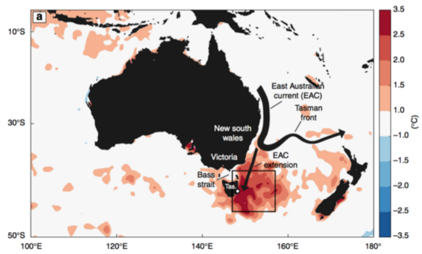
climate extremes
ARC centre of excellence

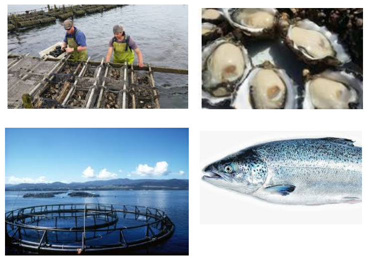
UNIVERSITY of TASMANIA | IMAS INSTITUTE FOR MARINE & ANTARCTIC STUDIES

Heatwaves in the sea – really?

Neil Holbrook

CLEX RP2.4:
Co-CIs: Lisa Alexander (UNSW), Andy Hogg (ANU), Michael Reeder (Monash)
PIs: Stephen Griffies (GFDL), Simon Marsland (CSIRO) | Res Assoc: Gabriela Pilo (UTAS)
Participants: Interested people!





Some Definitions

Heatwave – UK Met Office
*"A **heatwave** is an extended period of hot weather relative to the expected conditions of the area at that time of year."*

World Meteorological Organisation guidance …
"A marked unusual hot weather (Max, Min and daily average) over a region persisting at least two consecutive days during the hot period of the year based on local climatological conditions, with thermal conditions recorded above given thresholds."

https://www.metoffice.gov.uk/learning/temperature/heatwave

Explainer: what is a marine heatwave? [BoM Social Explainer]
07 June 2018
"Marine heatwaves happen when sea temperatures are warmer than normal for an extended period. Warmer waters for swimming and surfing—what's not to like? Unfortunately, quite a lot. The effect on marine life and the aquaculture industry can be devastating."

http://media.bom.gov.au/social/blog/1760/explainer-what-is-a-marine-heatwave/

Coral bleaching from persistent temperature extremes

2016 bleaching
[Princess Charlotte Bay]

Clonal staghorn corals failed to recover from 1998 bleach
[Orpheus Island]

2016 bleaching
[Lizard Island]

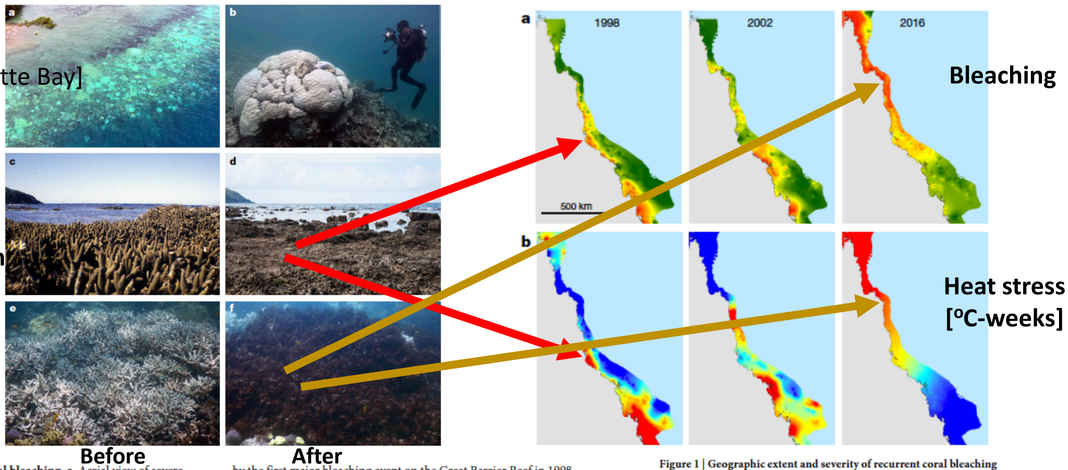
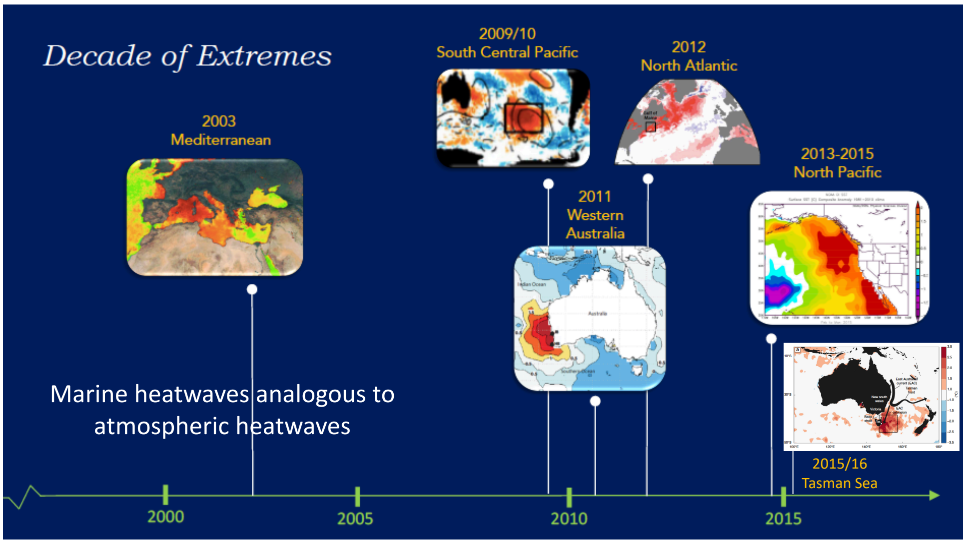


