Extreme marine heatwave off southeast Australia in austral summer 2015-2016

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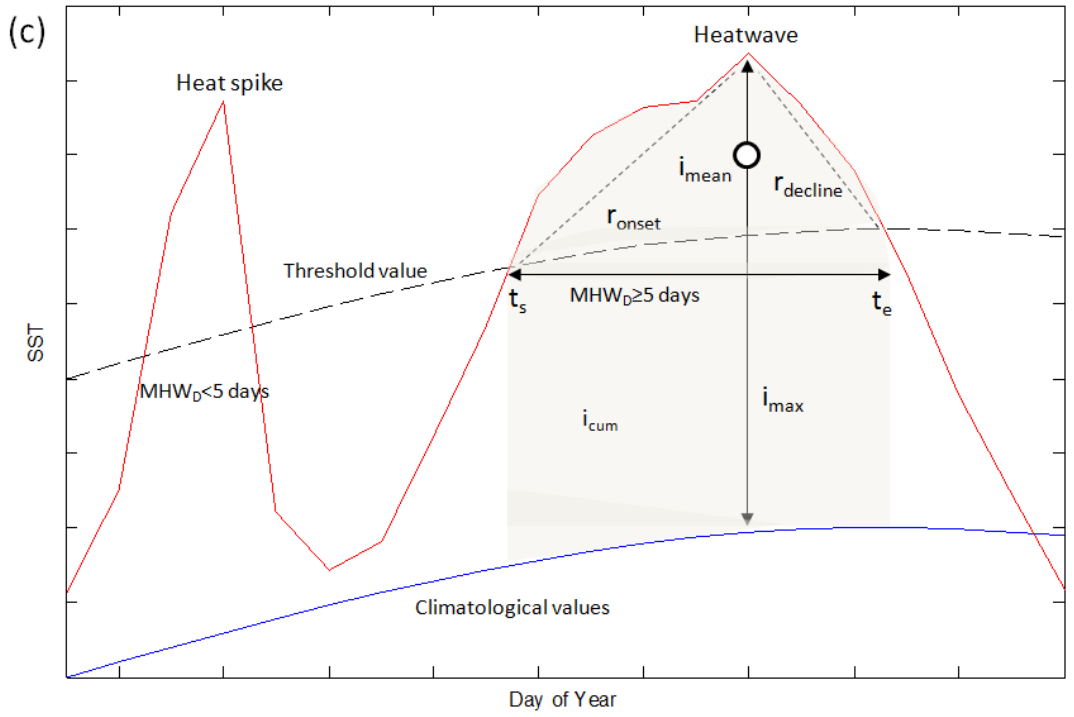
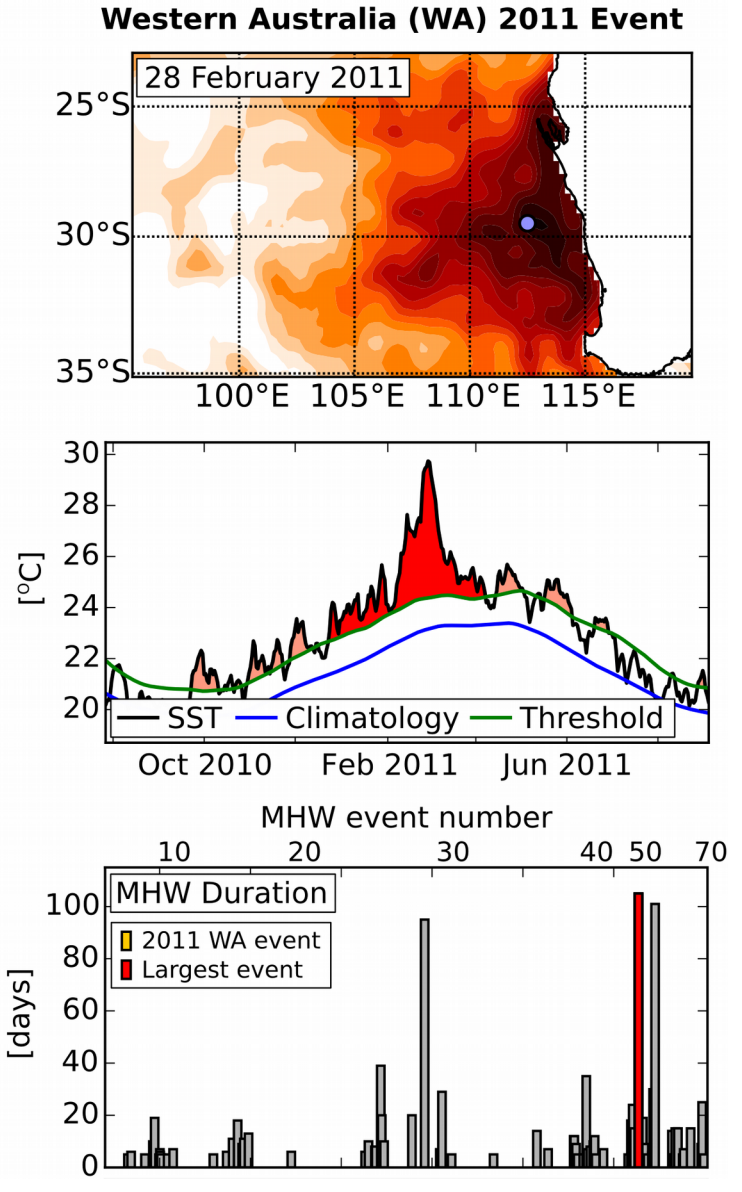
What is a Marine Heatwave?

- A **marine heatwave** (MHW) is defined to be **a discrete prolonged anomalously warm water event at a particular location** (Hobday et al., 2016)
- Specifically, **SSTs above the seasonally-varying 90th percentile** that persist **for at least 5 days**.
- Definition includes a set of **metrics**, including:
  - **Intensity** [^{o}C]
  - **Duration** [days]



Software implementation free-ly available in Python here:
`github.com/ecjoliver/marineHeatWaves`
and in R here: `github.com/cran/RmarineHeatWaves`

