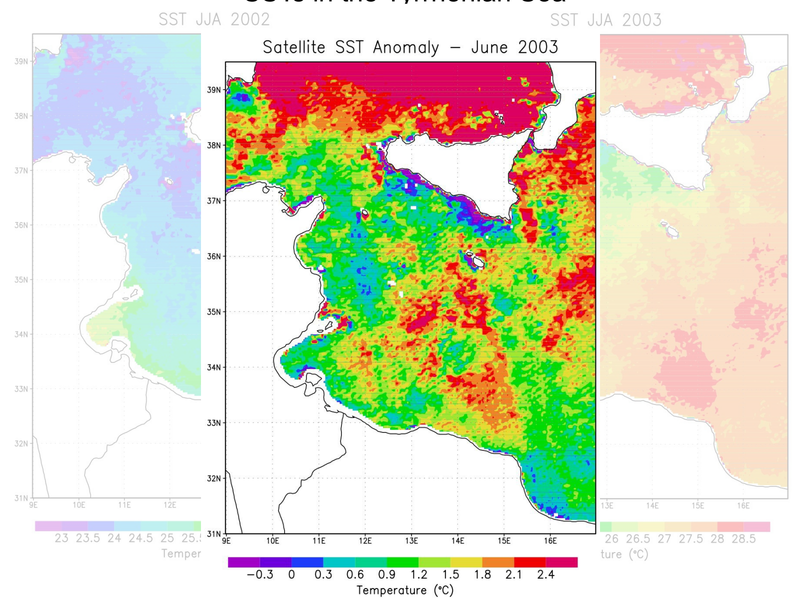

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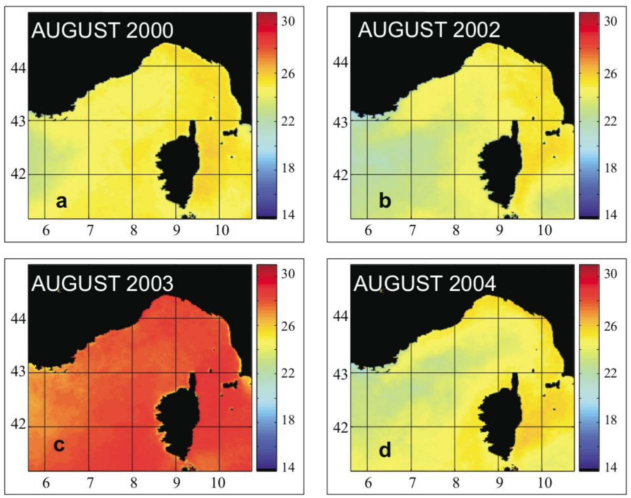
Mediterranean 2003

- In **summer 2003 a record heatwave** was experienced in Europe (particularly in France)
- Black et al. (2004) noted that the European heatwave in the summer of 2003 was coincident with anomalous SSTs in the Atlantic ocean, configured in a roughly zonal banded pattern of positive and negative anomalies. This was also coincident with record SSTs in the Mediterranean (temperatures exceeding 30^{O}C)
- Sutton and Hodson (2005) linked basin-scale changes in Atlantic Ocean (i.e., the Atlantic Multidecadal Oscillation) as a driver of summertime climate in North America and western Europe

SSTs in the Ligurian Sea



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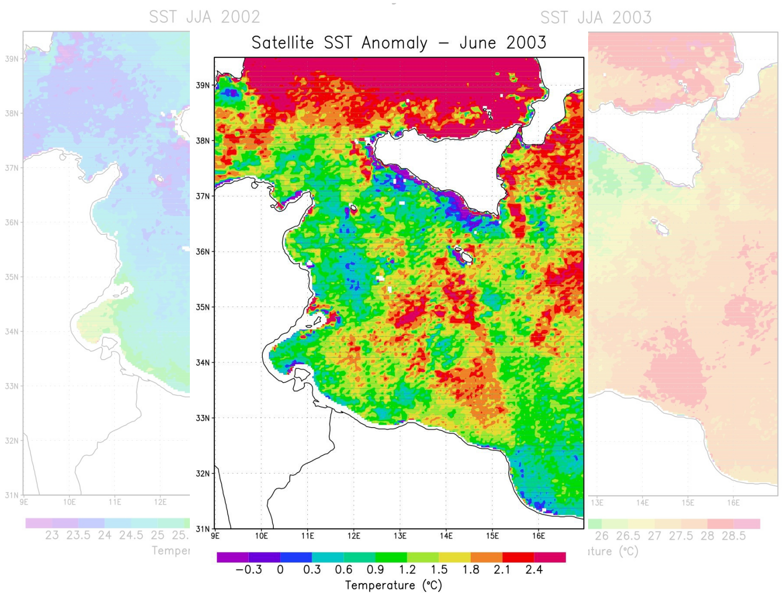