Figure 2 | Recurrent severe coral bleaching. a, Aerial view of severe bleaching in Princess Charlotte Bay, northeast Australia, March 2016. Close to 100% of corals are bleached on the reef flat and crest. Bleaching occurs when algal symbionts (*Symbiodinium* spp.) in a coral host are killed by environmental stress, revealing the white underlying skeleton of the coral. **b**, Severe bleaching in 2016 on the northern Great Barrier Reef affected even the largest and oldest corals, such as this slow-growing *Porites* colony. **c**, Large, old beds of clonal staghorn corals, *Acropora pulchra*, on Orpheus Island, Queensland photographed in 1997 were killed by the first major bleaching event on the Great Barrier Reef in 1998. **d**, Eighteen years later in May 2016, corals at this site have never recovered, with the original assemblages still visible as dead, unconsolidated and muddy rubble that is unsuitable for successful colonization by coral larvae. **e**, **f**, Mature stands of clonal staghorn corals were extirpated by heat stress and colonized by algae over a period of just a few weeks in 2016 on Lizard Island, Great Barrier Reef. Before (**e**) and after (**f**) photographs were taken on 26 February and 19 April 2016. Photo credits: **a**, J.T.K.; **b**, J. Marshall; **c**, B.W.; **d**, C.Y.K.; **e**, **f**, R. Streit.

Figure 1 | Geographic extent and severity of recurrent coral bleaching at a regional scale, Australia. a, The footprint of bleaching on the Great Barrier Reef in 1998, 2002 and 2016, measured by extensive aerial surveys: dark green (<1% of corals bleached), light green (1–10%), yellow (10–30%), orange (30–60%), red (>60%). The number of reefs surveyed in each year was 638 (1998), 631 (2002), and 1,156 (2016). **b**, Spatial pattern of heat stress (DHWs; °C-weeks) during each mass-bleaching event. Dark blue indicates 0 DHW, and red is the maximum DHW for each year (7, 10 and 16, respectively). Orange and yellow indicate intermediate levels of heat exposure on a continuous scale. **c**, Frequency distribution

Hughes et al., 2017: Global warming and recurrent mass bleaching of corals. *Nature*, **543**, 373-378, doi:10.1038/nature21707

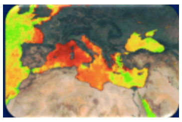
Recent history/timeline

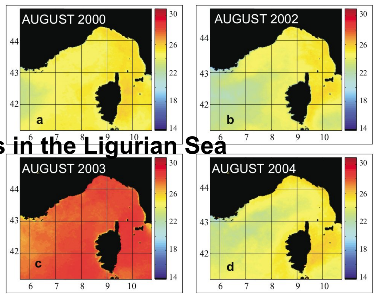


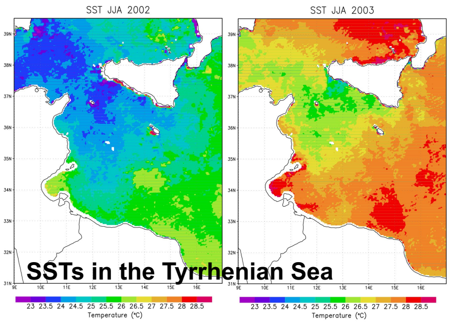
Modified after presentation by Hillary Scannell (2017)

2003 Mediterranean Sea marine heatwave

- In **summer 2003** a **record heatwave** was experienced in **Europe!**
  => Mediterranean Sea
- **Ligurian Sea** SST 28^{O}-28.5^{O}C (August) **2-3^{O}C higher** than previous summers (Sparnocchia et al. 2006)
- **Tyrrhenian Sea** >29.5^{O}C, **June SST anomaly ~2.5^{O}C** (Olita et al. 2007)
- Warming in upper layers (<20 m depth), anomalously cold below this depth
- Cause: **anomalous air-sea heat flux**: *high air temperatures* (the atmospheric heatwave) and *low wind speeds*
- This **marine heatwave (MHW)** linked to mass mortality of **rocky reef communities** (Garrabou et al. 2009)