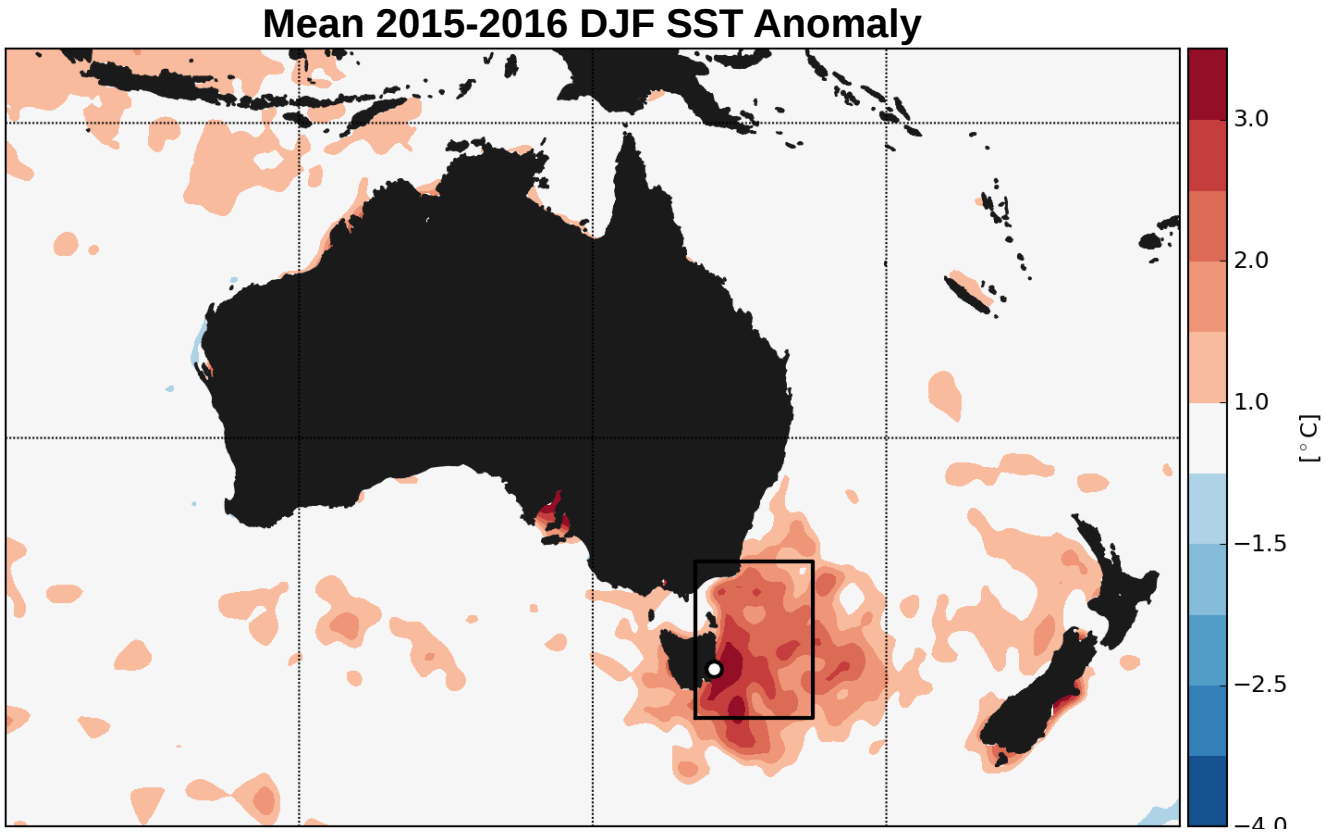


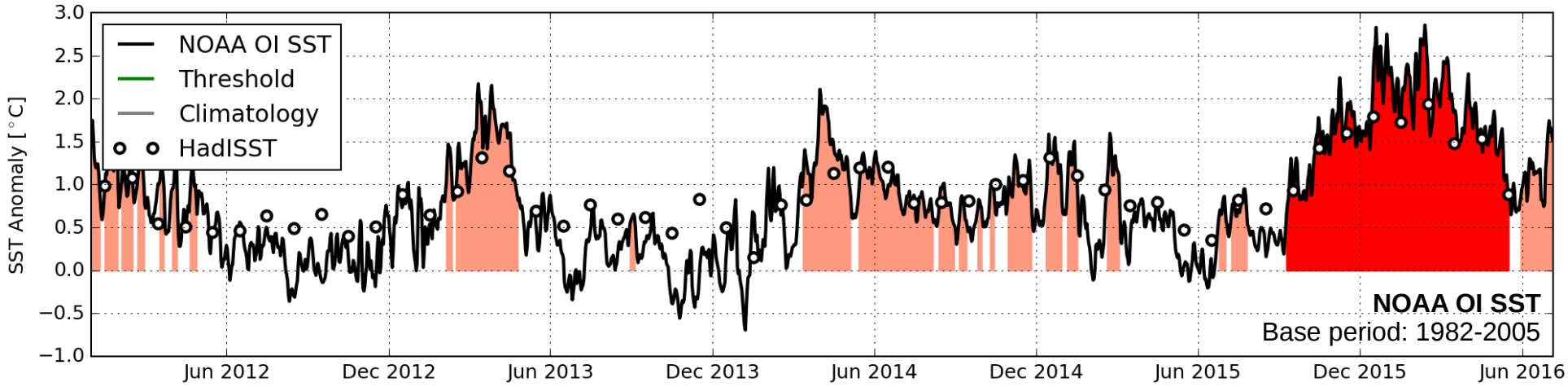
Figures from Hobday et al. (2016) *Prog. Ocean.*

2015-2016 SE Australia MHW

- There was a **marine heatwave** that occurred in **Austral Summer 2015/16** off southeastern Australia:
  9 Sep 2015 – 16 May 2016
- It is unprecedented in
  - **Duration (251 days)**
  - **Intensity (2.9°C max)**
- **Impacts**: POMS (Oysters), dead abalone, poor salmon farm performace, strange fish intrusions, kelp thinning…

Oliver, Benthuysen, Bindoff, Hobday, Holbrook, Mundy and Perkins-Kirkpatrick, *Nat Comms* (under review)





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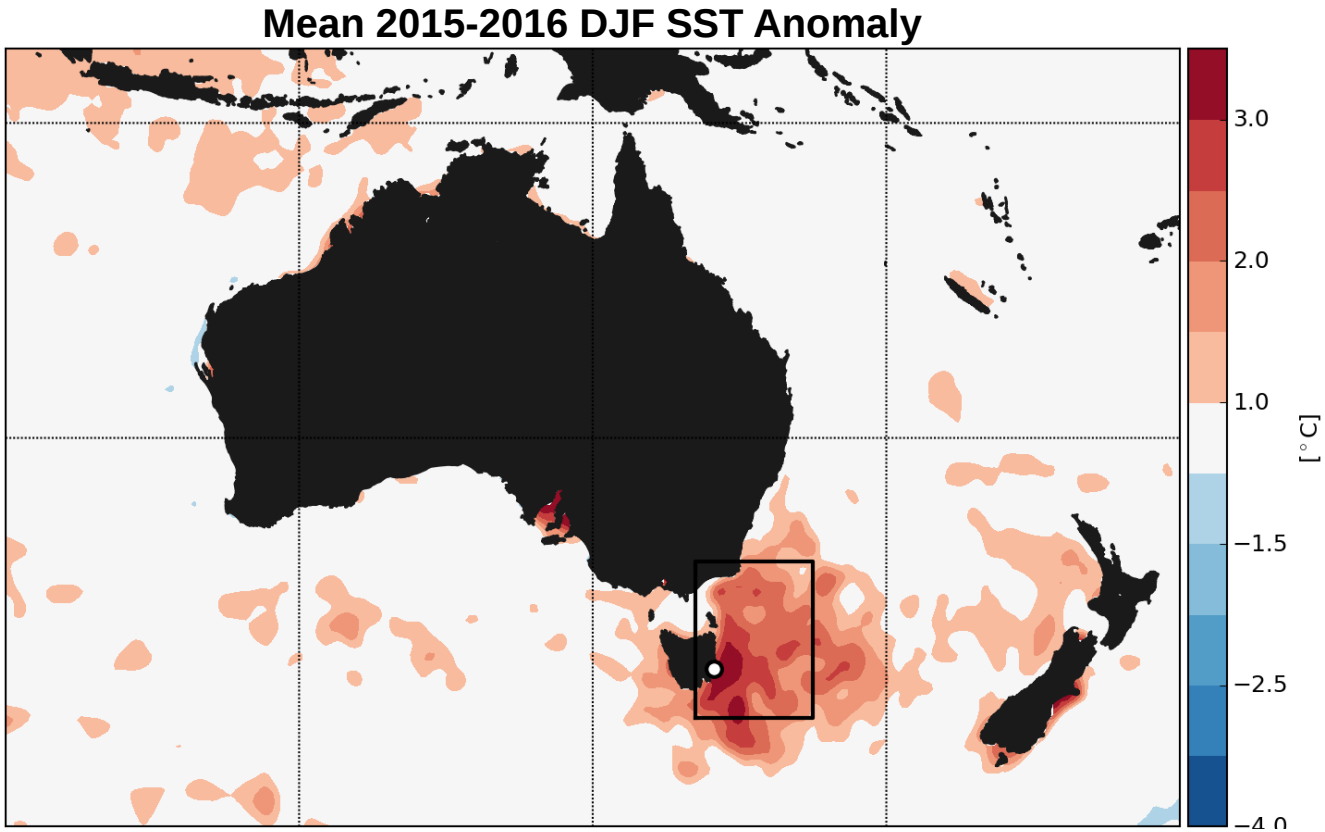
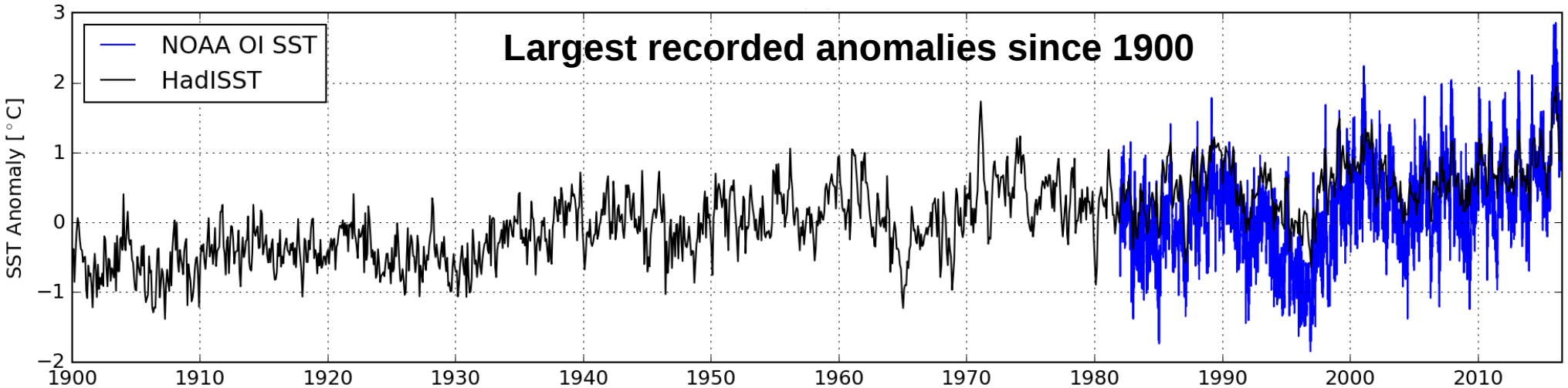
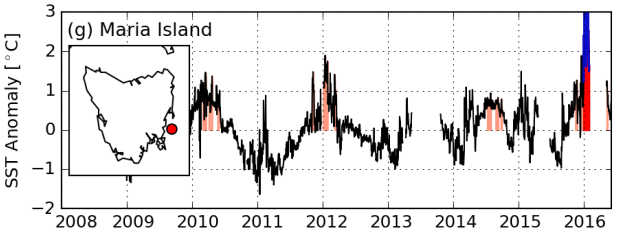




