A framework for defining marine heatwaves

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translating**nature**into**knowledge**

Marine Heatwaves

- While **oceanic extremes** have been studied for several decades, research has primarily focussed on a few key physical variables (**sea levels**, **wave heights** and **current speeds**)

- However, extreme events in water properties (such as **temperature**, **salinity**, **chlorophyll**, etc...) have received relatively little attention

- **Extreme events** in water properties are important for determining marine ecosystem structure (e.g., 2011 WA marine heatwave)

- A cross-disciplinary **"Marine Heatwaves – Physical drivers and properties Workshop"** held in Perth in January 2015 led to three main research themes

  - "A hierarchical approach to defining marine heatwaves" (Hobday et al., *under review, Prog. Ocean.*)   (*this talk*)

  - "Spatial patterns and long-term trends in global marine heatwaves" (Oliver et al., *in prep.*)

 - Drivers and dynamical processes of marine heatwaves (Holbrook et al., *in prep.*)

- The **2003 European heatwave** co-occurred with sea surface temperatures (SSTs) in the northern Mediterranean Sea that were **2-3°C higher than previous summers**

- In **summer 2010/2011** an unprecedented "marine heatwave" was documented off **Western Australia** in which SST anomalies were **3°C above the expected value** along a broad stretch of WA coast.

- In **Boreal summer 2012** a dramatic heat wave occurred in the **northwest Atlantic**, SST anomalies were **3°C above the expected value** along eastern Canada and USA
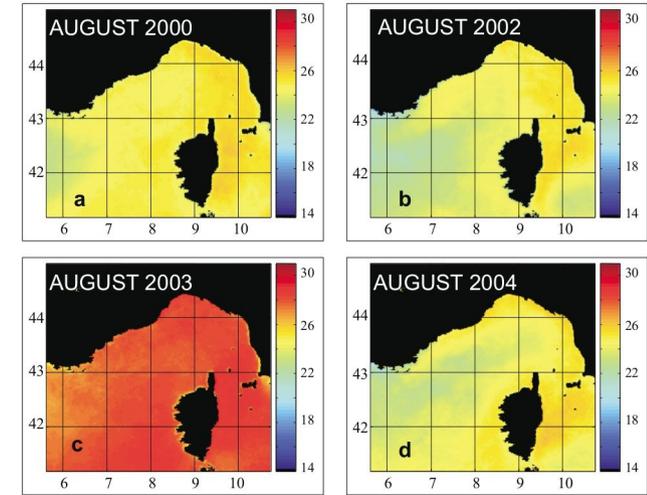
Sparnocchia, S. et al. (2006), *Annalles Geophysicae*, 24, 443-452
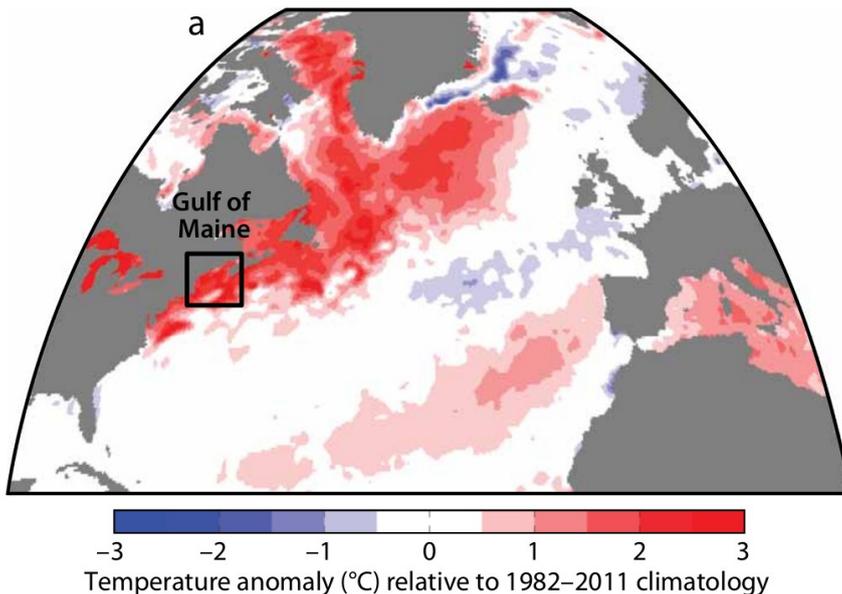
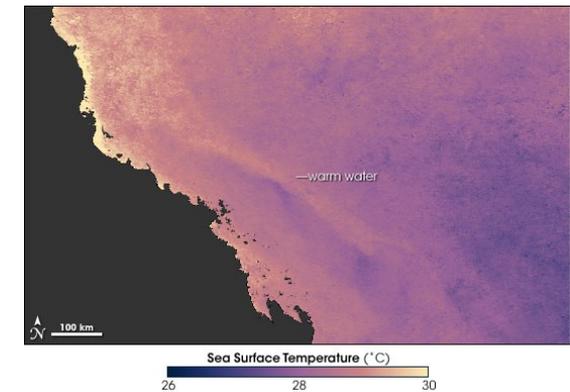Mills, K.E. et al. (2013), *Oceanography*, 26(2), 60-64
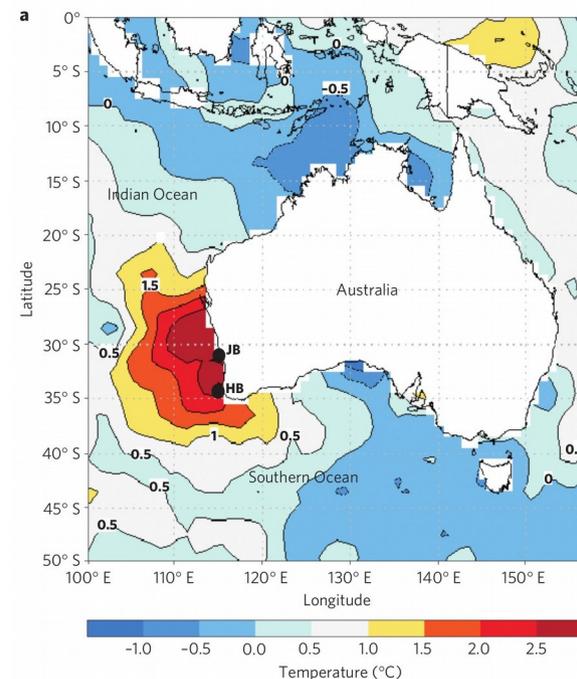
Wernberg, T. et al. (2013), *Nature Climate Change*, 3, 78-82
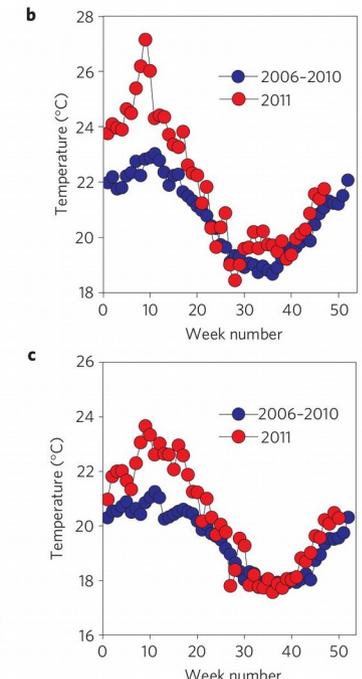
- 2003 Mediterranean