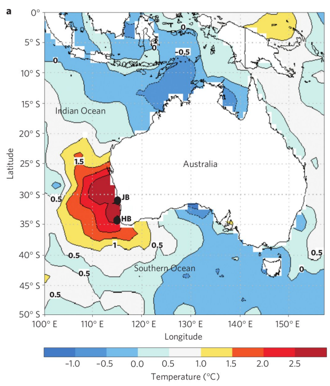


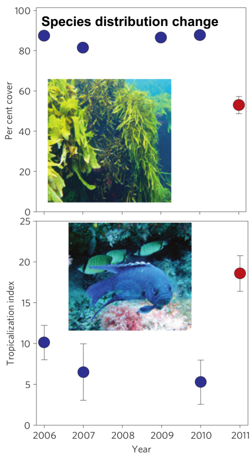


Sparnocchia et al. (2006)
Olita et al. (2007)
Garrabou et al. (2009)

2011 Western Australia marine heatwave

- In **summer 2010/2011** an unprecedented **marine heatwave** documented off **Western Australia (WA)**
- SSTA **~3^{O}C above seasonal values** along WA coast (Ningaloo at 22^{O}S to Cape Leeuwin at 34^{O}S) and >200 km offshore (Pearce & Feng 2013)
- Feng et al. (2013) identified event as a **"Ningaloo Niño"**
  => warming due to warm water surge south along the coast due to Leeuwin current
- Remotely forced via near-record 2010/11 **La Niña** and **regional wind changes**

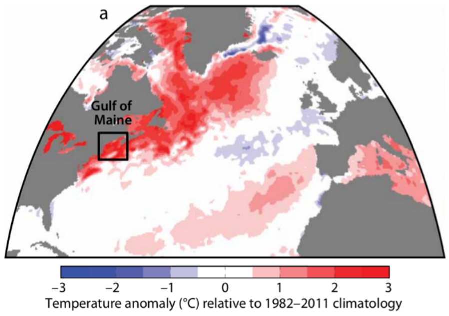


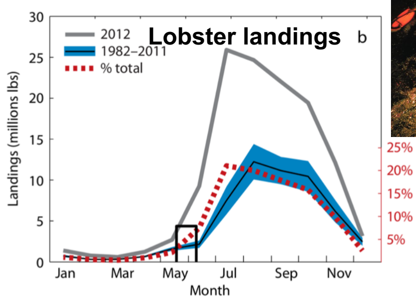


Wernberg et al. (2013) noted significant observable impacts on biodiversity including temperate seaweeds, sessile invertebrates, and demersal fish
=> "**tropicalization**" of fish communities

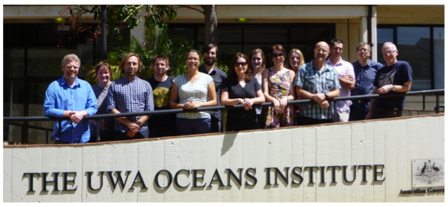
2012 Northwest Atlantic marine heatwave

- In **Boreal summer 2012**, the **northwest Atlantic** also experienced a **heatwave**
- SST anomalies peaked at 3°C above seasonal value along a stretch of eastern Canada and USA (Mills et al. 2013)
- Linked to **atmospheric warming** and anomalous position of the **Gulf Stream**
- Dramatic impact on **lobster fishery**:
  - Lobster fishery season peaked early
  - Increased catch sizes lowered price
  - Processing plants were flooded
  - Increased Canada-US economic tensions





Marine Heatwave Definition



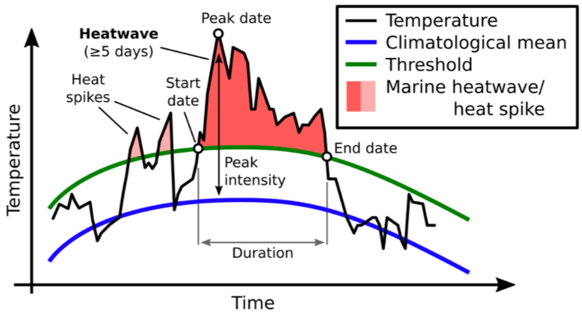
- The definition of a **marine heatwave**:

A prolonged discrete anomalously warm water event in a particular location

persistence for at least five days

well-defined start and end dates

warmer than 90th percentile in a 30-yr baseline climatology



http://www.marineheatwaves.org/all-about-mhws.html

Hobday et al. (2016) *Progress in Oceanography,* **141**, 227-238 AND **www.marineheatwaves.org**

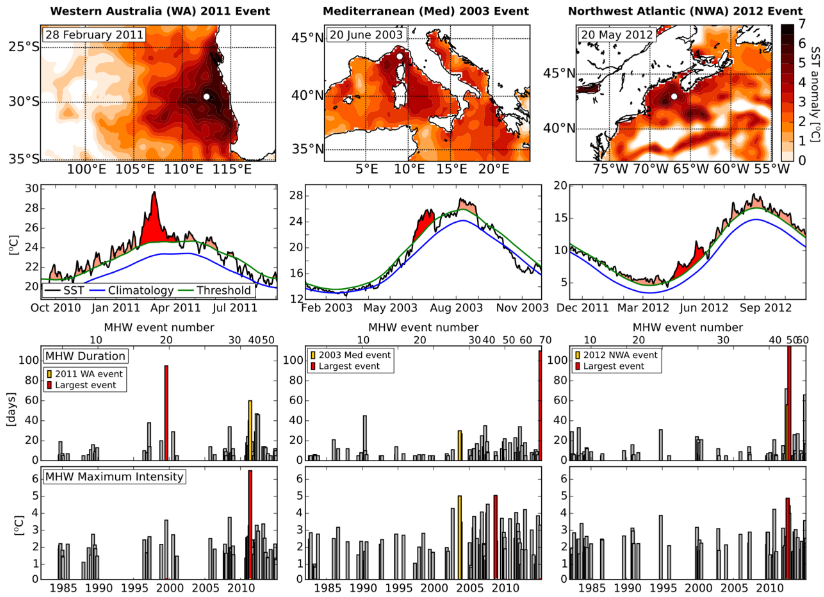
Marine Heatwave Characteristics and Historical Trends