Nearshore Records

- ***IMOS Maria Island NRS***
  - 20 m temperature
  - Full-depth velocities
- ***IMAS Nearshore Temperature Monitoring***
  - A number of sites in 6-20 m depth
- This event was **record strength** (**red**) and duration (**blue**) in the ~10-year coastal records
- Record **southward flows**, possible indication of **forcing mechanism**



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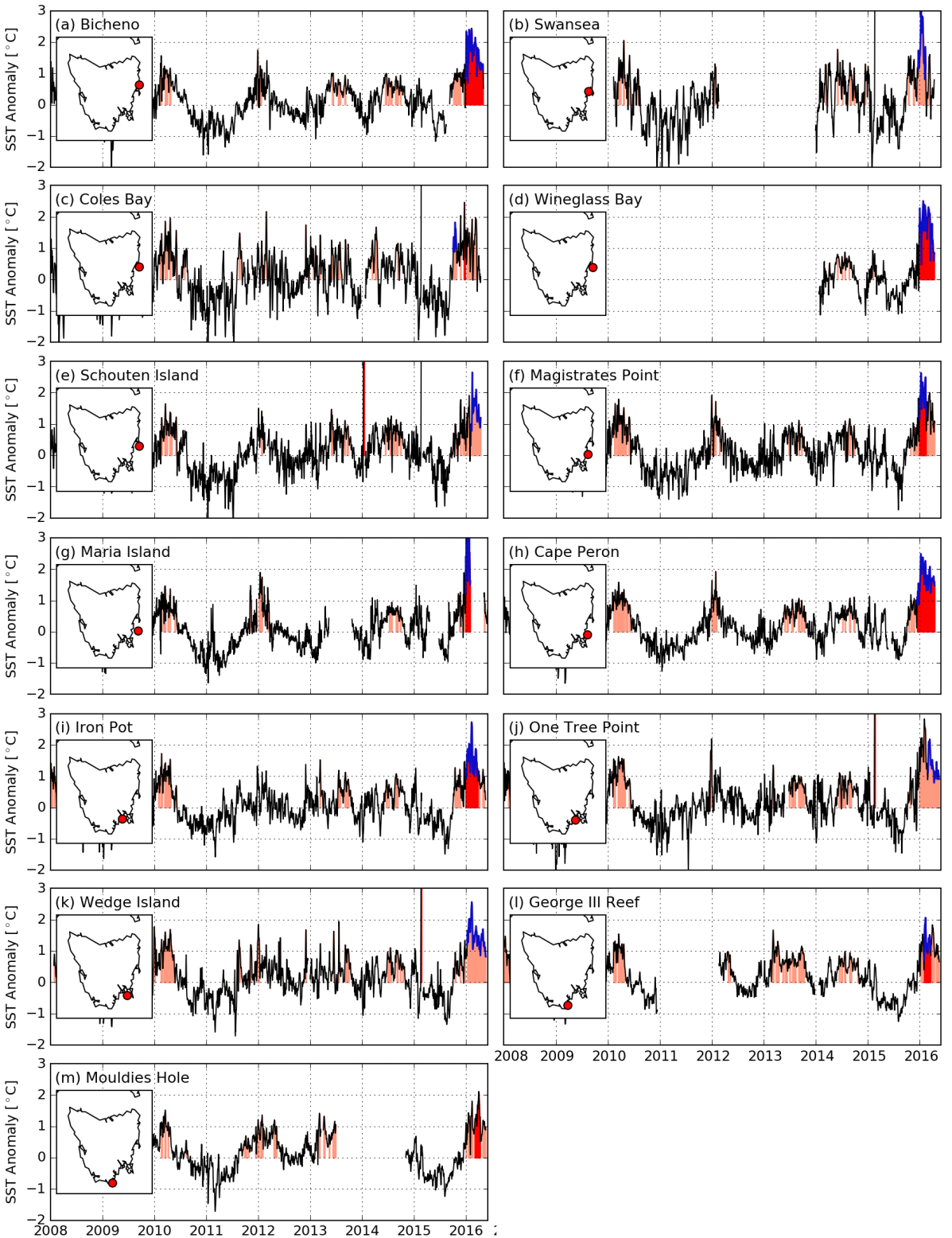