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Sutton, R. T. and D. L. R. Hodson (2005), Atlantic ocean forcing of North American and European summer climate, *Science*, 309, 115-118

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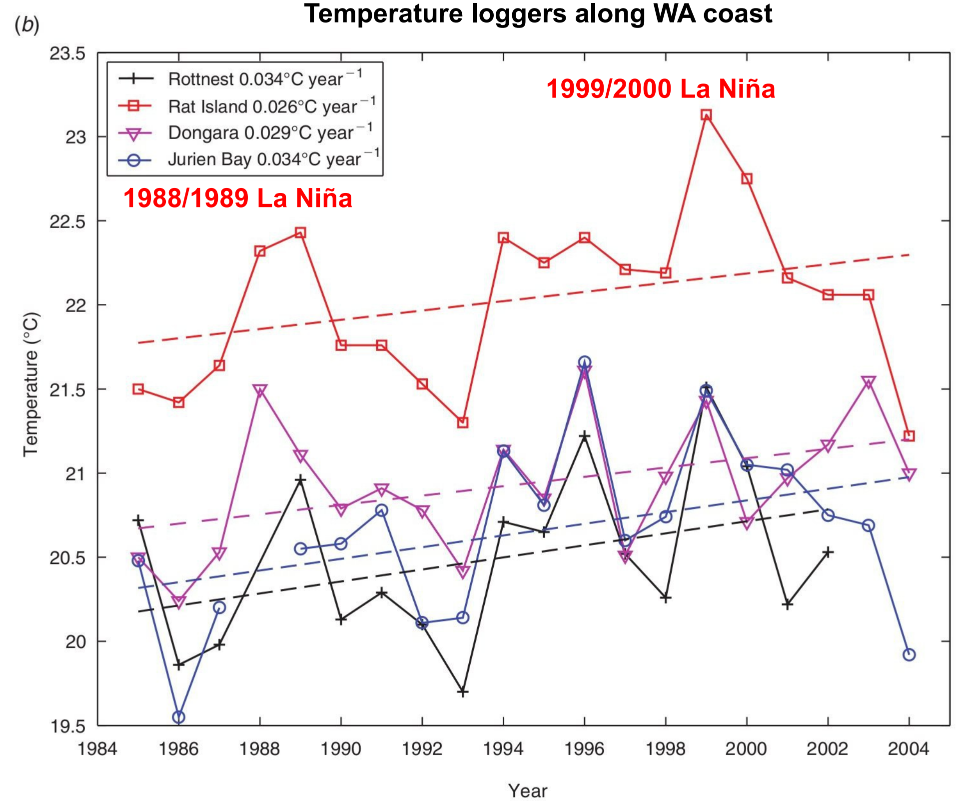
Western Australia 2011

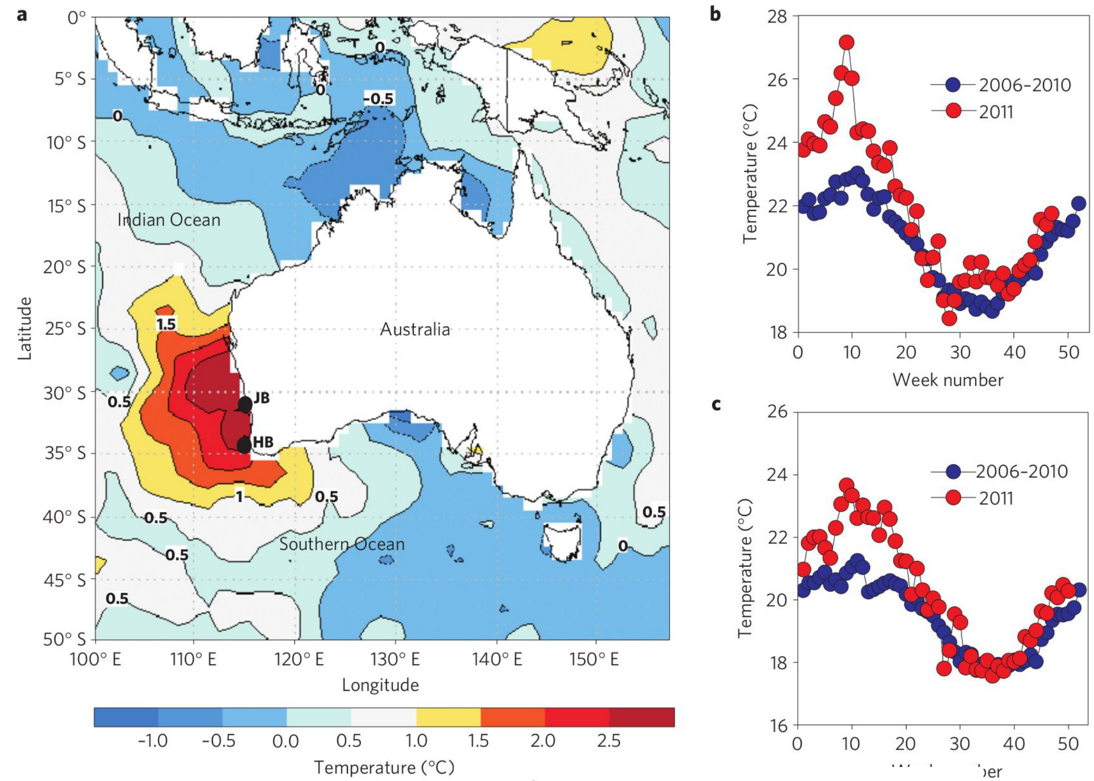
- It was noted by Pearce and Feng (2007) that coherent temperature variability at various stations along the WA coast are linked with ENSO-related events in coastal sea level and thus the Leeuwin Current.
- The implication is that during La Nina periods the Leeuwin Current is anomalously strong, transporting warmer water southwards along (and onto) the continental shelf.