Can **identify, re-examine and quantify historical events** in the observational record

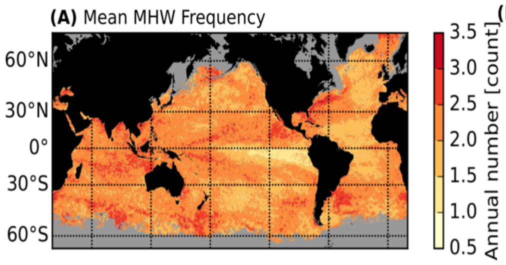
(satellite SST measurements: NOAA OI SST)

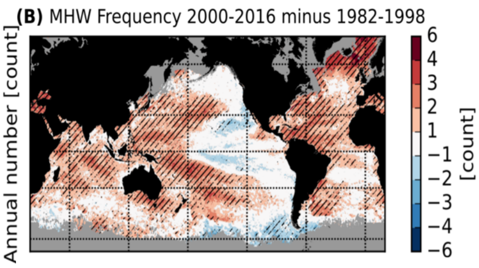
Duration

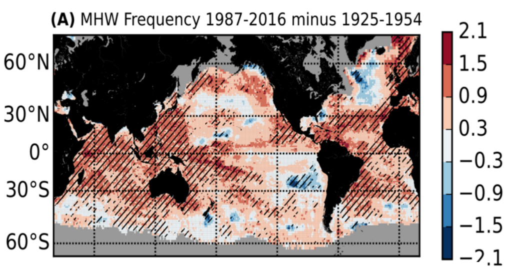
Max Intensity

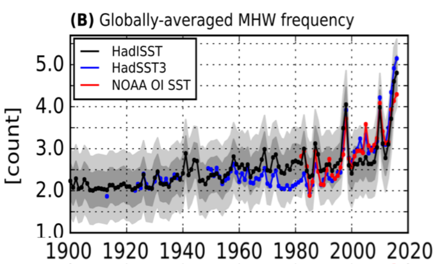


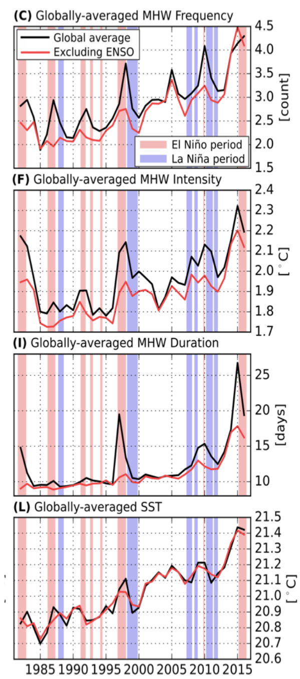
Trends in marine heatwaves











Oliver ECJ et al. (2018) *Nature Communications*, DOI:10.1038/s41467-018-03732-9.

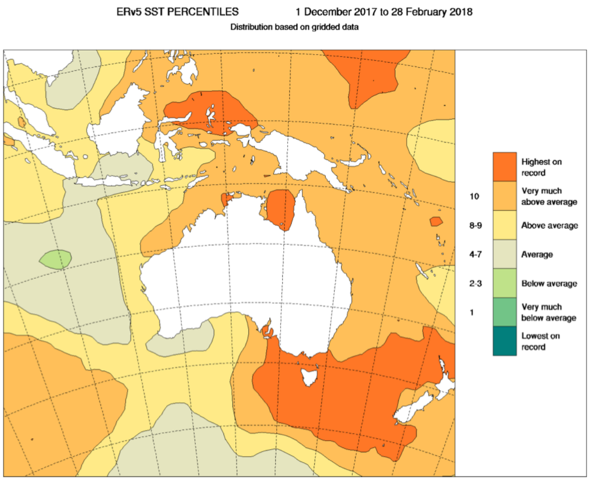
Drivers of marine heatwaves [BoM Social Explainer]

What causes them?

“Like heatwaves over land, heatwaves in the ocean come about from a mix of factors.

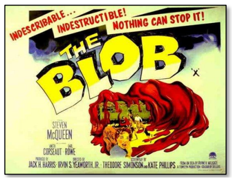
On sunny days, **sunlight passes through the atmosphere and heats the surface of the ocean**. If there are weak winds this warm water doesn't mix with the cooler waters below; it sits on top and continues to heat. Such warming can be local (such as when a high-pressure system remains slow-moving for an unusual period of time), or large scale, covering much of an ocean basin, as can occur during El Nino / La Nina events.