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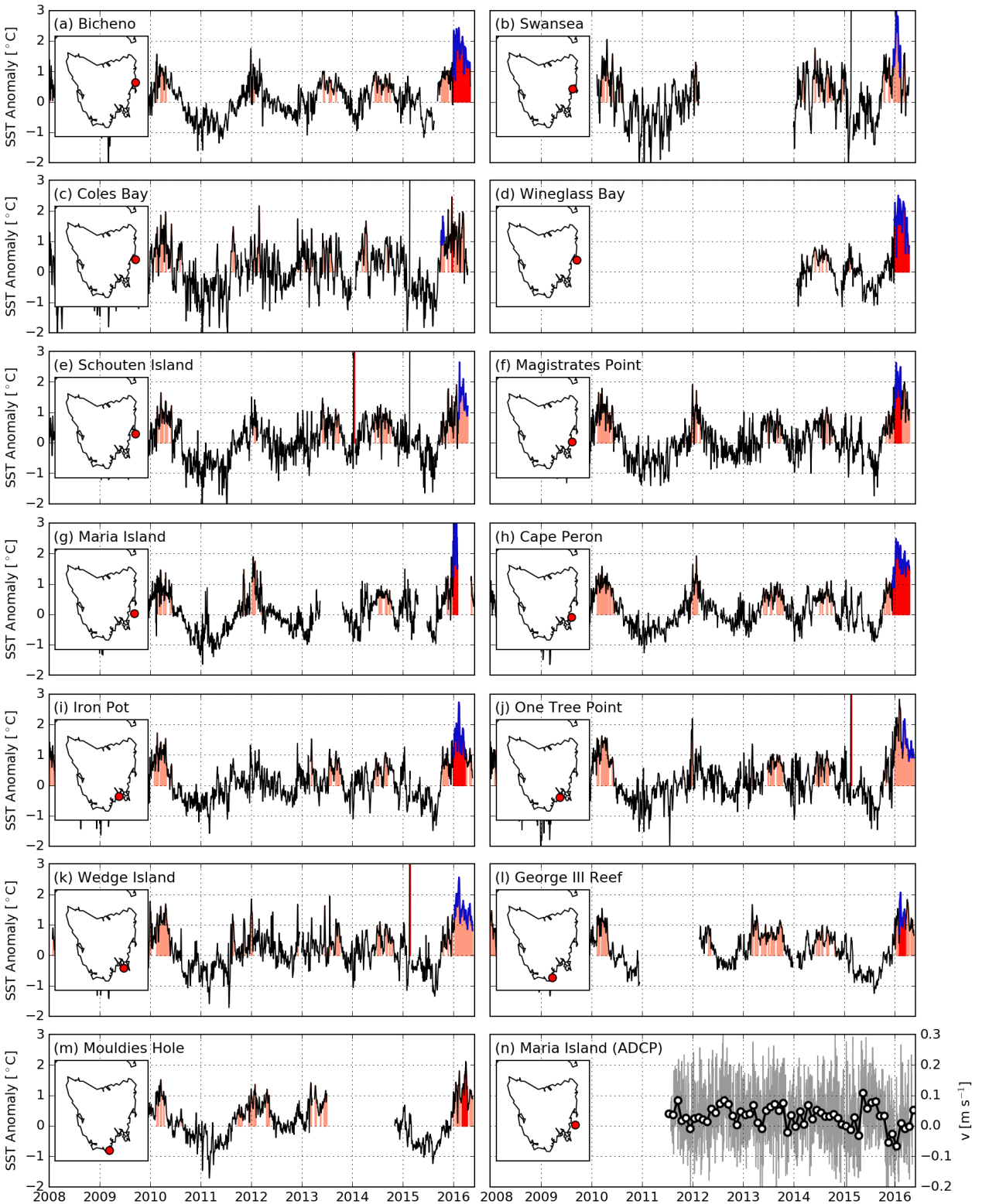
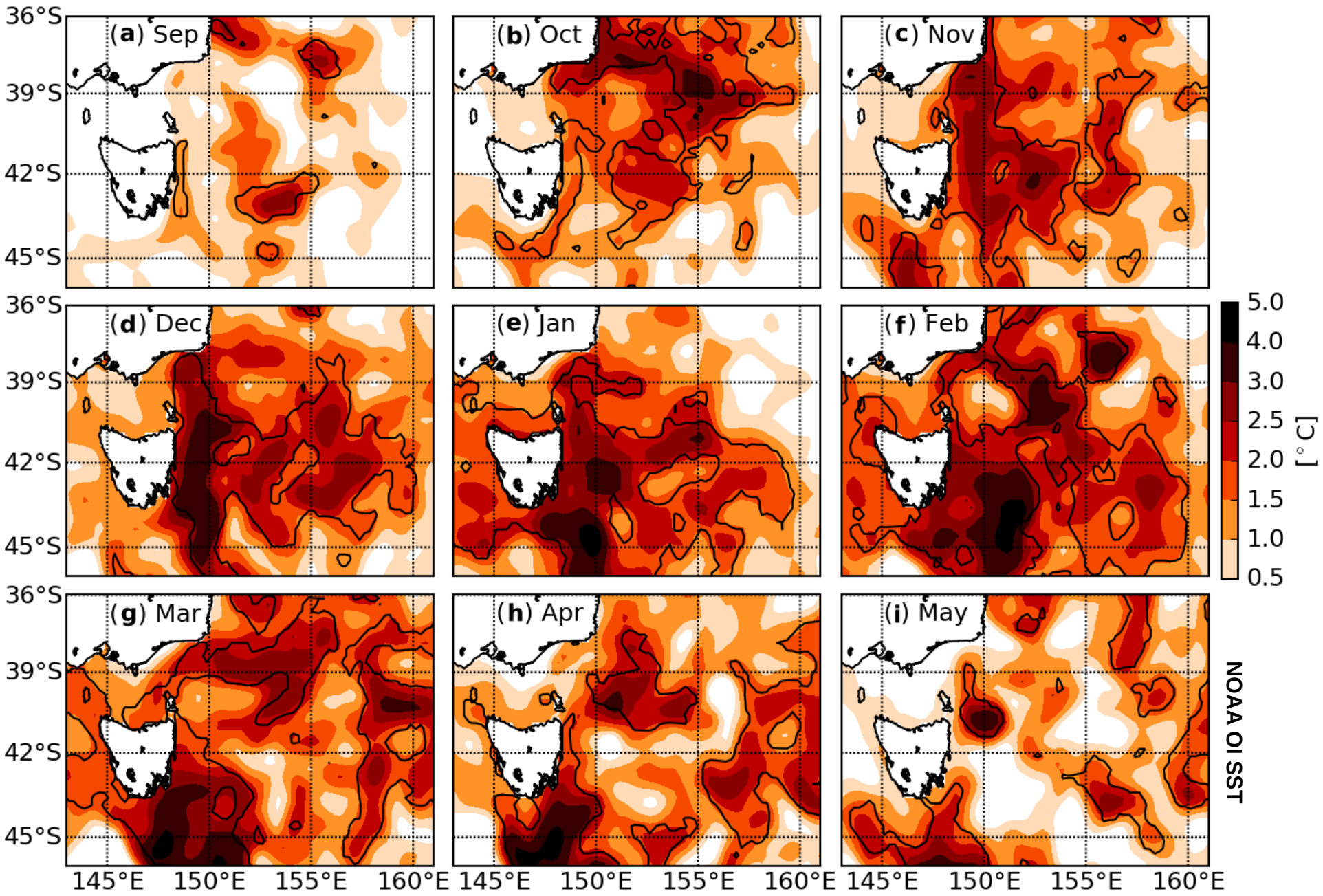


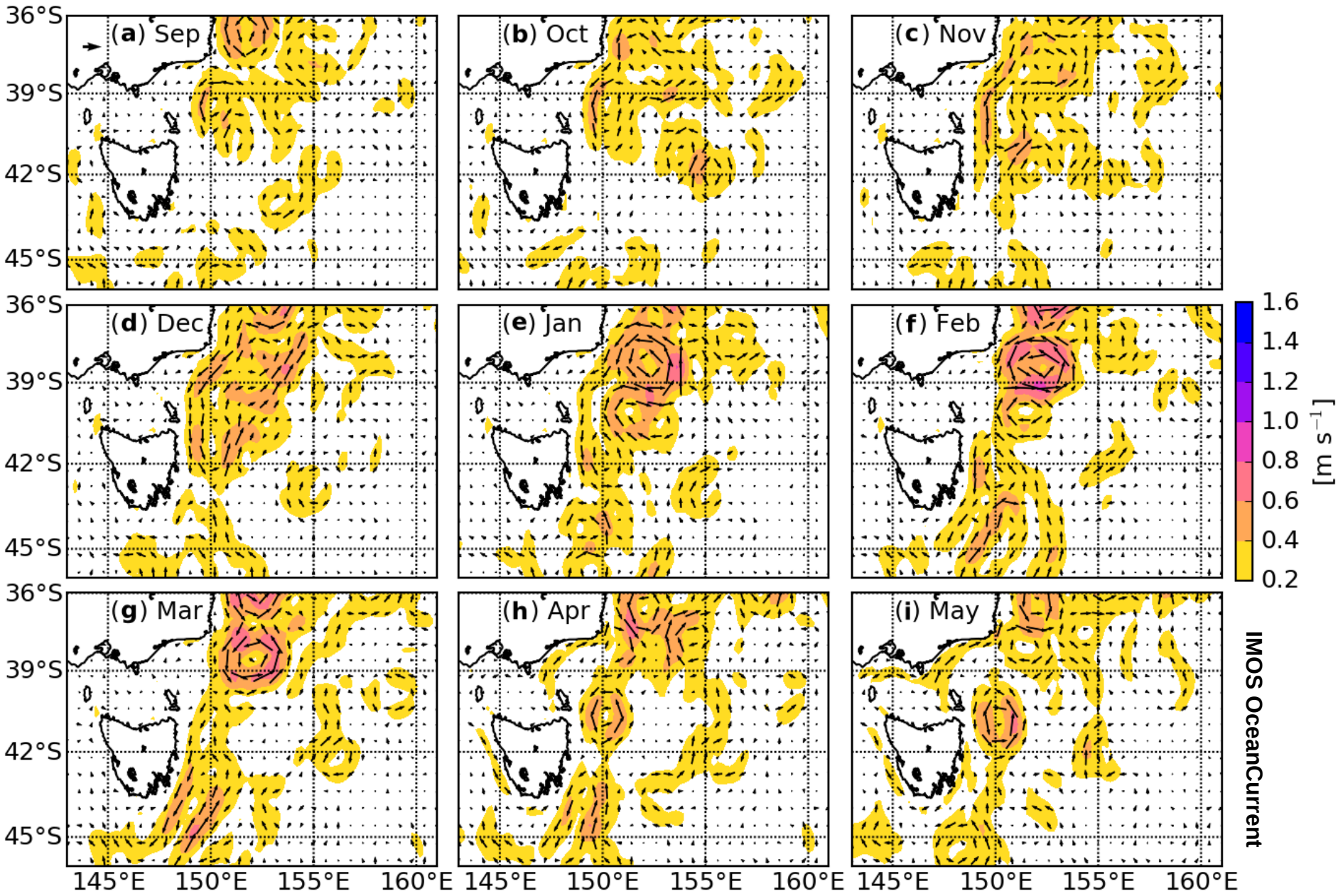
Evolution of the event

Monthly SST anomalies: contour encloses areas that were detected as MHWs for >90% of that month