  - Mass mortality in local **rocky reef communities** (Garrabou et al. 2009)

- 2011 WA

  - Changes in **biodiversity patterns** (seaweeds, invertebrates, and fish)

  - A "**tropicalization**" of fish communities

- 2012 NW Atlantic:

  - Dramatic impact on **lobster fishery** including increased Canada-US economic tensions

- Implication: frequency and intensity events – superimposed upon a general warming trend – can have **major implications for ecosystem distribution and structure** (Wernberg et al. 2013)

Garrabou, J. et al. (2009), *Global Change Biology*, 15, 1090-1103

Species distribution change

distribution of *Centrostephanus rogersii*
- barrens patches
- no barrens, individuals common
- no barrens, individuals rare
- uncertain

Coral bleaching

Sea Surface Temperature (°C)

Lobster landings

- 2012
- 1982–2011
- % total

Landings (millions lbs)

Jan   Mar   May   Jul   Sep   Nov

Chlorophyll Concentration (mg/m³)
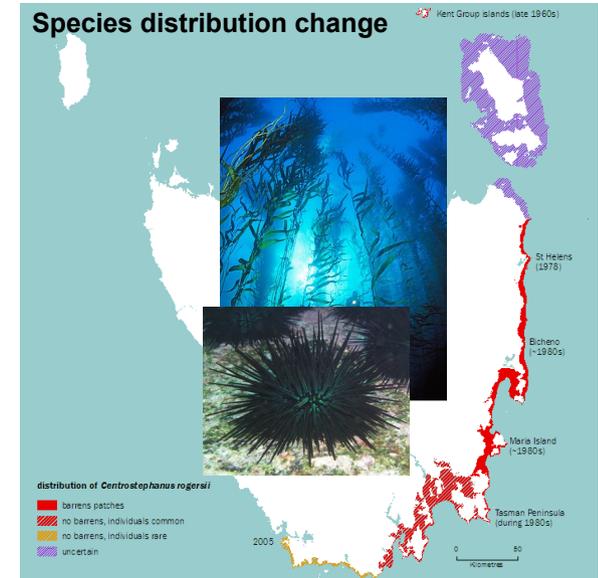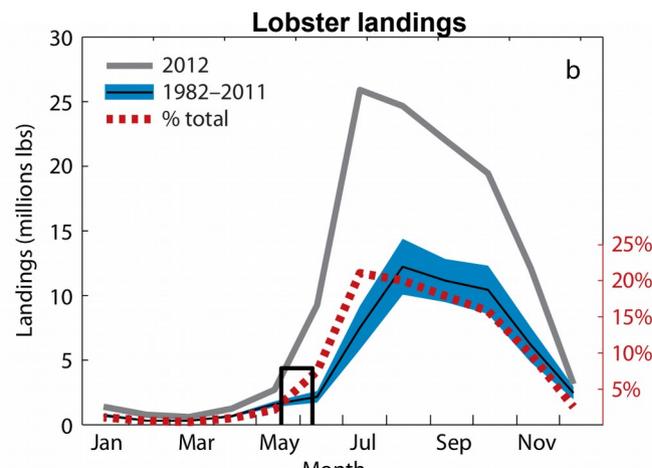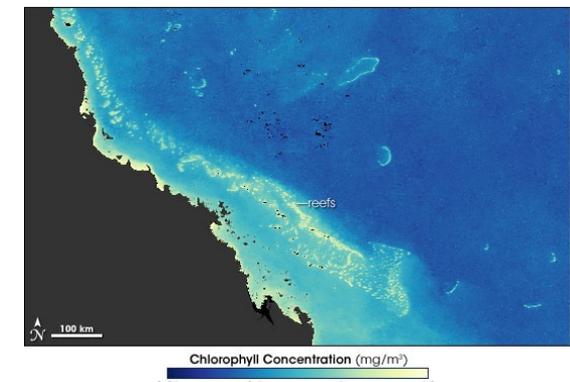
- "Marine heatwave" (MHW) **terminology** very new...