Another contributor to marine heatwaves is **warm water moving from one location to another (cooler) location**. Ocean currents vary over time and can wiggle around, speed up and slow down, and replace colder water with warmer water.”



http://media.bom.gov.au/social/blog/1760/explainer-what-is-a-marine-heatwave/

2014/15 NE Pacific MHW (‘The Blob’)



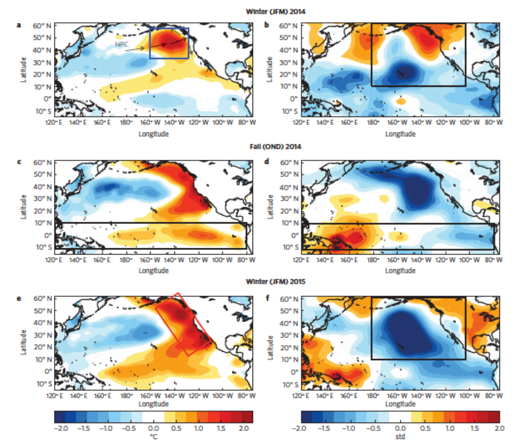


Figure 1 | Evolution of seasonal NOAA SSTa and NCEP SLPa during 2014 and 2015. a,b, January–February–March (JFM) 2014 SSTa and SLPa, respectively. **c,d**, October–November–December (OND) 2014 SSTa and SLPa, respectively. **e,f**, JFM 2015 SSTa and SLPa, respectively. The blue box in **a** denotes region used to compute the GOA SSTa index. The red box in **e** denotes region used to compute the ARC SSTa index. The mean position and direction of the North Pacific Current (NPC) and gyre circulation in the North Pacific Ocean is indicated with the grey arrows in panel **a**. Std: units of standard deviation.

Evolution of the North Pacific Warm Anomaly 2014–2015

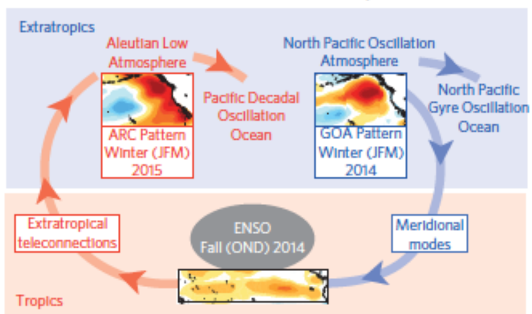


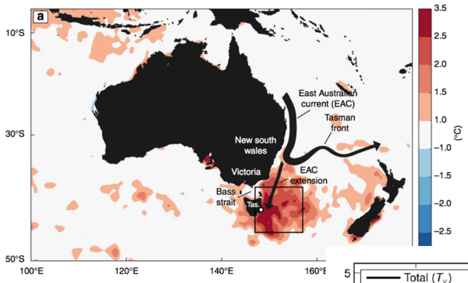
Figure 4 | Climate hypothesis to explain the generation, evolution and persistence of the North Pacific warm anomaly between the winters of 2013/14 and 2014/15.

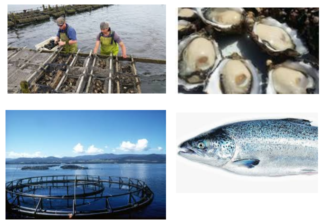
Di Lorenzo E and N Mantua (2016) *Nature Climate Change*, DOI:10.1038/NCLIMATE3082.

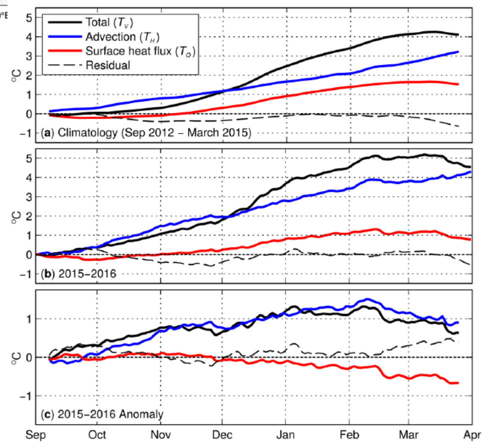
The 2015/16 Tasman Sea MHW

- Longest and most intense MHW on record in the region
- Commenced 9 Sep 2015 and ended on 16 May 2016
- Duration 251 days (>8 mths!)
- Maximum intensity of 2.9°C

- Profound impacts on marine ecosystem and economy, e.g. Pacific oyster, blacklip abalone and farmed Atlantic salmon







Oliver et al. (2017) *Nature Communications*, **8**, 16101.