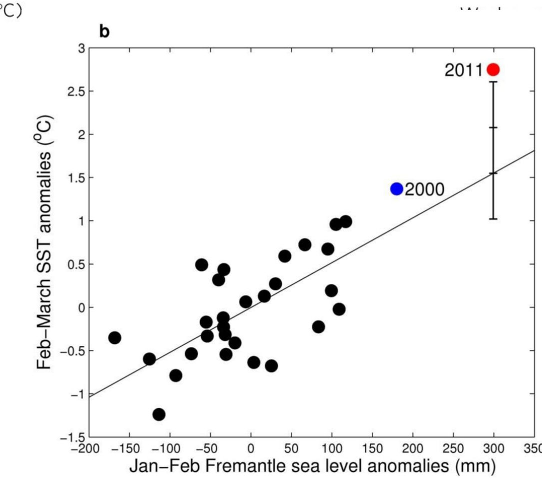


Pearce, A. and M. Feng (2007), Observations of warming on the Western Australian continental shelf, *Marine and Freshwater* Research, 58, 914-920

Western Australia 2011

- In **summer 2010/2011 an unprecedented “marine heat wave” was documented off Western Australia**
- Sea surface temperature (SST) anomalies peaked at 3^{O}C above the expected value (from the long term mean; up to 5^{O}C in some coastal regions) along a broad stretch of WA coast (from Ningaloo at 22^{O}S to Cape Leeuwin at 34^{O}S) and out to over 200 km offshore (Pearce and Feng, 2013)
- Feng et al. (2013) dubbed this type of event “Ningaloo Niño” and noted the warming was primarily due to an unseasonable surge of warm water southward along the coast due to an intensification of the Leeuwin current. This was forced remotely and associated with the near-record 2010-2011 La Nina.





