Primary drivers of marine heatwaves in the Northwest Atlantic

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Introduction

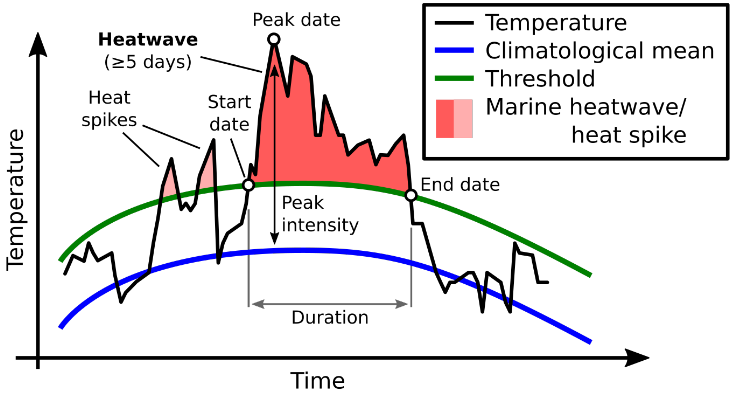
Marine heatwaves (MHWs): definition

"A prolonged discrete anomalously warm water event that can be described by its duration, intensity, rate of evolution, and spatial extent."

(Hobday et al., 2016)

- The temperature at a location exceeds the 90% percentile of that calendar day
- This occurs at least 5 days in a row with no more than a 2 day gap thereafter

Marine heatwaves (MHWs): schematic



(*Eric Oliver, www.marineheatwaves.org*)

Known drivers and effects of past MHWs

- Mediterranean 2003
  - Driver - Atmospheric forcing
  - Effect - Gorgonian mortality up to 80% (Garrabou et al., 2009)
- Western Australia 2011
  - Driver - La Nina + Abnormal Leeuwin Current movement onto coast (Benthuysen et al., 2014; Feng et al., 2013)
  - Effect - Permanent loss of 100+ km of kelp forest (Wernberg et al., 2016)
- Northwest Atlantic 2012
  - Driver - Atmos. forcing due to anomalous jet stream (Chen et al., 2015)
  - Driver - Labrador Current vs. Gulf Stream (Brickman et al., 2018)
  - Effect - Range shifts, early lobsters, CAN vs. USA (Mills et al., 2013)

Methods

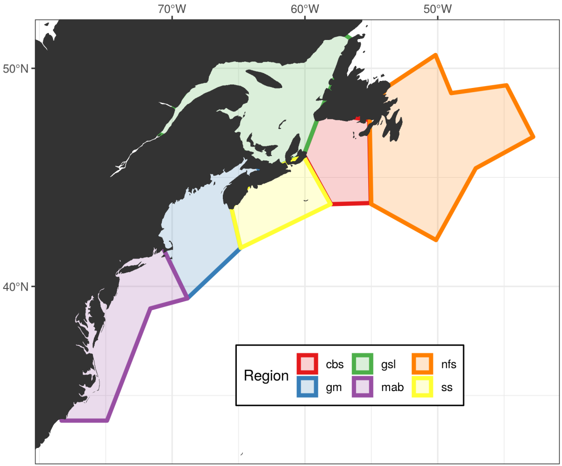
Departure from established methodology

- Primary drivers are generally determined by analysing the physical state during a single MHW
- Large MHWs are happening too rapidly to spend a year+ working on them one at a time
- Smaller events may also be important
- The use of self-organising maps (SOM) to identify MHW drivers has already been tested
- This technique allows a machine to show us which drivers are most prominent during hundreds of MHWs
- We are asking two questions:
  1. Are there recurrent environmental patterns during MHWs?
  2. If so, can these be detected/quantified by the computer?

Data

- NOAA OISST
  - Sea surface temperature (SST; °C)
- GLORYS
  - Mixed layer depth (MLD; m)
  - Surface ocean currents (U and V; m/s)
  - Mean sea level pressure (MSLP; hPa) - **NOT USED IN SOM**
- ERA 5
  - Surface air temperature (t2m; °C)
  - Net positive downward heat flux (Q_{net}; W/m2)
    - Latent + sensible heat flux + short + long-wave radiation (Q_e + Q_h + Q_s + Q_l)
  - Surface wind currents (U and V; m/s)