Subsurface intensification of marine heatwaves

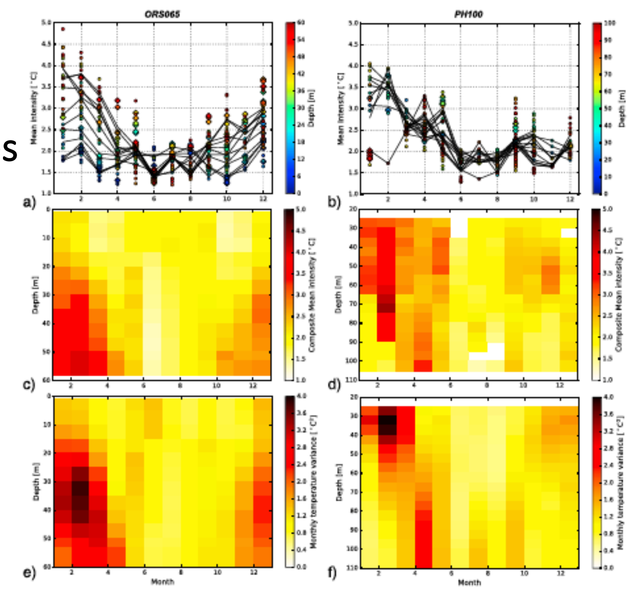
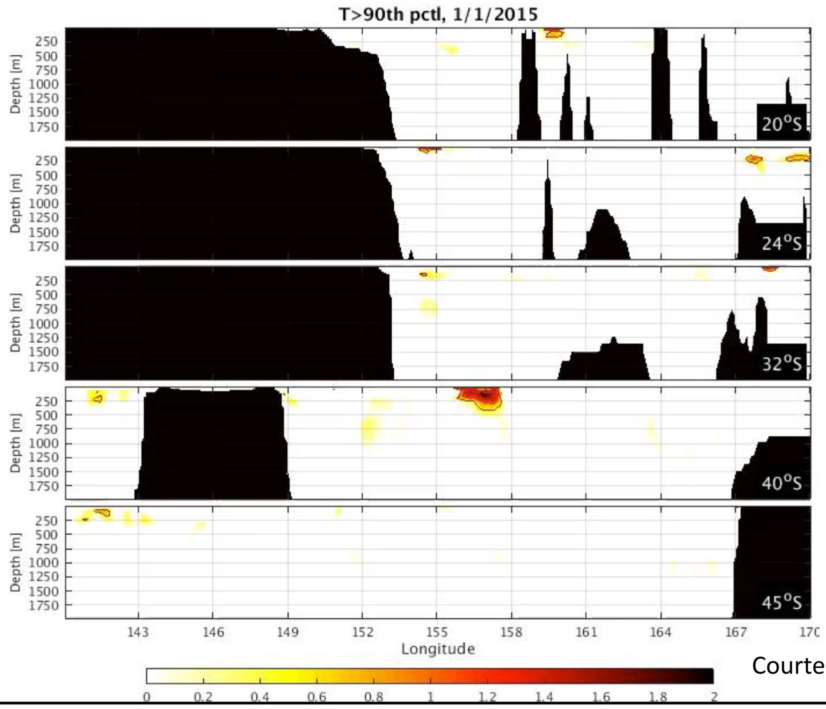


Figure 4. Mean intensity of MHW events as a function of their start month at (a) ORS065 and (b) PH100. Colors show the depth of the event, solid lines link the composite values for each depth and month. Diamonds refer to long events (> 10 days). Composite mean intensity during MHWs binned by depth and month at (c) ORS065 and (d) PH100. White cells show depths and months with no events. Temperature variance over the climatological period binned by depth and months at (e) ORS065 and (f) PH100.

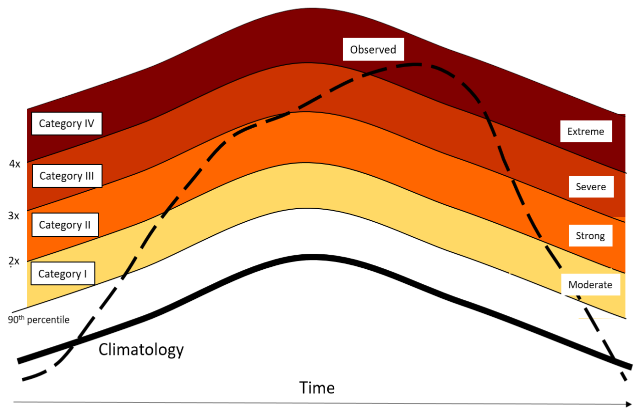
Schaeffer and Roughan (2017)



Courtesy of Gabriela Pilo

Categorising Marine Heatwaves

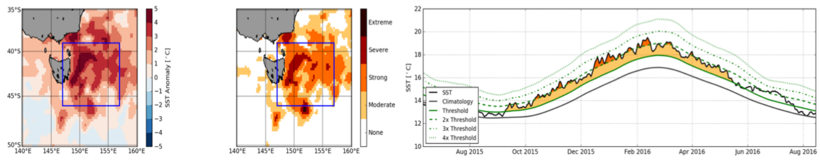
Categories



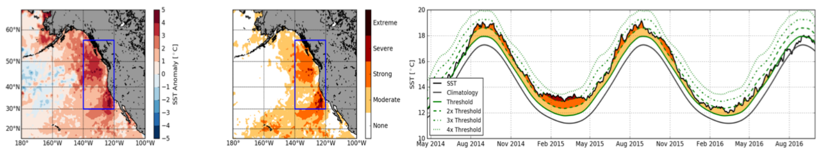
Hobday et al. (2018) *Oceanography,* **31**(2), DOI:10.5670/oceanog.2018.205.