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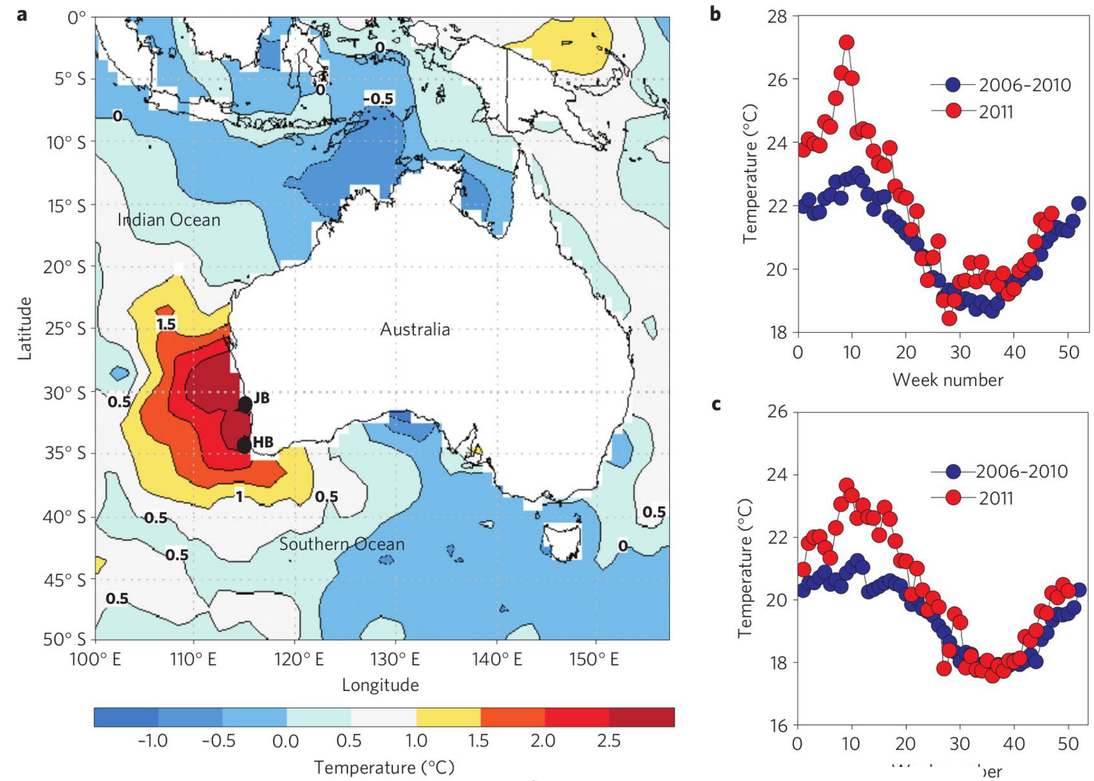

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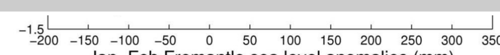
Wernberg et al. (2013) noted that this event had significant observable impacts on existing biodiversity patterns including temperate seaweeds, sessile invertebrates, and demersal fish. It led to a "**tropicalization**" of fish communities. Implication is that frequency and intensity of such events – superimposed upon a general warming trend – can have major implications for ecosystem distribution and structure.

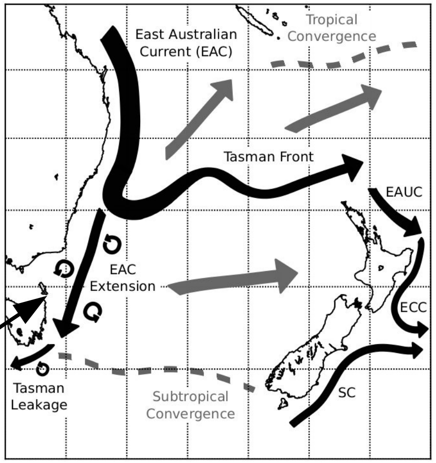


Southeastern Australia

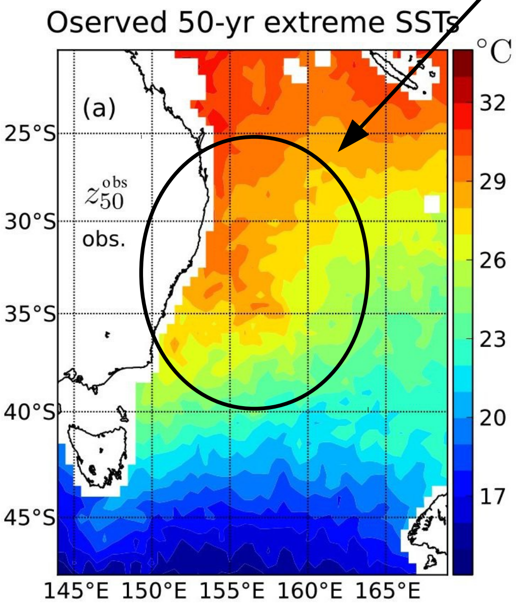
- Recently, attention has focussed on marine climate change off of SE Australia due to its magnitude (surface waters warming nearly 4 times the global average rate) and the associated risks for fragile regional marine ecosystems

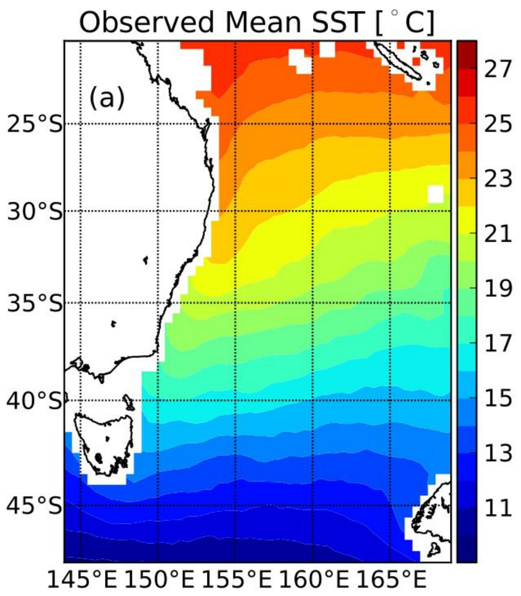
- The marine environment off southeastern Australia is highly variable due to large eddies being spun off from the separating East Australian Current