  first use appears to be Pearce and Feng (2013)

- Many **MHW "definitions"** have been used:

  - Maximum temperature [^{o}C] (Berkelmans et al. 2004)

  - Temperature anomaly [^{o}C] (Sorte et al. 2010; Wernberg et al. 2013)

  - Degree heating weeks [^{o}C x weeks] or days [^{o}C x days] (Maynard et al 2008; Eakin et al 2010; Donner 2011)

  - Heating rate [^{o}C/day] (Maynard et al 2008)

  - Thermal stress anomalies [^{o}C] (Selig et al. 2010)

  - A period of at least three to five days during which mean or maximum temperature anomalies were at least 3–5°C above normal (Sorte et al. 2010; Meehl and Tebaldi 2004)

  - Coral bleaching metrics generally include the effect of extreme event duration and magnitude of temperature anomalies

- **Limited consistency** (outside coral bleaching research) regarding how MHW metrics are applied or how useful they are in ecological applications

- The atmospheric community has recently sought to define standard metrics (e.g., the ETCCDI) and the proposed MHW definition has leveraged off of these efforts

Proposed MHW definition

Hobday et al. (under review, *Prog. Ocean.*) proposed MHW definition

- <u>Qualitative</u>: **a discrete prolonged anomalously warm water event at a particular location**

  - Does not assume any particular driver or any specific impact

  - Provides a flexible definition that can be specifically targeted towards end-user applications such as coral reef monitoring or fisheries management

- <u>Quantitative</u>:

  - **'anomalously warm'**: a MHW must lie above a high percentile and referenced to a baseline climatology

    - Recommend 90th percentile

    - Climatology and percentile both vary with time of year

  - **'prolonged'**: a MHW must persist for ≥ 5 days

    - Sensitivity tests show spatial uniformity at this threshold

  - **'discrete'**: a MHW event has well-defined start and end times

    - Subsequent events with gaps of ≤ 2 days considered as one event

Figure from Hobday et al. (*under review*)

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Figure from Hobday et al. (*under review*)

(c) Heatwave, Heat spike, i_{mean}, $r_{decline}$, r_{onset}, Threshold value, t_s, MHW$_D$≥5 days, t_e, MHW$_D$<5 days, i_{cum}, i_{max}, SST, Climatological values, Day of Year

- For each MHW event, a set of metrics include measures of intensity, duration, frequency and spatial extent

- **A hierarchical set of such metrics is proposed:**

- **Primary metrics** (most general; duration and intensity)

  - Intensity (mean, maximum) [deg C]

  - Duration [days]

Figure from Hobday et al. (*under review*)

- **Secondary metrics** (less general; still inherent physical properties)

  - Cumulative intensity (~DHDs/DHWs) [deg C x days]

  - Rate of onset/decline [deg C/day]

  - Spatial extent (linear or areal) [km or km^2]

- **Tertiary metrics** (specific to the system under investigation)

  - Preconditioning factors (e.g., drivers, processes, states)

  - Ecological impacts (e.g., stress in a biological sense)