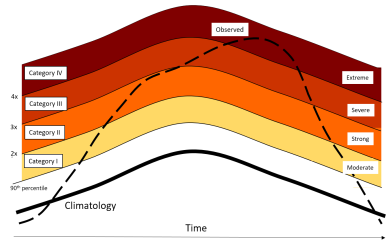
Categorising Marine Heatwaves

Tasman Sea 2015/16



Northeast Pacific 2014-16





Hobday et al. (2018) *Oceanography,* **31**(2), DOI:10.5670/oceanog.2018.205.

Process-based understanding of marine heatwaves & marine cold spells

Can we identify mechanisms for subsurface marine heatwaves (MHWs)?

How important is model resolution to the timing, intensity, frequency and duration of MHW and marine cold spell (MCS) events?

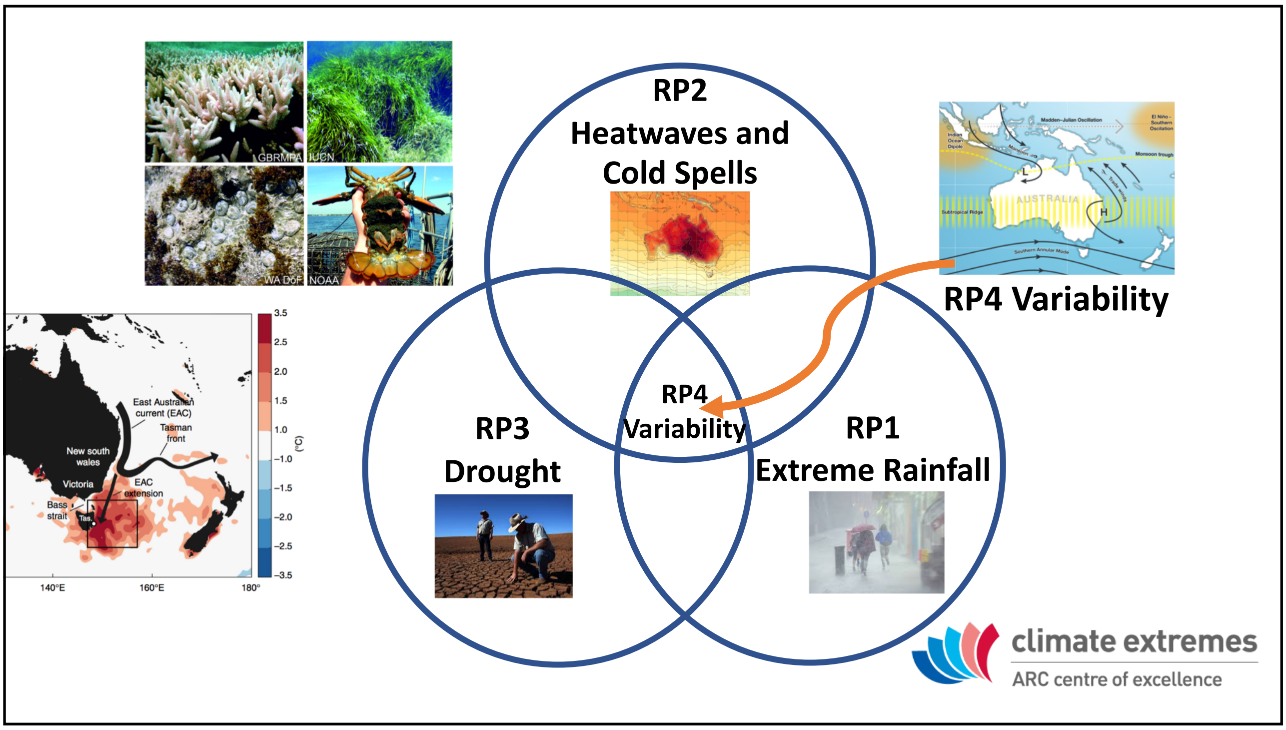
ACCESS-OM2, ACCESS-OM-025, ACCESS-OM-01 [Hogg, Kiss, Holbrook]

What physical processes cause MHWs and MCSs around Australia?

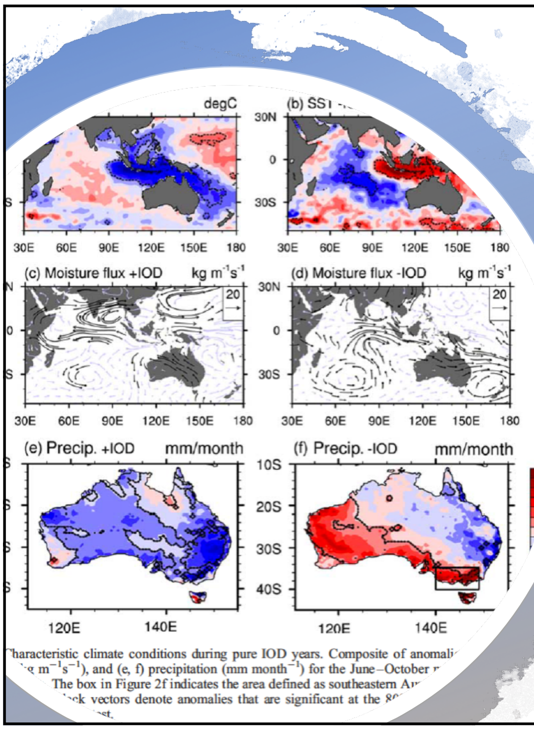
Which processes can be targeted to improve MHW/MCS predictability?