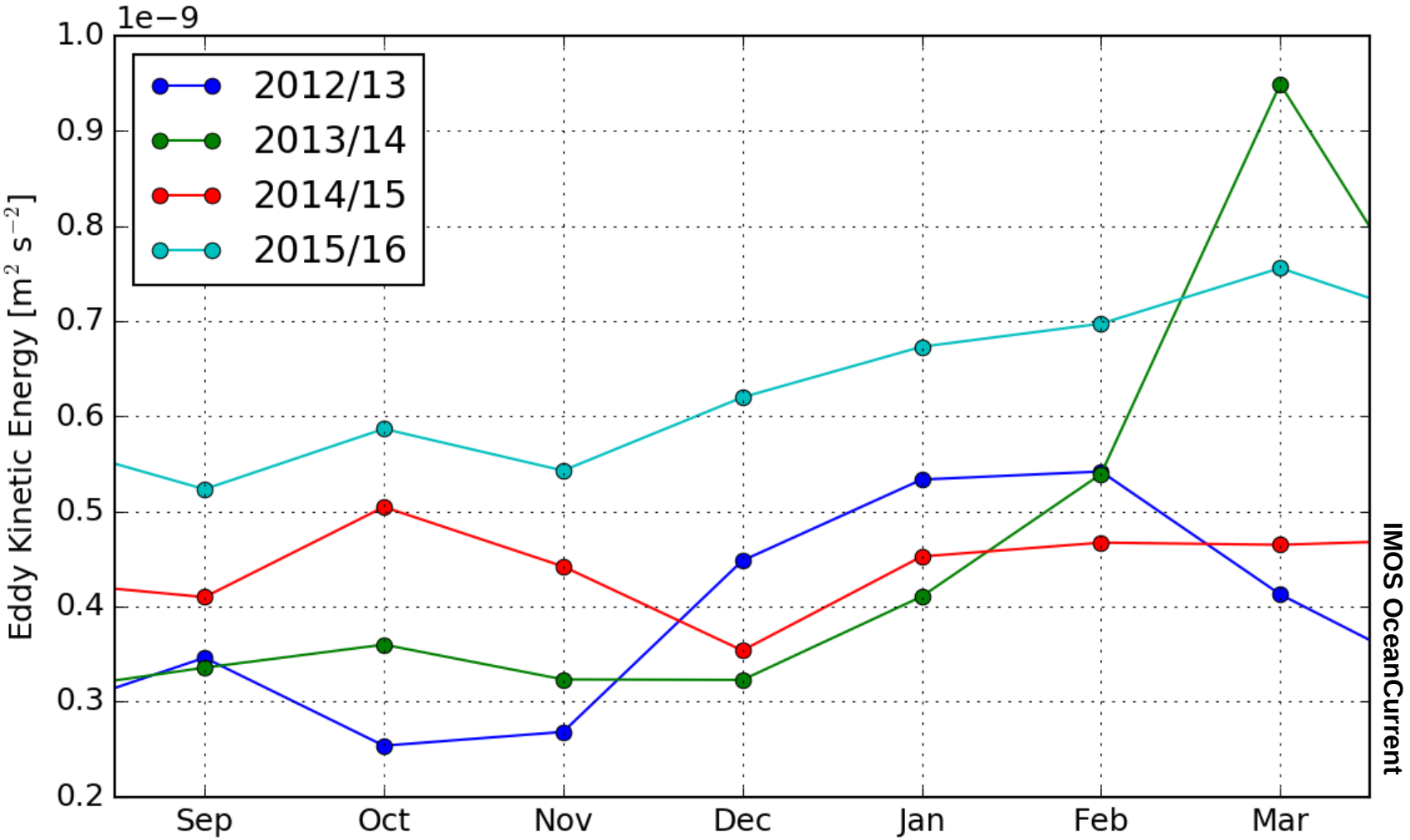
Evolution of the event

Monthly surface currents (*u*, *v*) (IMOS OceanCurrent)



Evolution of the event

Monthly surface Eddy Kinetic Energy (*EKE*) (IMOS OceanCurrent)



Physical drivers

- **<u>Upper ocean temperature budget</u>**, following:
  - Benthuysen et al. (*CSR*, 2014) for 2011 West. Aus. MHW
  - Chen et al. (*JGR*, 2015, 2016) for the 2012 NW Atlantic MHW
- **Volume averaged temperature** tendency equation:

$$\frac{dT}{dt} = -u_{\mathrm{H}} \cdot \nabla_{\mathrm{H}} T + \frac{1}{A} \int_{\mathrm{A}} \frac{Q}{\mathrm{H}} dA + \mathrm{Residual}$$