- Oliver et al. (2014a) examined extreme SSTs in this region. Mapped 50-year return period extremes indicate a clear influence of ocean eddies, in addition to the North-South gradient in mean temperature



Role of eddies in this region act to tilt contours in a nearly North-South orientation





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Southeastern Australia

- There is much interest in projections of how extreme ocean temperatures in this region may change in a changing climate
- However, climate models often provide poor estimates of extremes (atmospheric and oceanic)

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- Oliver et al. (2014b) developed a technique, a Bayesian hierarchical extremes model, to improve the (generally poor) estimates of extreme SSTs from global ocean and climate models.

Assumption: While, global ocean and climate models often poorly simulate the extremes they often do simulate the overall climate rather well (mean temperature, variability, etc...)

Model Concept: Model *observed extremes* as a function of what the models do well (*historical climate*). Then assume the model parameters are stationary in time and use a model projected *future climate* to estimate future extremes.

Crudely,

$$\text{“historical extremes”} = f(\boldsymbol{X}_{\text{hist}}, \boldsymbol{\beta}) + \epsilon$$

Where $\boldsymbol{X}_{\text{hist}}$ is the climate model historical climate. Then if we assume the model parameters ($\boldsymbol{\beta}$) do not change we can estimate the future extremes using the climate model projected climate $\boldsymbol{X}_{proj}$:

$$\text{“projected extremes”} = f(\boldsymbol{X}_{proj}, \boldsymbol{\beta}) + \epsilon$$

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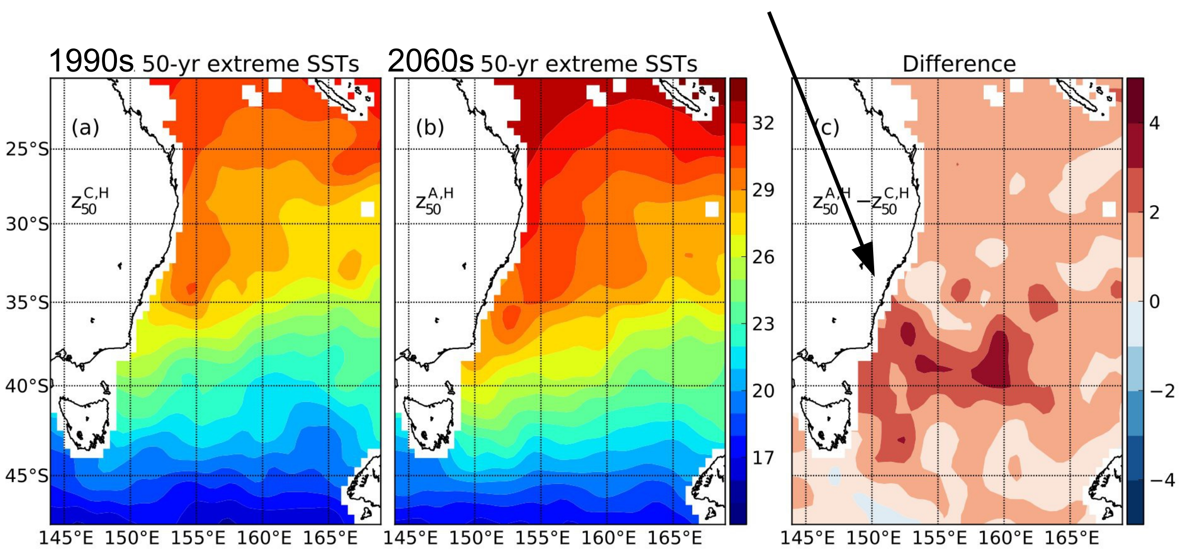
Projected change leads to increased extremes nearly everywhere but also a “hotspot” of enhanced extremes located in the southwestern Tasman Sea