  - ..etc...
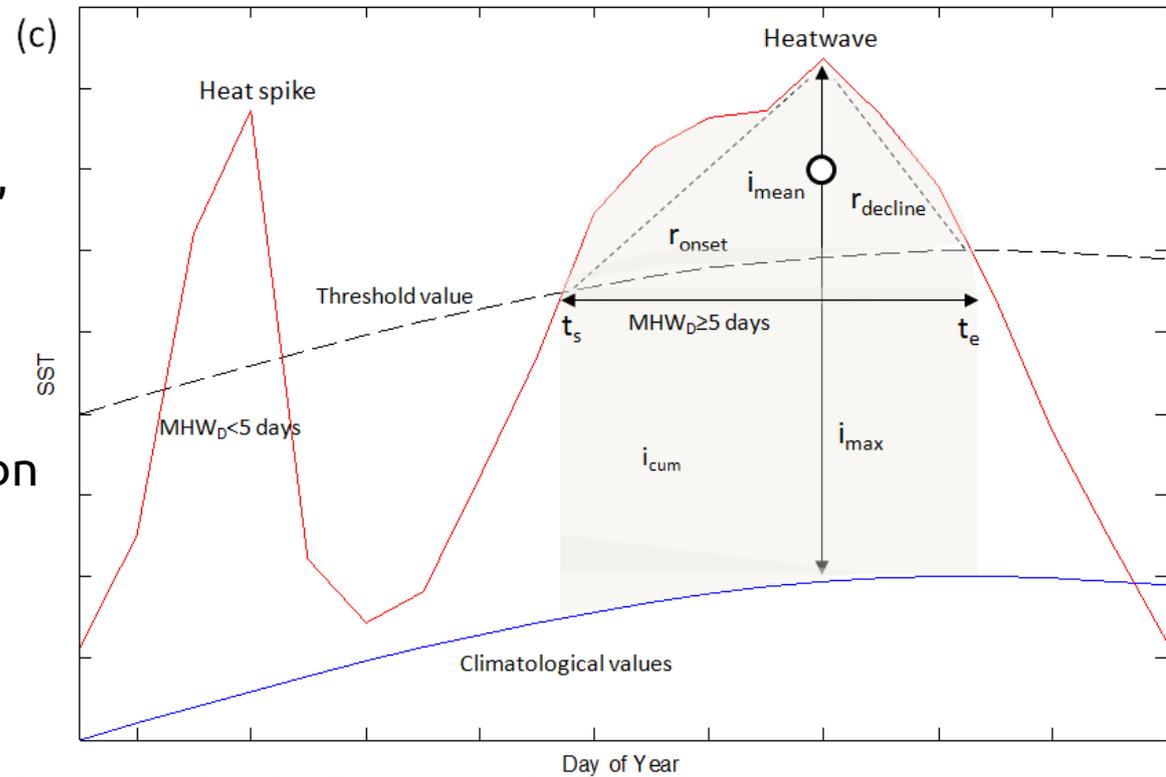
Western Australia (WA) 2011 Event
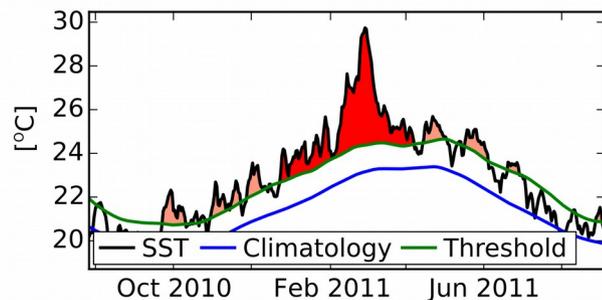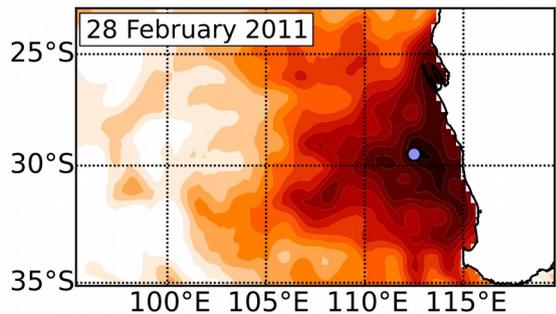
Mediterranean (Med) 2003 Event
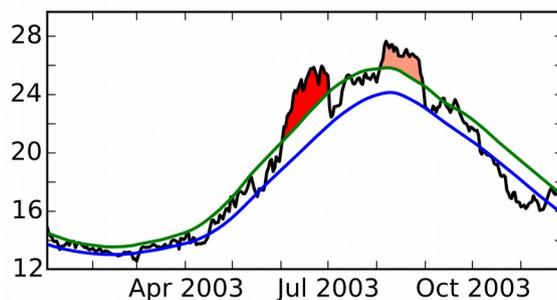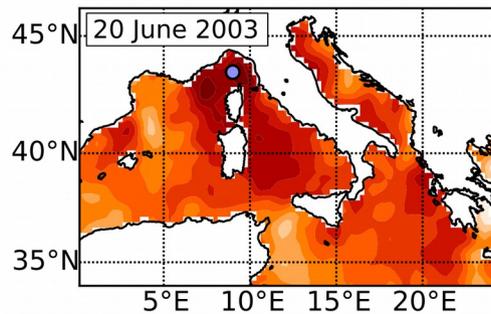
Northwest Atlantic (NWA) 2012 Event
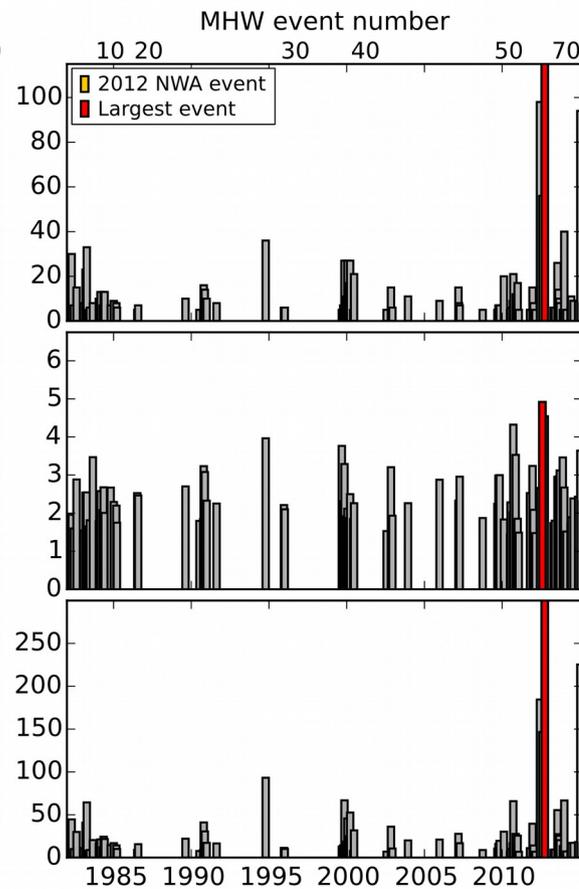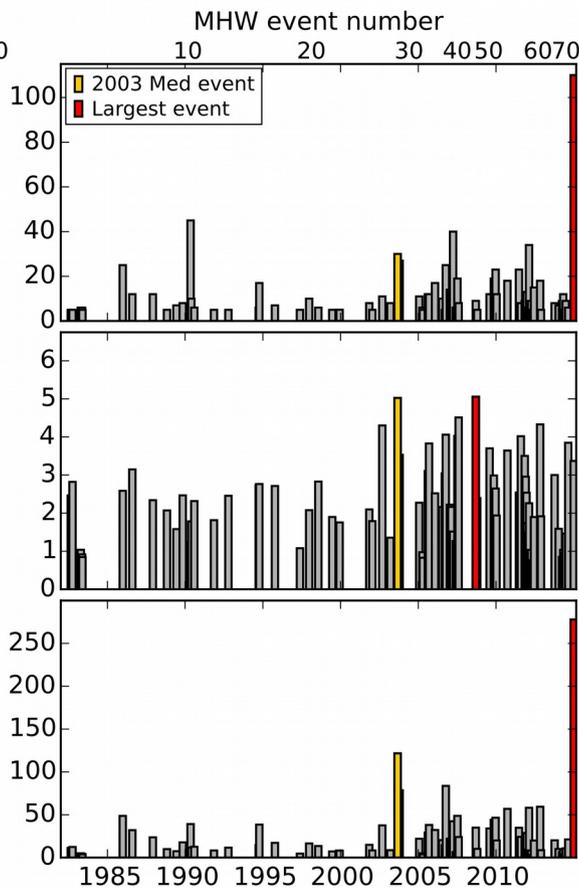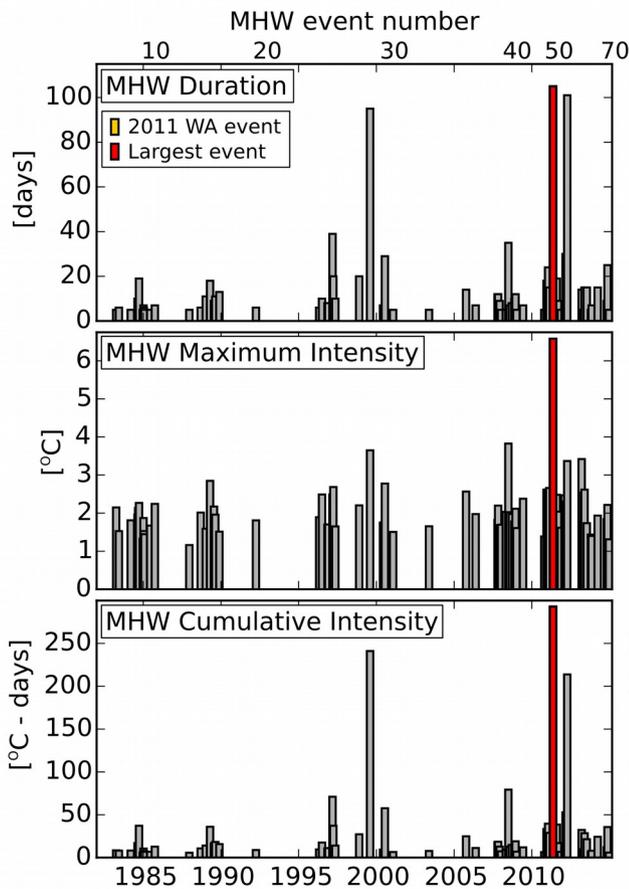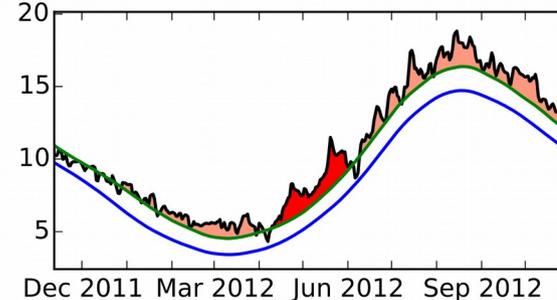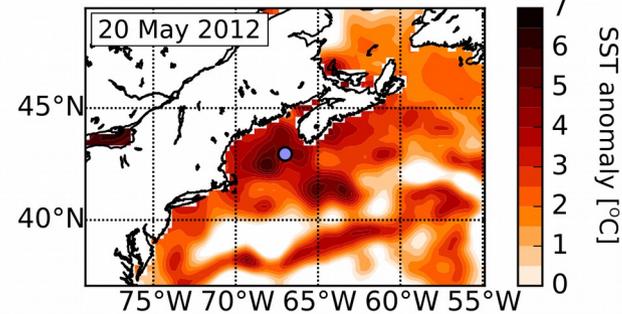
- 2011 WA event was measured by **different instruments, different time scales**