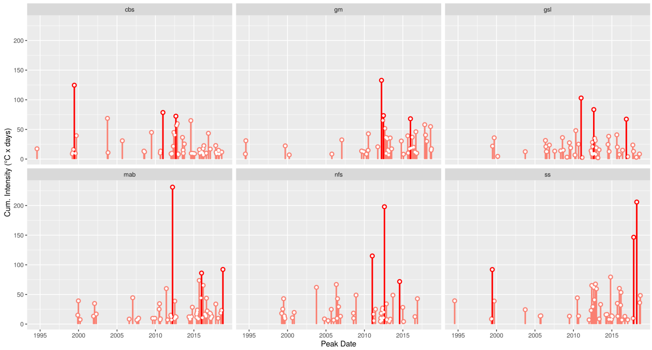
Study area



(Richaud et al., 2016)

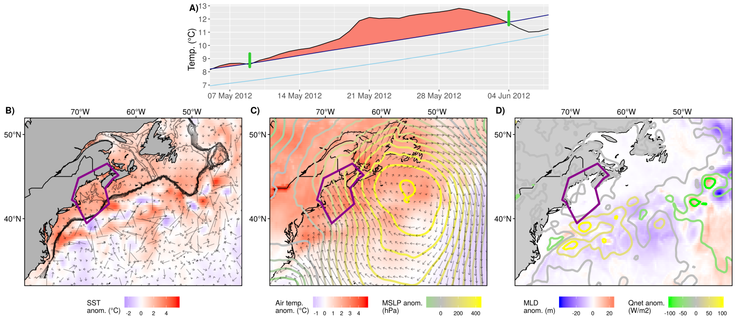
MHW detection

- Total of 298 MHWs calculated from the time series averaged over the pixels in the six regions



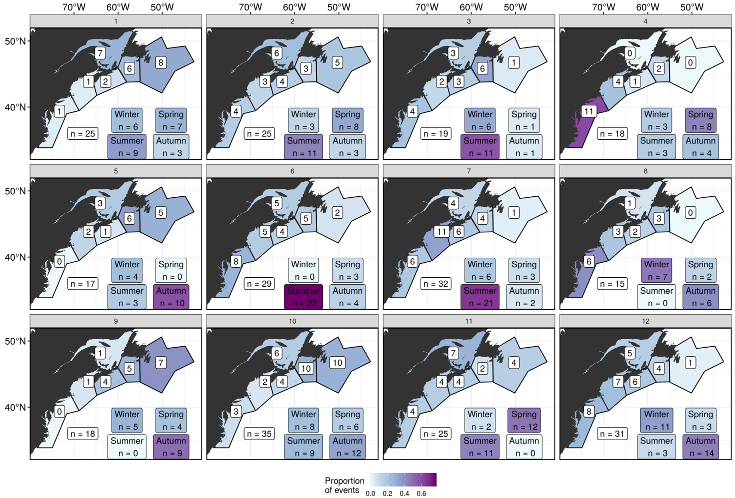
Data packets

- Data packet of mean anomalous air/sea state created for each MHW
- 289 data packets fed to SOM to produce 12 most common synoptic air/sea patterns