Horizontal temperature advection

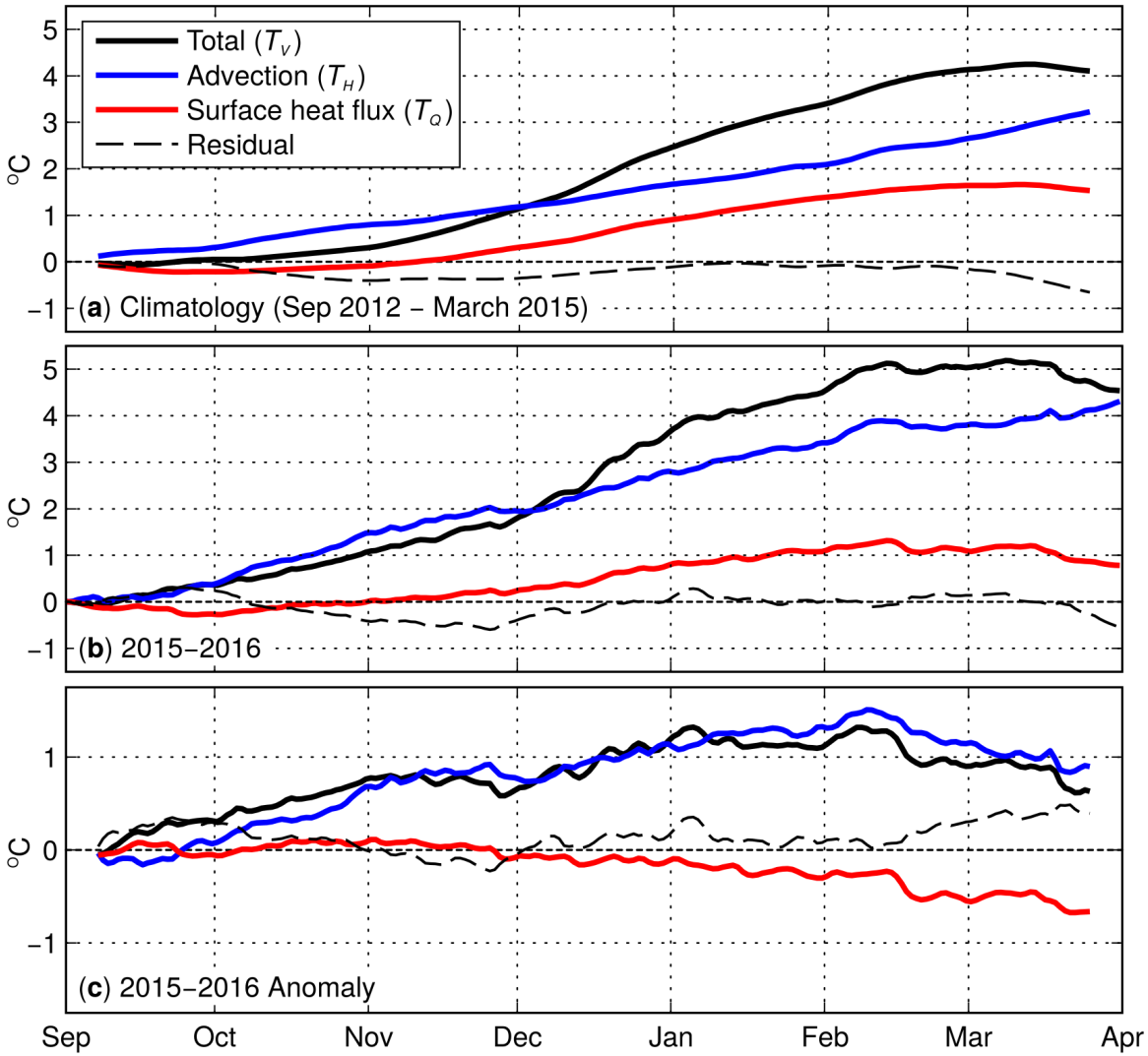
Air-sea heat flux

Includes: Horizontal and vertical diffusion, vertical advection

  - *Depth: H* = 100 m
  - *Area: A* = "SEAus box"
  - *Temperature* (*T*) and *velocities* (u_H) from OceanMAPS
  - *Surface heat flux* (*Q*) from NCEP CFSv2 reanalysis

Physical drivers

- **Temperature budget**
- Volume averaged temperature (T_V) since Sep 1st of:
  - 2012/13, 2013/14, 2014/15, 2015/16
- Consider:
  - Temperature avection (T_H)
  - Air-sea heat flux (T_Q)
- **Climatology:** by mid-February T_H contributes ~60% of the warming while T_Q contributes ~40%
- **2015-2016:** by mid-February T_H contributes ~80% of the warming while T_Q contributes ~20%
- Marine heatwave primarily driven by **anomalous temperature advection**



Role of climate change

- **<u>Event Attribution study</u>** following
  - Lewis & Karoly (*GRL*, 2013) on Australia's “angry summer” of 2013
  - King et al. (*ERL*, 2015) on Central England temps. of 2014
- **Calculation:** *Fraction of Attributable Risk (FAR)*:

$$\mathrm{FAR} = 1 - \frac{P_{\mathrm{histNat}}}{P_{\mathrm{hist}}}$$

where P_X is the probability of an the event larger/longer than the event in question based on the modelled climate *X*.

- **Informs:** change in likelihood of occurrence of an event like the one in question due to anthropogenic influence (*hist*) as opposed to a naturally-forced world (*histNat*)
- **Data:** Look at *SEAus* MHWs in CMIP5 *historical*, *historicalNat* and *RCP8.5* runs

Role of climate change

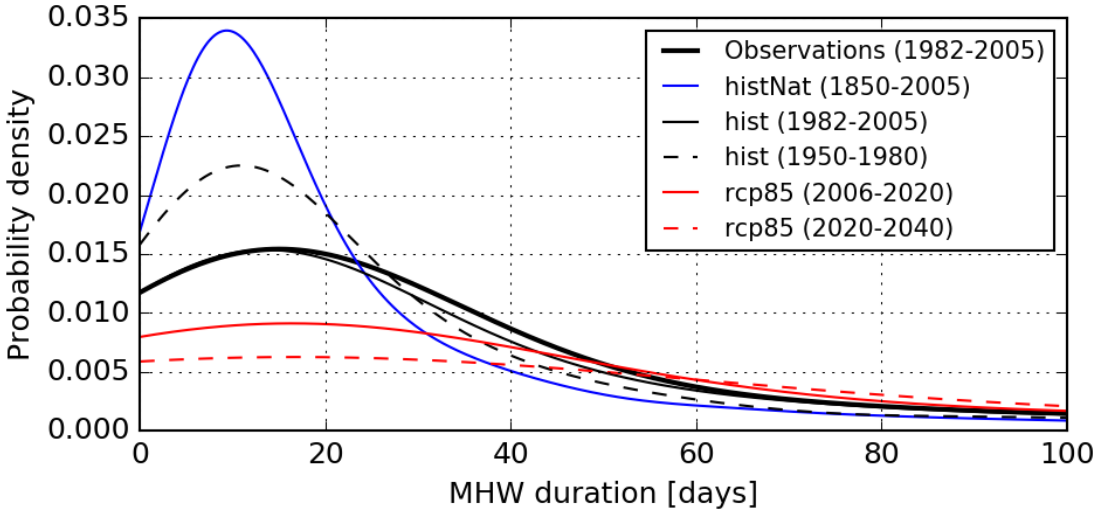
- Need *daily* SSTs, limits the number of available models:

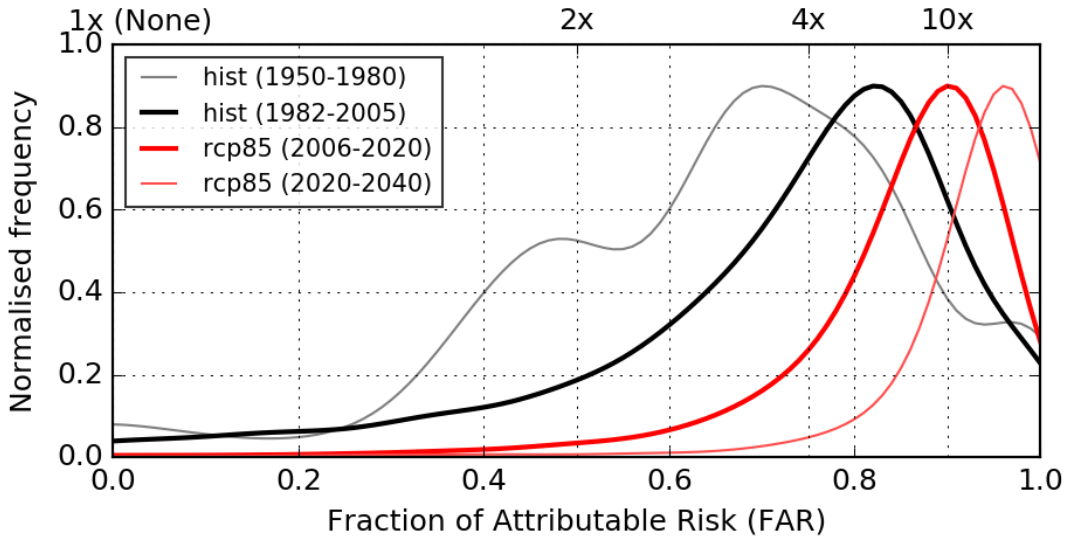
Model	Historical	HistoricalNat	RCP8.5	Bias correction
ACCESS1.3	3	3	1	1.32
CanESM2	1	3	5	1.10
CSIRO Mk3.6.0	10	10	10	1.42
CNRM-CM5	1	5	5	0.80
HadGEM2-ES	4	4	4	0.96
IPSL-CM5A-LR	6	3	4	0.98
IPSL-CM5A-MR	3	3	1	0.91
Total	**28**	**31**	**30**	

- Did a **bias correction** rather than a model selection (so few models):
- **Decompose SST** time series as follows: $T_t = a + bt + T_t^{\mathrm{S}} + T_t'$
- **Isolate** *linear trend* ($a + bt$) and *seasonal cycle* ($T^{\mathrm{s}}{}_t$) by regression, compare variance of non-seasonal variability (T'_t) between observations and model historical runs as a *ratio*
- **Bias correct**: *Scale variance of each model run* based on the calculated bias ratio, then add it back to the linear and seasonal component

Role of climate change

- **Attribution statement** made separately around 2nd-largest (intensity) and 2nd-longest (duration) event *(1911-1940 base period)*:
  - 3.1 °C
  - 377 days
- **Duration**: An event of this duration was
  - **4x as likely** in 1982-2005 (hist simulations) compared to the "natural world" (historicalNat 1850-2005 simulations) *[95% CI: 0.5-53x]*
  - **9x as likely** by 2006-2020 (RCP8.5 simulations) *[95% CI: 2-22x]*