- Not all instruments/time scales can be used to fully characterise MHWs

Figure from Hobday et al. (*under review*)
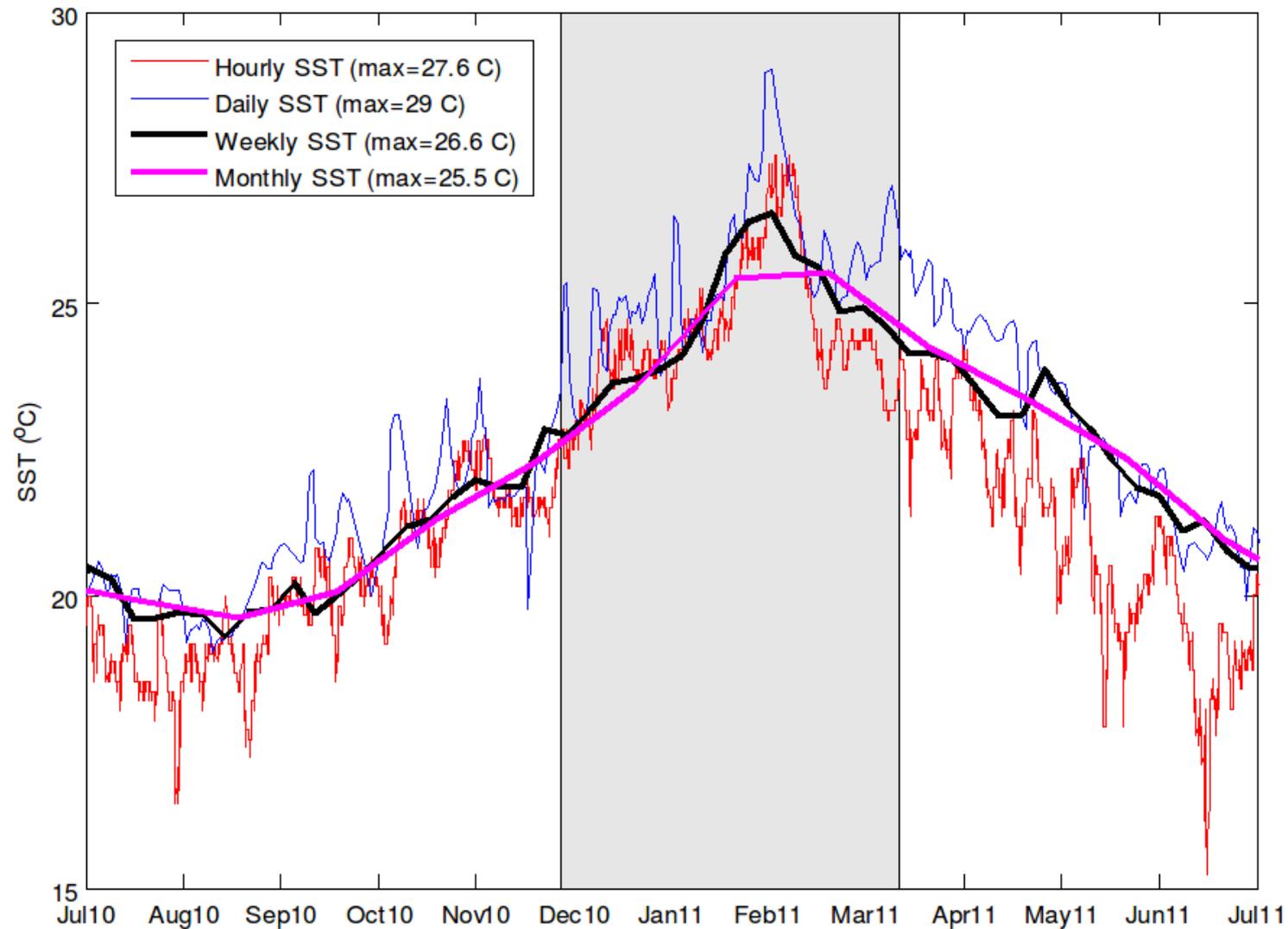
Software