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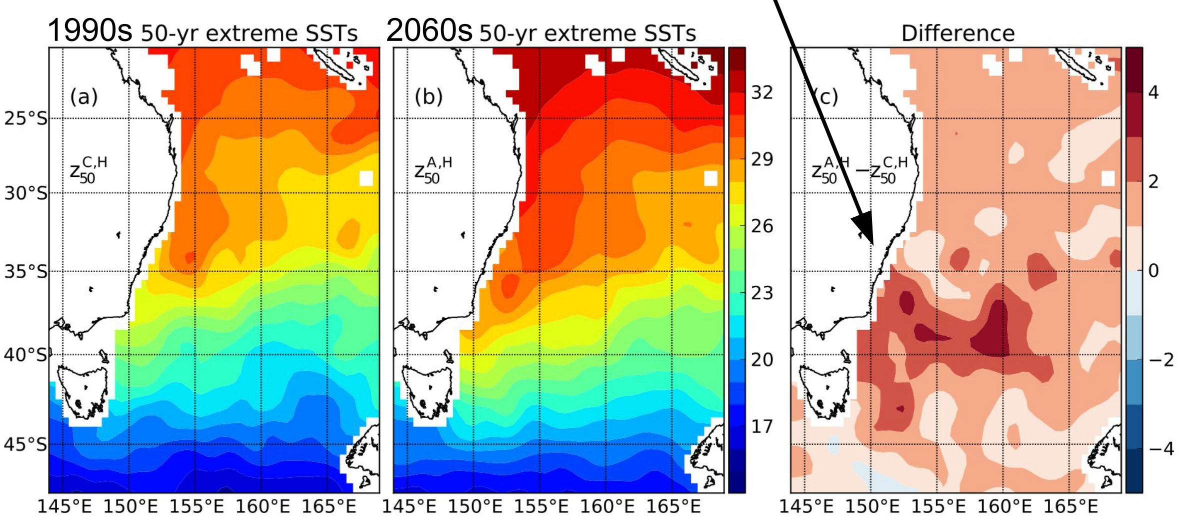

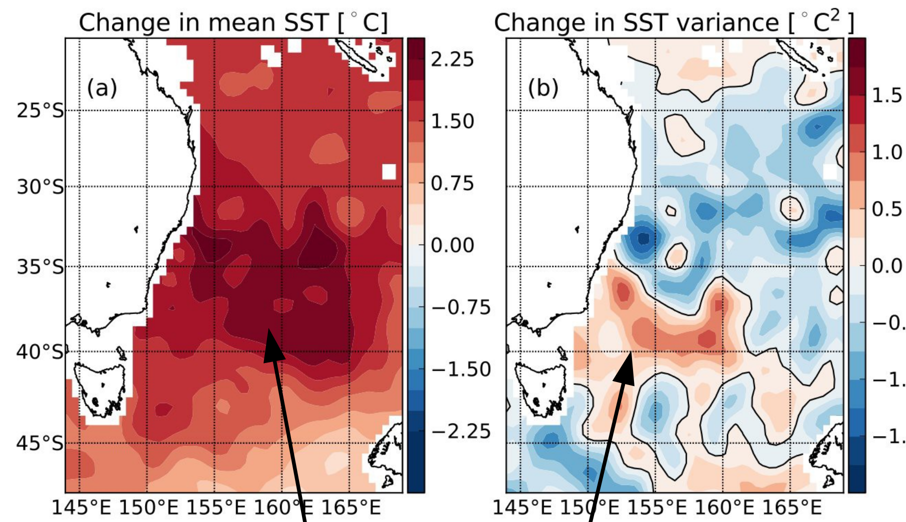

This hotspot is not colocated with the hotspot in the projected change of mean SST

The change in extreme SSTs is due to a combined effect of the change in mean and variance of SSTs