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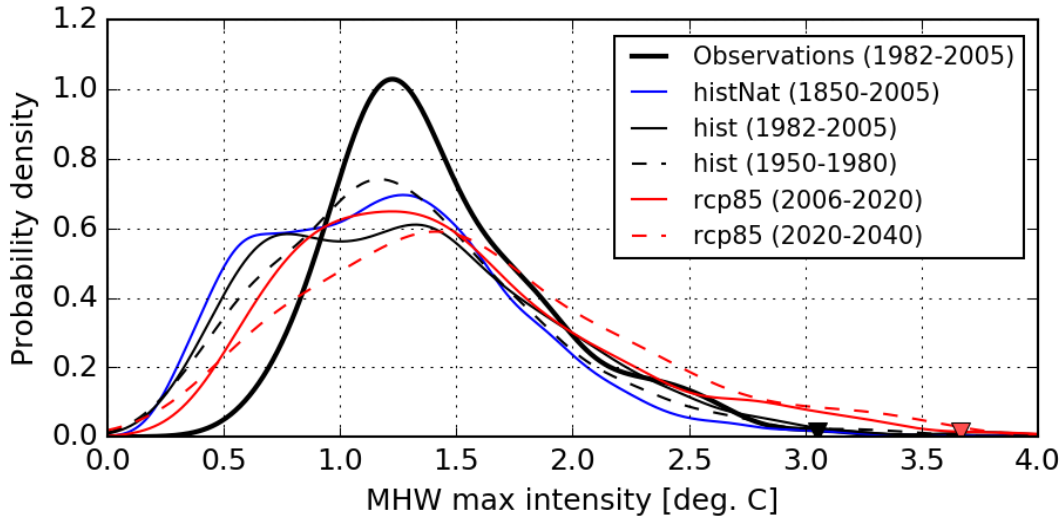
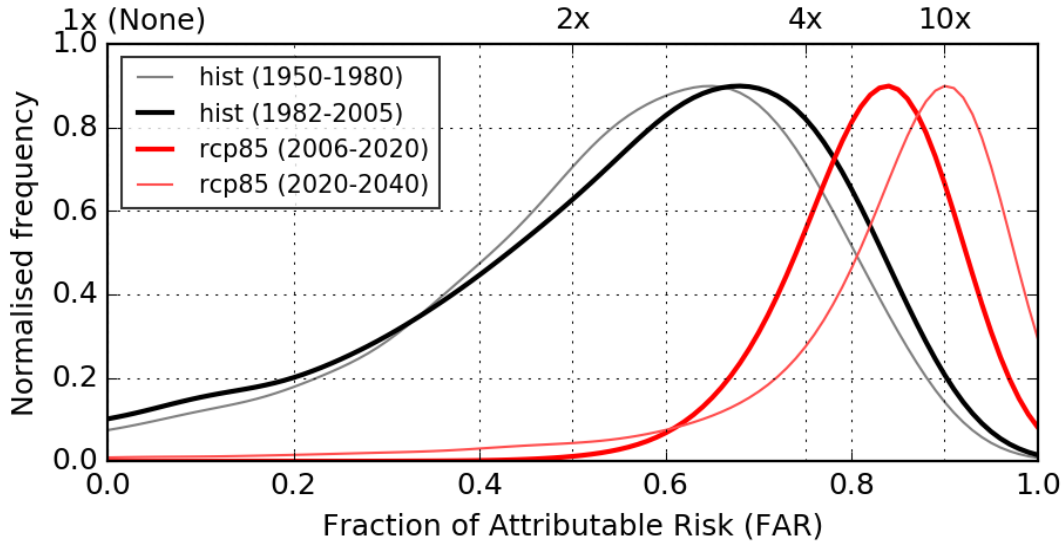
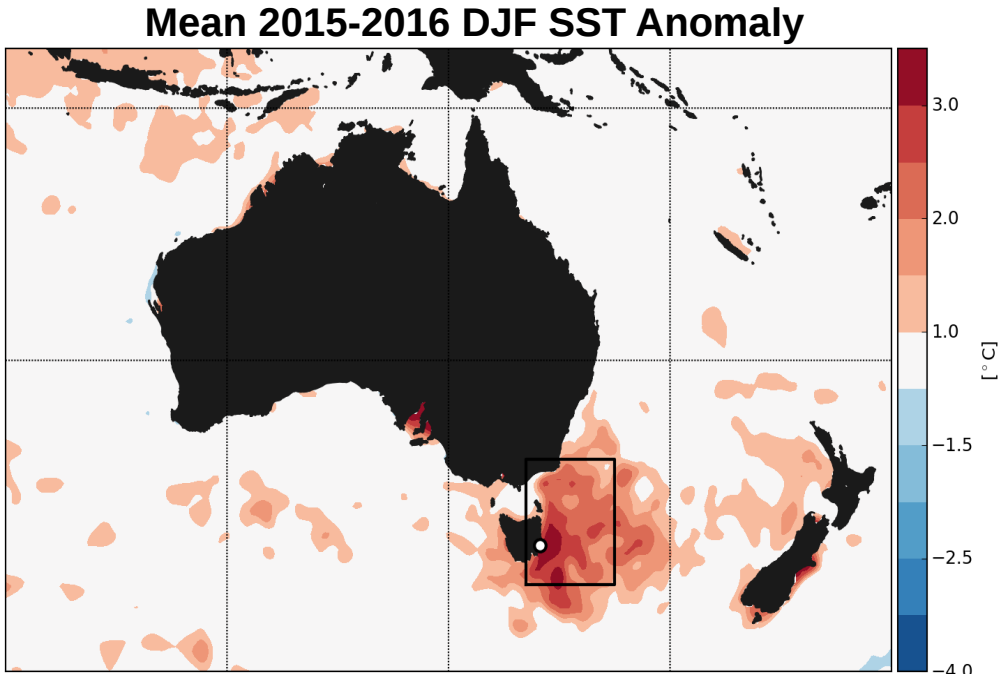
- **Intensity**: An event of this intensity was
  - **2x as likely** in 1982-2005 (hist simulations) compared to the "natural world" (historicalNat 1850-2005 simulations) *[95% CI: 1-6x]*
  - **6x as likely** by 2006-2020 *[95% CI: 3-13x]*
- → Virtually certain (>99%) that anthropogenic climate change increased the likelihood of an event of this duration or intensity by 2005-2020





Conclusions

1. The **2015/16 Tasman Sea MHW** was the **longest** and **most intense** ever recorded in this region
2. **Driven** by anomalous temperature advection (an **EAC Extension event**)
3. **Anthropogenic climate change** significantly **raised the likelihood** of such an event