- MHW definition has been implemented as a **software package**

- Written in **Python**, freely available, open-source

- Available here: `github.com/ecjoliver/marineHeatWaves`

- Requires daily data (for now), allows for missing values, **feedback requested**

- Nothing ocean-specific about code: default parameters (e.g. 5-day minimum duration, 2-day gap duration) can be modified to suit atmospheric (or other) data

Scripps Pier, USA

- **Long-term trends**: MHW definition applied to the few stations with long, daily records

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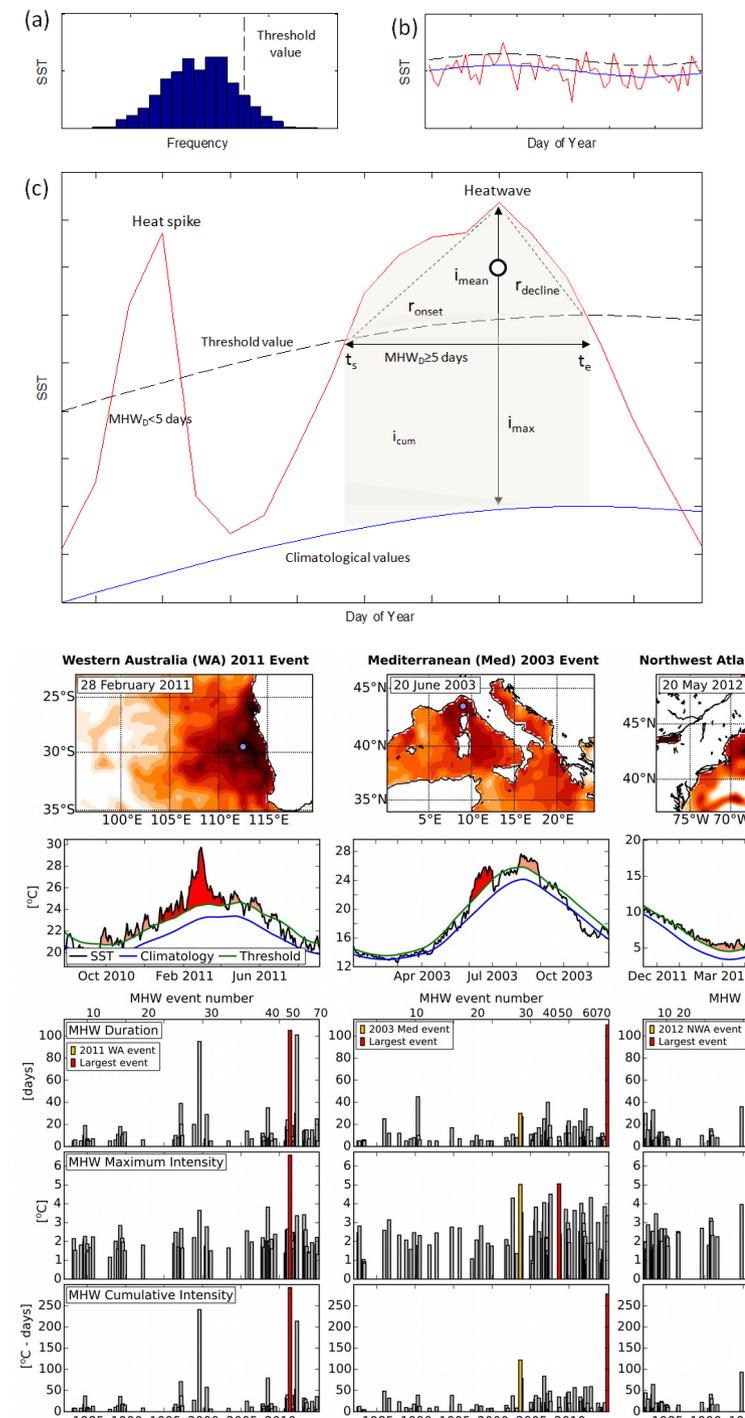- **Spatial patterns**: Global, 1982-2014, remotely-sensed SST