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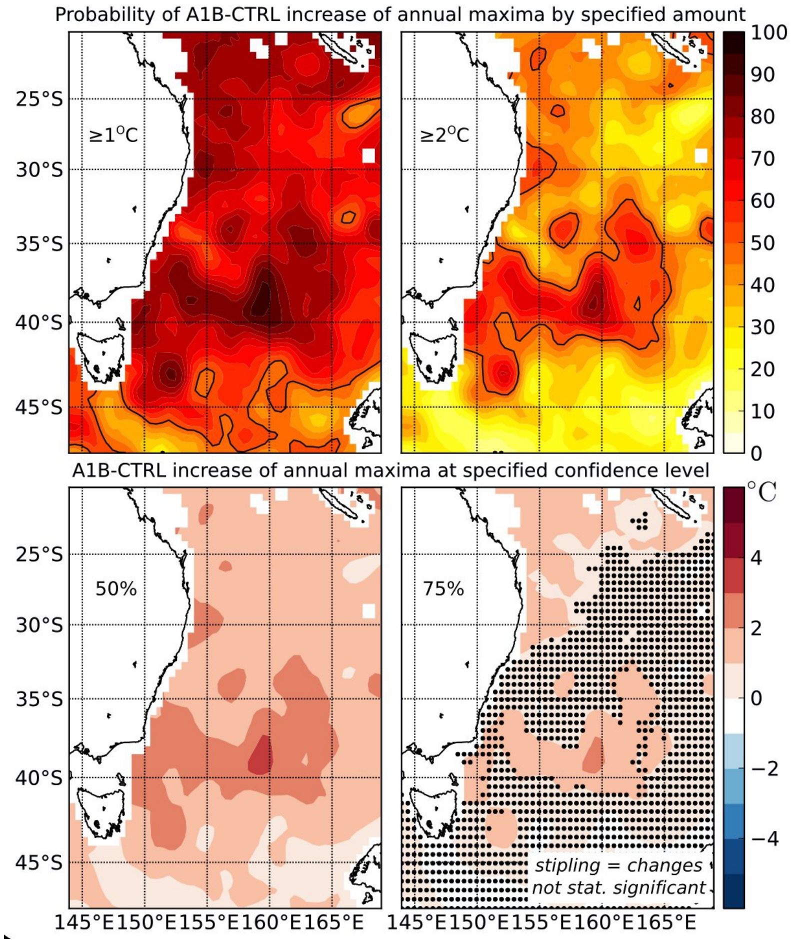
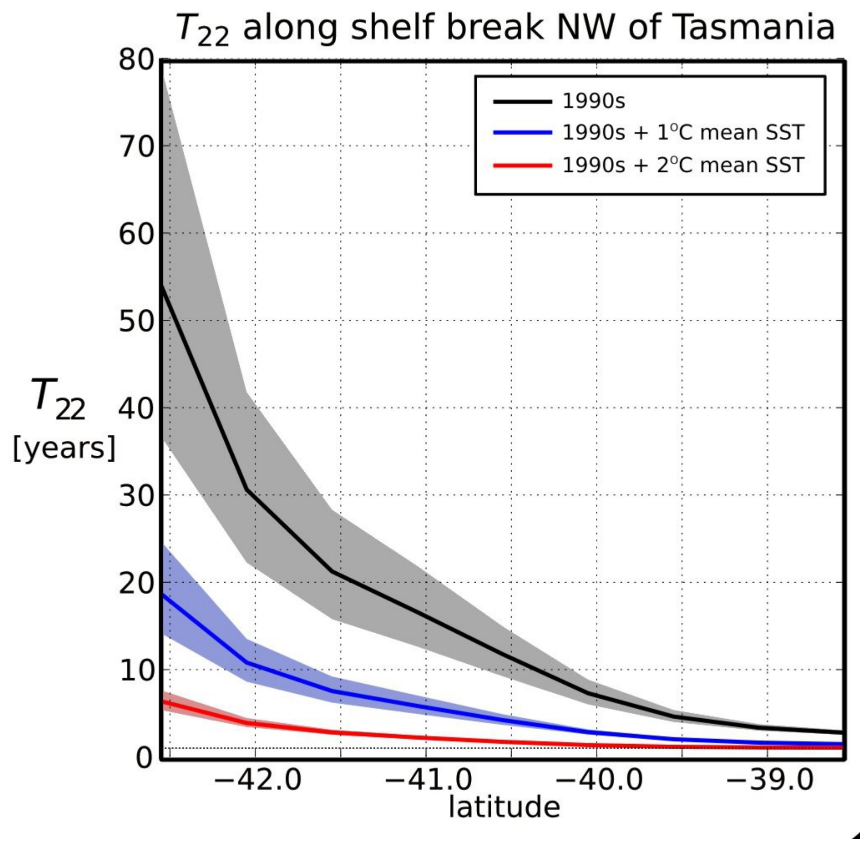
- Due to the probabilistic (Bayesian) nature of the model we are able to assign probabilites (and confidence) to the model projections:



- We are not restricted to model simulated climates, and can in fact test the response of the extremes to specified climates, i.e., and constant increase in mean temperature



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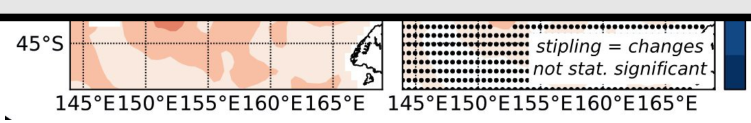
This technique is not limited to the case shown here: SSTs off southeastern Australia

It is a **general technique** that can be used to improve estimates of extremes from global ocean and climate models provided you have:

i) realistic estimates of historical extremes (i.e., observations)
ii) model estimates of historical and projected climates



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Australian Marine Heat Waves