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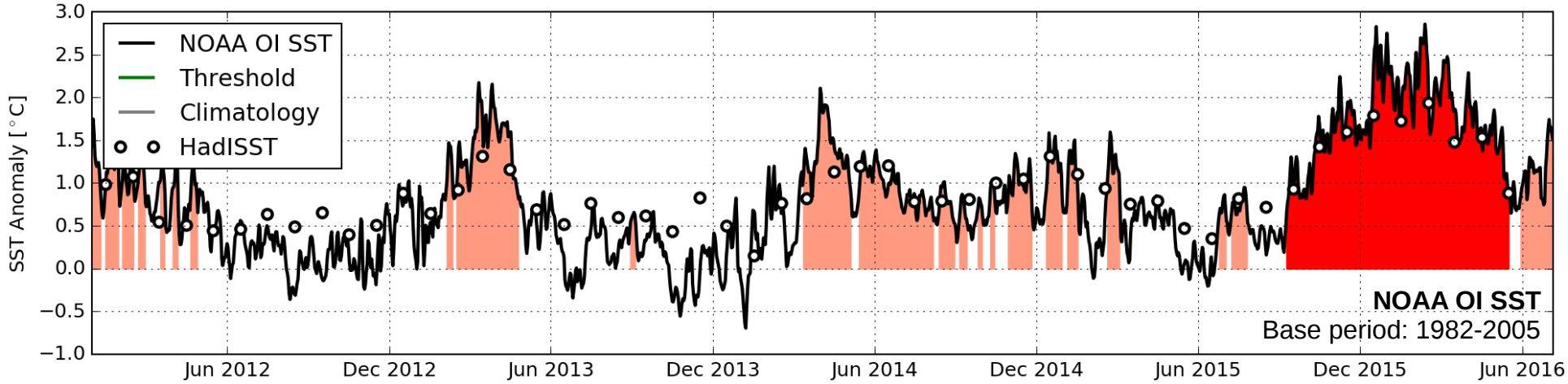
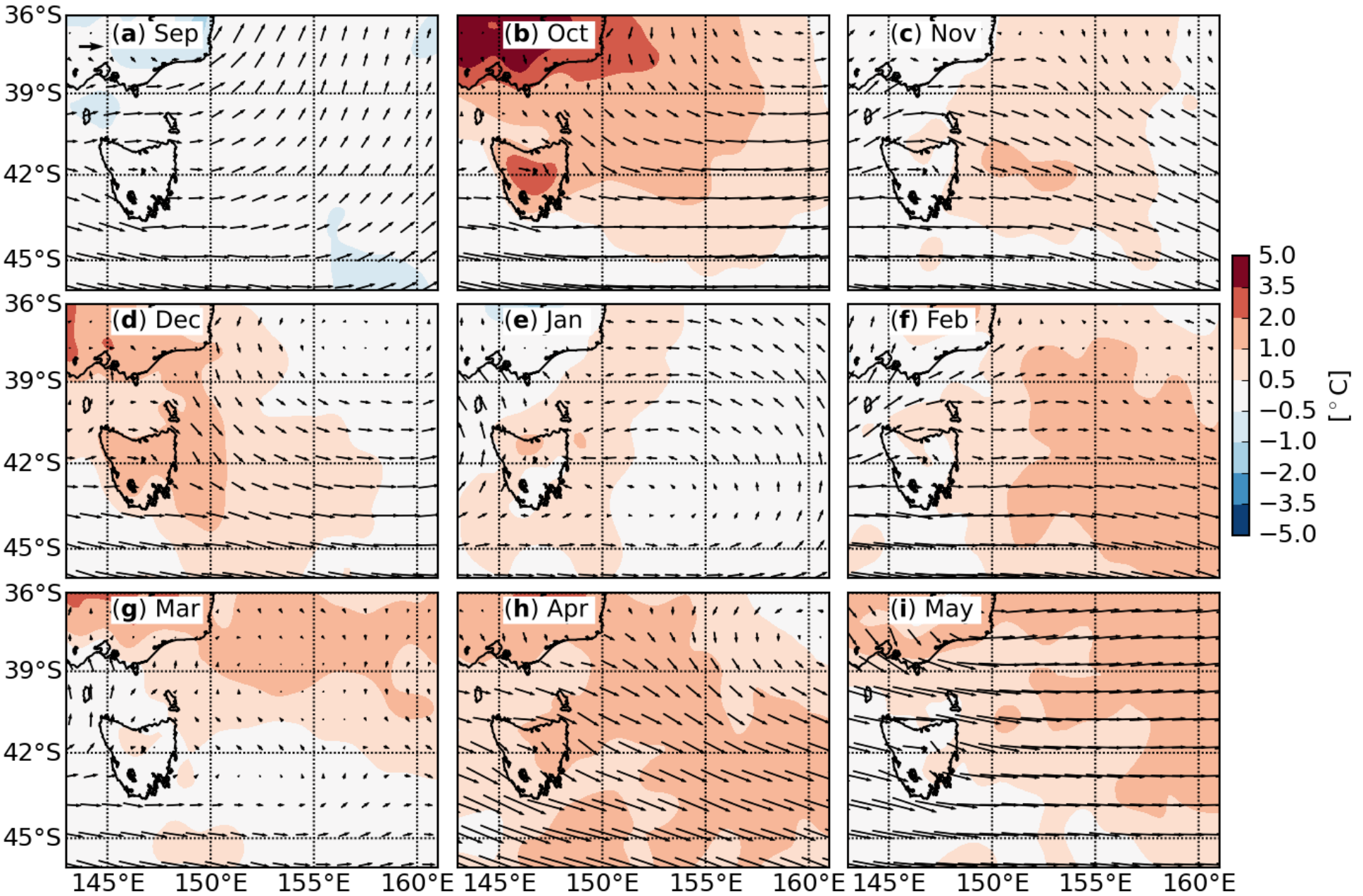


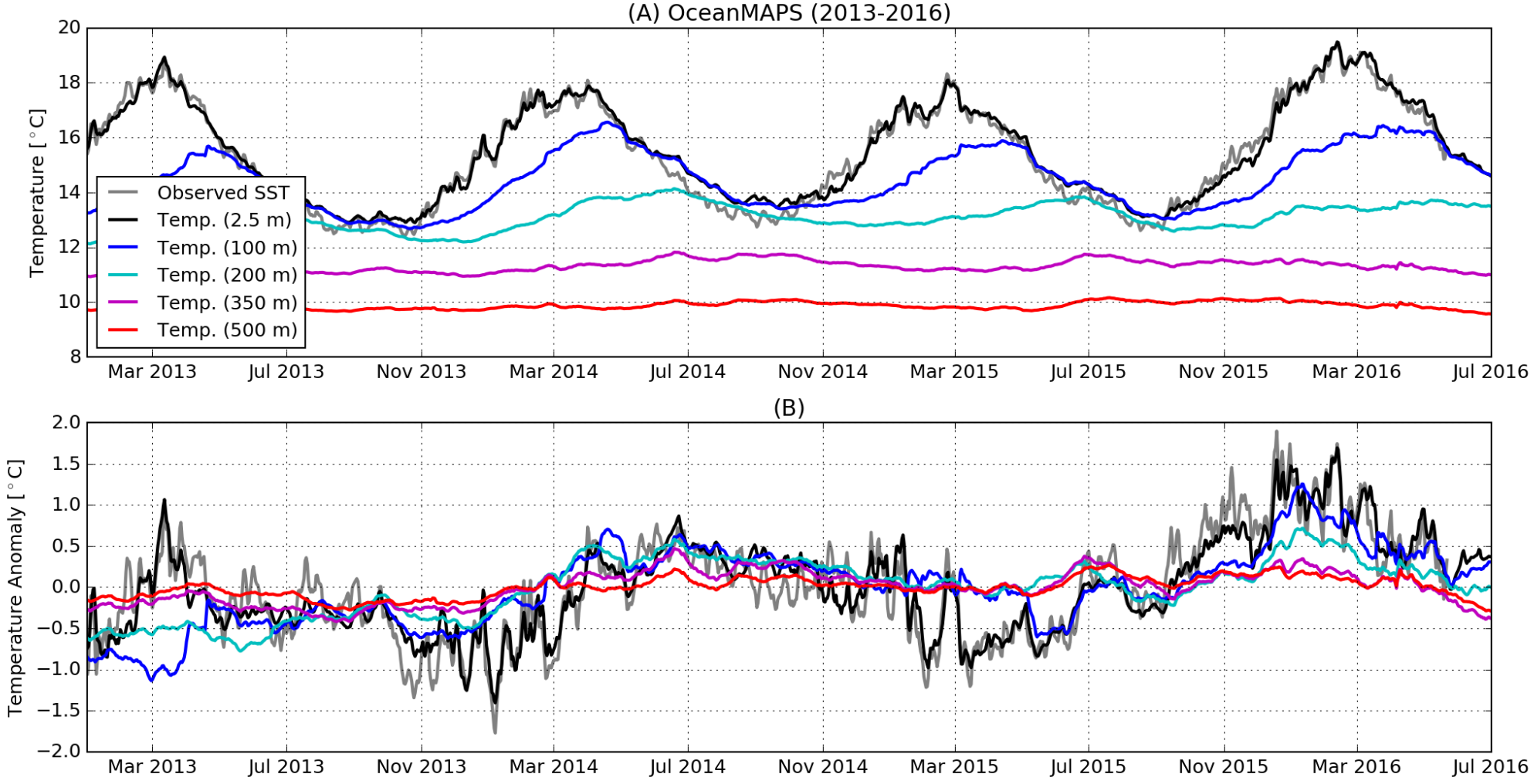
Evolution of the event

Monthly SAT and 10 m wind anomalies (NCEP CFSv2)



Physical drivers

- **<u>How well does OceanMAPS get the temperature?</u>**
- Good agreement at surface → we can trust OceanMAPS
- Warming evident down to 100-200 m → H = 100 m



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