Scripps Pier, USA
MHW frequency
Proxy prediction
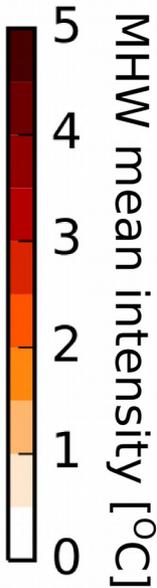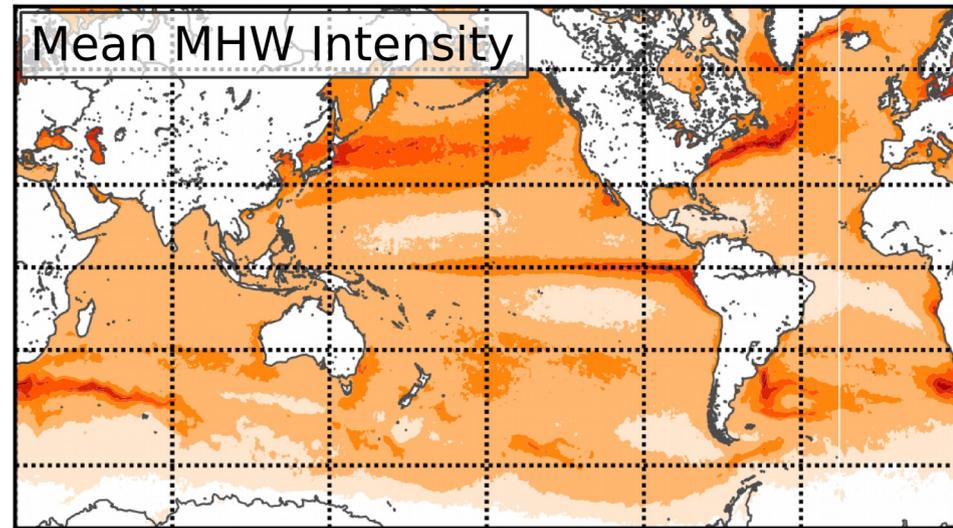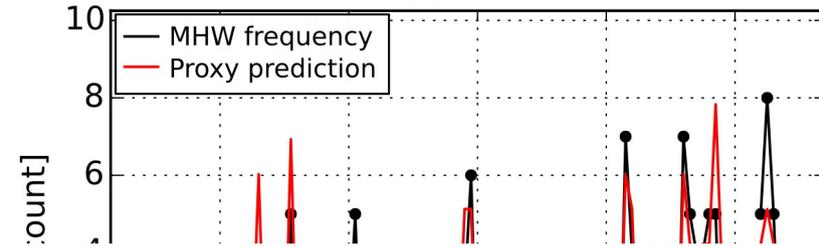
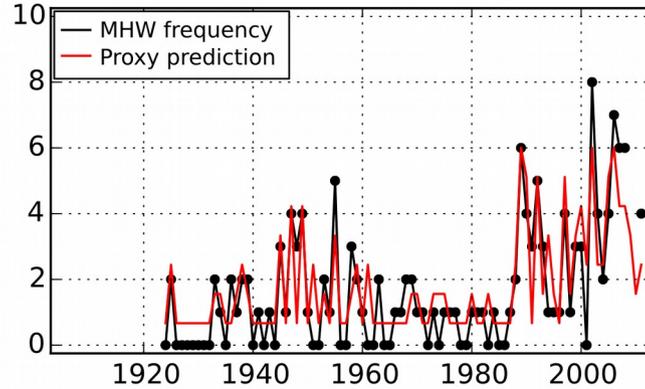Mean MHW Intensity

MHW mean intensity [°C]

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- **Spatial patterns**: Global, 1982-2014, remotely-sensed SST