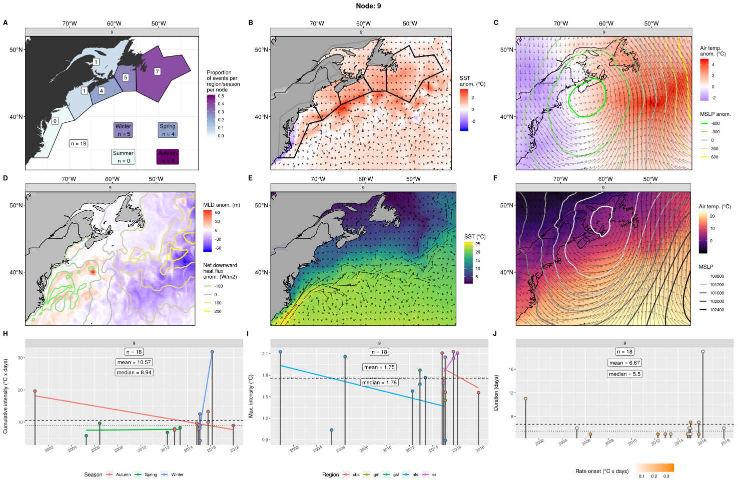


Results

All nodes


70°W 60°W 50°W
50°N
40°N
1
n = 25
Winter n = 6
Spring n = 7
Summer n = 9
Autumn n = 3
2
n = 25
Winter n = 3
Spring n = 8
Summer n = 11
Autumn n = 3
3
n = 19
Winter n = 6
Spring n = 1
Summer n = 11
Autumn n = 1
4
n = 18
Winter n = 3
Spring n = 8
Summer n = 3
Autumn n = 4
5
n = 17
Winter n = 4
Spring n = 0
Summer n = 3
Autumn n = 10
6
n = 29
Winter n = 0
Spring n = 3
Summer n = 22
Autumn n = 4
7
n = 32
Winter n = 6
Spring n = 3
Summer n = 21
Autumn n = 2
8
n = 15
Winter n = 7
Spring n = 2
Summer n = 0
Autumn n = 6
9
n = 18
Winter n = 5
Spring n = 4
Summer n = 0
Autumn n = 9
10
n = 35
Winter n = 8
Spring n = 6
Summer n = 9
Autumn n = 12
11
n = 25
Winter n = 2
Spring n = 12
Summer n = 11
Autumn n = 0
12
n = 31
Winter n = 11
Spring n = 3
Summer n = 3
Autumn n = 14
Proportion of events
0.0 0.2 0.4 0.6

Node 9


Node: 9
A
B
C
D
E
F
H
I
J
Proportion of events per region/season per node
Winter n = 5
Spring n = 4
Summer n = 0
Autumn n = 9
n = 18
SST anom. (°C)
Air temp. anom. (°C)
MSLP anom.
MLD anom. (m)
Net downward heat flux anom. (W/m2)
SST (°C)
Air temp. (°C)
MSLP
n = 18
mean = 10.57
median = 8.94
Cumulative intensity (°C x days)
Season Autumn Spring Winter
mean = 1.75
median = 1.76
Max. intensity (°C)
Region cbs gm gsl nfs ss
mean = 6.67
median = 5.5
Duration (days)
Rate onset (°C x days)

Conclusions

Conclusions

- The nodes tell three main stories:
  - Warm GS + air pushing up from south along coast
  - Warm air sitting over entire coast
  - Warm air being pushed over the AO from the South/Southeast onto the coast
- A few nodes tell smaller stories:
  - Short lived storms that barely manage to perturb T_{mix} for long enough to qualify as a MHW
  - These are distinctly different from the patterns associated with intense MHWs
- Overall the most intense MHWs occur during Autumn/Winter when they match patterns that are normally seen in Summer
- It is likely that this SOM technique will not work on scales larger than one meso-scale feature at a time

Acknowledgements

OCEAN FRONTIER INSTITUTE

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

References I

Benthuysen, J., Feng, M., and Zhong, L. (2014). Spatial patterns of warming off Western Australia during the 2011 Ningaloo Niño: quantifying impacts of remote and local forcing. *Continental Shelf Research* 91, 232–246. doi:10.1016/j.csr.2014.09.014.

Brickman, D., Hebert, D., and Wang, Z. (2018). Mechanism for the recent ocean warming events on the scotian shelf of eastern canada. *Continental Shelf Research* 156, 11–22.

Chen, K., Gawarkiewicz, G., Kwon, Y.-O., and Zhang, W. G. (2015). The role of atmospheric forcing versus ocean advection during the extreme warming of the Northeast U.S. continental shelf in 2012. *Journal of Geophysical Research: Oceans* 120, 4324–4339. doi:10.1002/2014JC010547.

References II

Feng, M., McPhaden, M. J., Xie, S.-P., and Hafner, J. (2013). La Niña forces unprecedented Leeuwin Current warming in 2011. *Scientific Reports* 3, 1277. doi:10.1038/srep01277.

Garrabou, J., Coma, R., Bensoussan, N., Bally, M., Chevaldonné, P., Cigliano, M., et al. (2009). Mass mortality in Northwestern Mediterranean rocky benthic communities: effects of the 2003 heat wave. *Global Change Biology* 15, 1090–1103. doi:10.1111/j.1365-2486.2008.01823.x.

Hobday, A. J., Alexander, L. V., Perkins, S. E., Smale, D. A., Straub, S. C., Oliver, E. C., et al. (2016). A hierarchical approach to defining marine heatwaves. *Progress in Oceanography* 141, 227–238.

References III

Mills, K., Pershing, A., Brown, C., Chen, Y., Chiang, F.-S., Holland, D., et al. (2013). Fisheries Management in a Changing Climate: Lessons From the 2012 Ocean Heat Wave in the Northwest Atlantic. *Oceanography* 26, 191–195. doi:10.5670/oceanog.2013.27.

Richaud, B., Kwon, Y.-O., Joyce, T. M., Fratantoni, P. S., and Lentz, S. J. (2016). Surface and bottom temperature and salinity climatology along the continental shelf off the canadian and us east coasts. *Continental Shelf Research* 124, 165–181.

References IV

Wernberg, T., Bennett, S., Babcock, R. C., Bettignies, T. D., Cure, K., Depczynski, M., et al. (2016). Climate driven regime shift of a temperate marine ecosystem. *Science* 149, 2009–2012. doi:10.1126/science.aad8745.