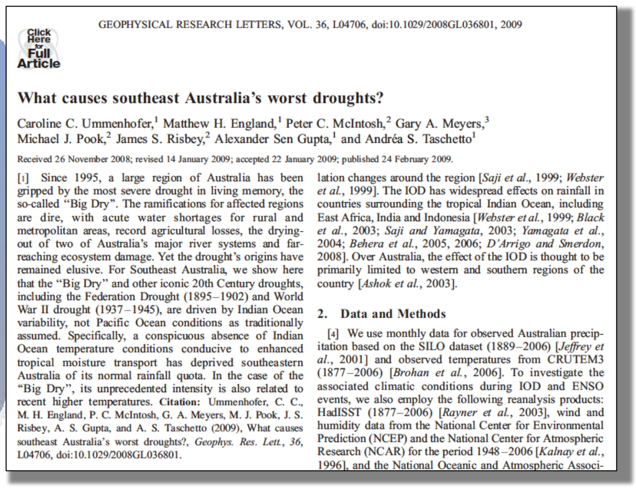
E.g. eddies, oceanic Rossby waves, etc.

What processes cause high intensity or long duration MHW or MCS events?



Andrea: "The ocean is important for everything …"
[Mon 19 Nov 2018 @ CLEX workshop]




GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L04706, doi:10.1029/2008GL036801, 2009

Click Here for Full Article

What causes southeast Australia's worst droughts?

Caroline C. Ummenhofer,[1] Matthew H. England,[1] Peter C. McIntosh,[2] Gary A. Meyers,[3] Michael J. Pook,[2] James S. Risbey,[2] Alexander Sen Gupta,[1] and Andréa S. Taschetto[1]

Received 26 November 2008; revised 14 January 2009; accepted 22 January 2009; published 24 February 2009.

[1] Since 1995, a large region of Australia has been gripped by the most severe drought in living memory, the so-called "Big Dry". The ramifications for affected regions are dire, with acute water shortages for rural and metropolitan areas, record agricultural losses, the drying-out of two of Australia's major river systems and far-reaching ecosystem damage. Yet the drought's origins have remained elusive. For Southeast Australia, we show here that the "Big Dry" and other iconic 20th Century droughts, including the Federation Drought (1895–1902) and World War II drought (1937–1945), are driven by Indian Ocean variability, not Pacific Ocean conditions as traditionally assumed. Specifically, a conspicuous absence of Indian Ocean temperature conditions conducive to enhanced tropical moisture transport has deprived southeastern Australia of its normal rainfall quota. In the case of the "Big Dry", its unprecedented intensity is also related to recent higher temperatures. **Citation:** Ummenhofer, C. C., M. H. England, P. C. McIntosh, G. A. Meyers, M. J. Pook, J. S. Risbey, A. S. Gupta, and A. S. Taschetto (2009), What causes southeast Australia's worst droughts?, *Geophys. Res. Lett.*, *36*, L04706, doi:10.1029/2008GL036801.

lation changes around the region [*Saji et al.*, 1999; *Webster et al.*, 1999]. The IOD has widespread effects on rainfall in countries surrounding the tropical Indian Ocean, including East Africa, India and Indonesia [*Webster et al.*, 1999; *Black et al.*, 2003; *Saji and Yamagata*, 2003; *Yamagata et al.*, 2004; *Behera et al.*, 2005, 2006; *D'Arrigo and Smerdon*, 2008]. Over Australia, the effect of the IOD is thought to be primarily limited to western and southern regions of the country [*Ashok et al.*, 2003].

2. Data and Methods

[4] We use monthly data for observed Australian precipitation based on the SILO dataset (1889–2006) [*Jeffrey et al.*, 2001] and observed temperatures from CRUTEM3 (1877–2006) [*Brohan et al.*, 2006]. To investigate the associated climatic conditions during IOD and ENSO events, we also employ the following reanalysis products: HadISST (1877–2006) [*Rayner et al.*, 2003], wind and humidity data from the National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) for the period 1948–2006 [*Kalnay et al.*, 1996], and the National Oceanic and Atmospheric Associ-

Summary - Take Home Messages

- Our understanding of marine heatwaves (MHWs) is in its infancy
- We have a working definition and categorisation scheme to unify estimates of MHW frequency, intensity and duration globally
- Surface MHWs have been increasing in frequency, intensity and duration => projected to continue
- Drivers of MHWs in the surface layers include climate modes + oceanic teleconnections and local processes (air-sea heat flux, advection are key)
- Little knowledge of
  - MHWs in ocean subsurface, or their dynamics
  - marine cold spells
  - how MHWs affect regional climate
- Great opportunity for CLEX => process-based understanding => improve predictability