- **Online atlas**: Interactive website

Summary
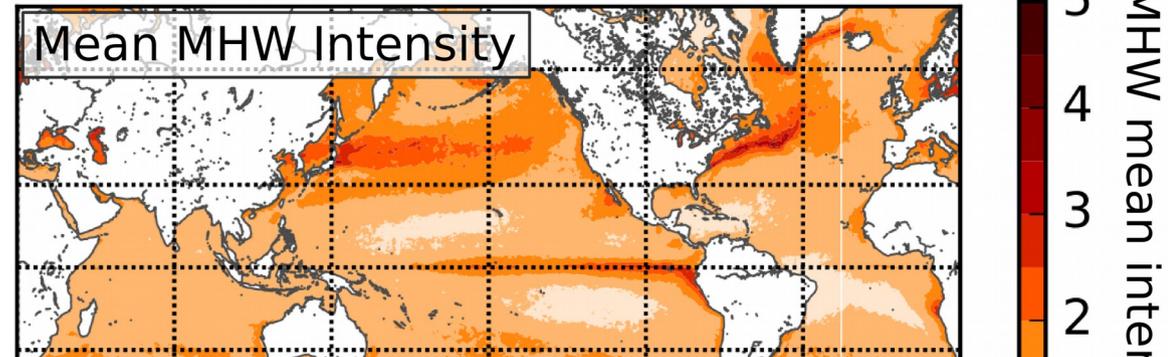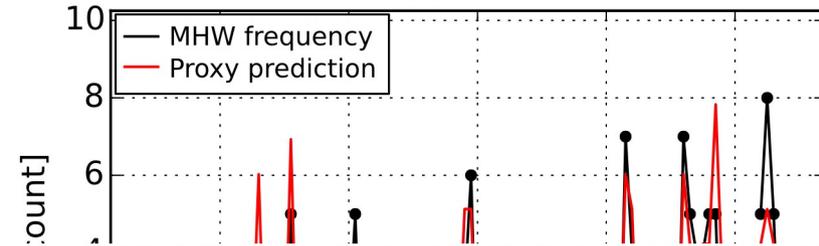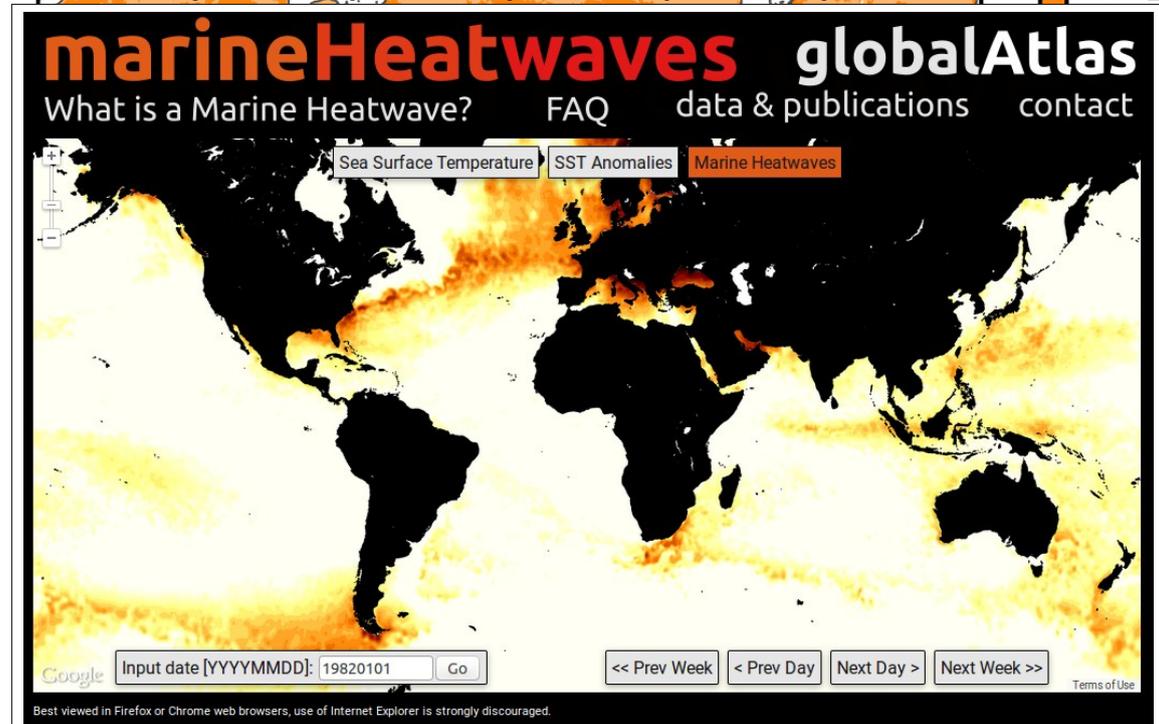
- **"Marine heatwaves"** is an exciting new field

- Opportunity for an informed MHW definition with use across disciplines (**physical**, **biological**, **industry**, etc)

- Hobday et al. definition proposed based on a "**a discrete prolonged anomalously warm water event**", including a hierarchy of metrics

- Definition performs well at **capturing historic events** (WA, Med, NW Atlantic), and puts them in context of a 30-year record

- **Software** freely available (**Python**) and can be easily adapted to non-ocean data

- **Ongoing/future work**

  - Spatial patterns and long-term MHW trends (Oliver et al.)

  - Case studies (Tassie, Med, UK, S. Africa), event attribution

  - MHW drivers and processes (Holbrook et al.)

- **Long-term trends**: MHW definition applied to the few stations with long, daily records

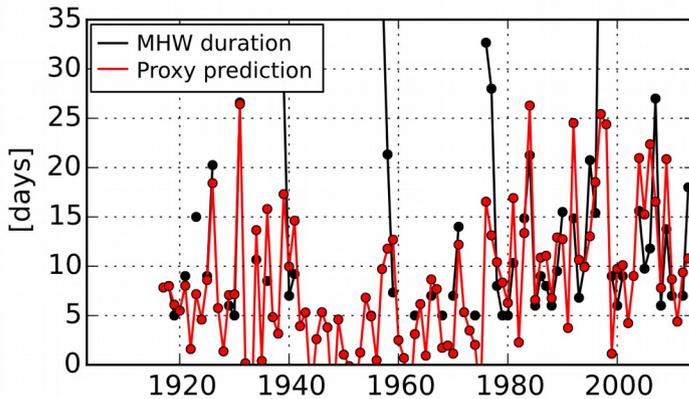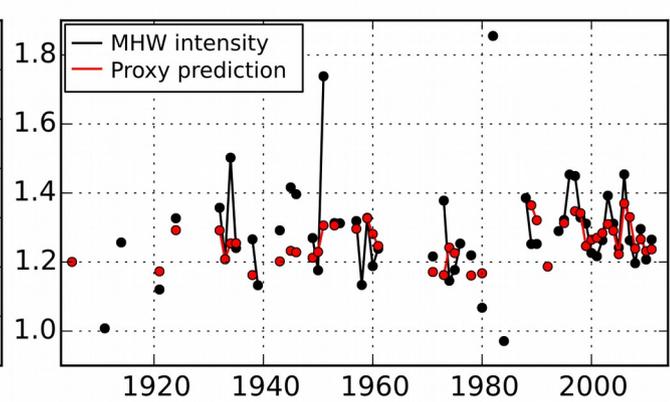- **Spatial patterns**: Global, 1982-2014, remotely-sensed SST