IMAS INSTITUTE FOR MARINE AND ANTARCTIC STUDIES

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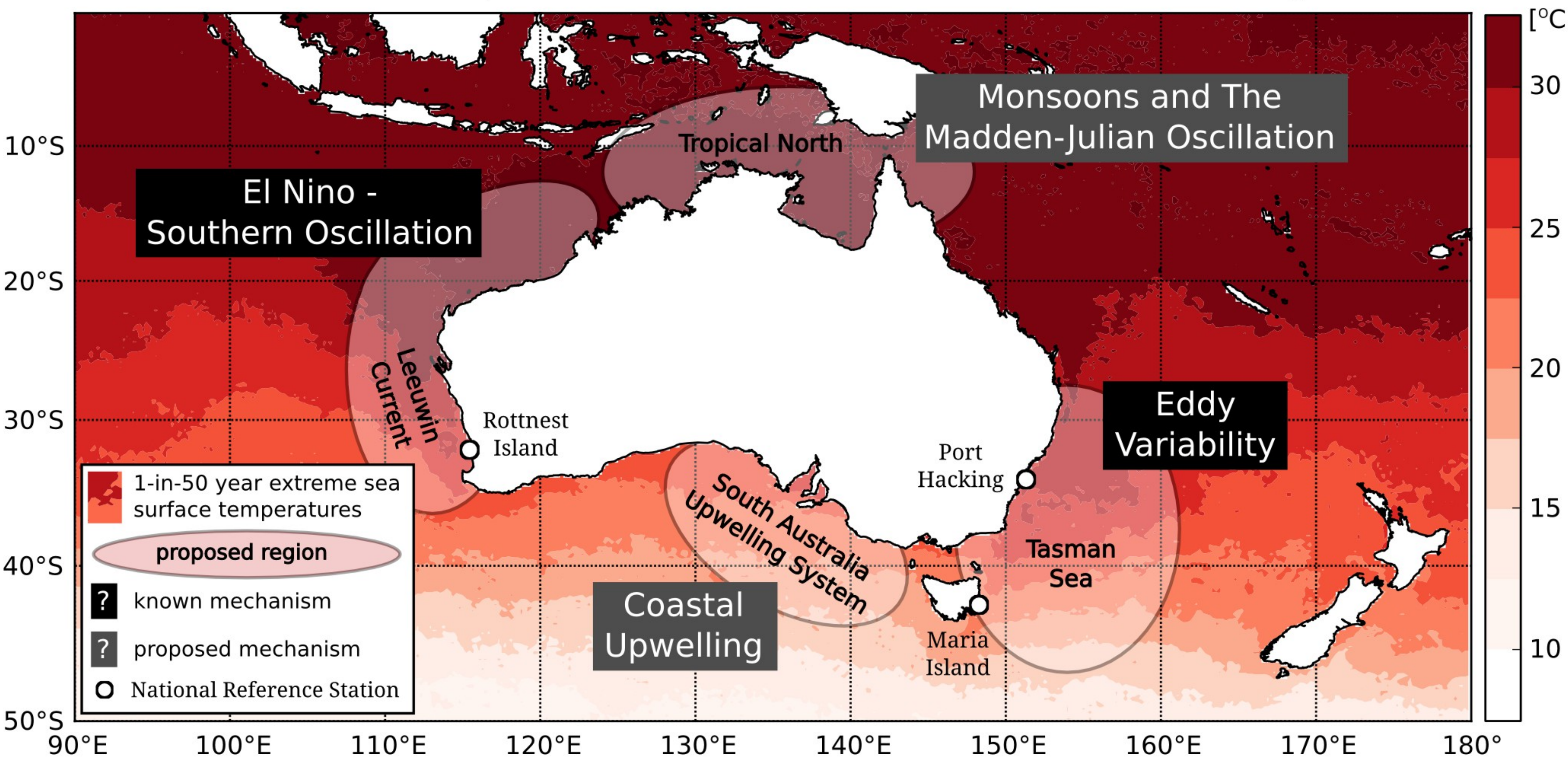
Extreme sea surface temperatures around Australia and their driving mechanisms



Thank You

- The study of marine heat waves are rapidly being recognized as important, esp. in a changing climage, and is a growing field
- Understanding marine heat waves are very important for managing the health of our fragile marine ecosystems as well as aquaculture and fisheries industries
- Existing work is quite limited, mostly confined to the last 1-2 decades, with focus being either globally, the Mediterranean, or around Australia (excl. coral reef studies)

ARC CENTRE OF EXCELLENCE FOR CLIMATE SYSTEM SCIENCE

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Extreme!