Along-shore structure of marine heat wave events in the California Current System

Gwendolyn Larson[1], Carlos Moffat[1], Melanie R. Fewings[2], Kevin S. Brown[3]

[1] School of Marine Science and Policy, University of Delaware
[2] College of Earth, Ocean, and Atmospheric Sciences, Oregon State University
[3] Department of Pharmaceutical Sciences and School of Chemical, Biological, and Environmental Engineering, Oregon State University

Summary and Conclusions

- **Goal:** To investigate the along-shore structure of past MHWs in the California Current System (CCS)
  - The MHW of 2013-16 had an unusual dipole shape in summer 2015 caused by a prolonged stage of a regional wind pattern[3]; this shape prompted our study. Specifically, we set out to:
    a) Determine if other identified MHWs bore the same unusual shape as the July 2015 event, and if so, had experienced the same prolonged stage of the regional wind pattern
    b) If other identified MHWs did not resemble that event, explore what is the typical along-shore structure of MHWs in the CCS
- **Conclusion**: In this preliminary analysis, we identified 104 MHW events in the system, and selected 16 of the most intense for further investigation.
  - The most intense MHW events along the CCS show large along-shore variability in both temperature and wind stress anomalies.
  - Typical along-shore structure resembled stages of the 2013-16 MHW, but an actual dipole was rare.
  - Observed patterns included a (1) Northern warming section, (2) Southern Warming Section, (3) Reverse of July 2015 pattern: Cold – Warm – Cold, and (4) July 2015-Like: Warm – Cold – Warm

Methods and Data

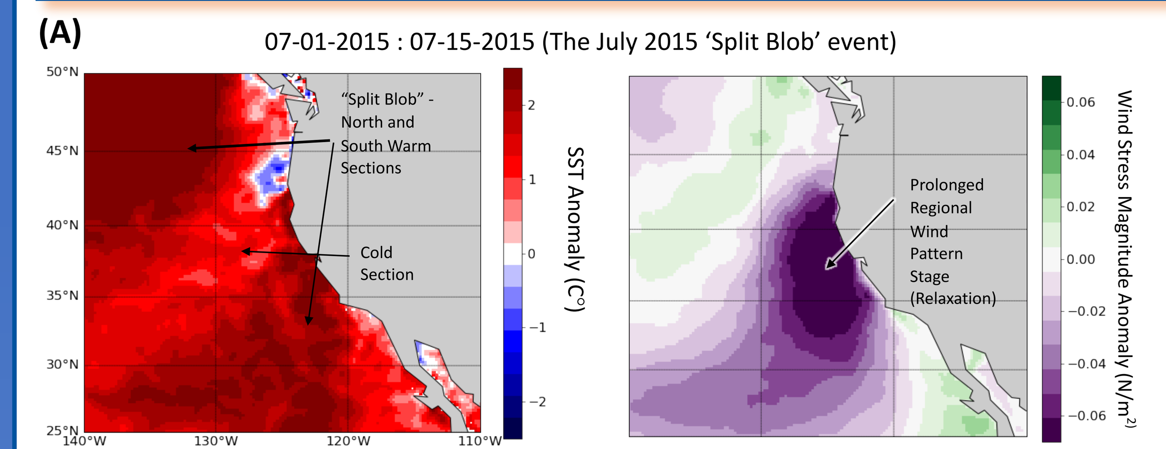
- **Sea Surface Temperature Data**:
  - Group for High Resolution Sea Surface Temperature (GHRSST), Level 4 (gridded, gap-free), daily data (doi:10.5067/GHCMC-4FM02).[1]
  - Sept 1, 1991 to March 17, 2017, 0.2° x 0.2° spatial resolution
- **Wind Stress Magnitude Data**:
  - European Centre for Medium-Range Weather Forecasts (ECMWR), fifth generation atmospheric reanalysis of the global climate product (ERA5)[2]
  - ERA5 data hourly 0.25° x 0.25 ° spatial resolution
- **Composite average anomalies:** SST and Wind Stress Magnitude
  - Created a daily climatology and anomalies from SST data and calculated wind stress magnitude anomaly at each grid point
  - Constructed composite "month" of average peaks for each MHW event. Average peaks refer to maximum intensity of SST anomalies averaged over entire grid during a MHW event. "Months" are then constructed by taking 30 days with the peak as the 15th day. Thus, we constructed the composite average anomaly by taking 15 days before the peak and 15 days after the peak and averaging the anomalies together.
- **MHW definition**: We used the standard definition of MHWs: they had to be 'anomalously warm', 'prolonged,' and 'discrete.'[4] While the threshold of the 90th percentile is typically recommended to qualify as anomalously warm, We used the 98th percentile for this study to focus on the most extreme events. 'Prolonged' refers to the length of time for which this anomalously warm water must persist to qualify as a MHW, and we adhered to the standard of at least five days.[4] We also followed the usual definition of 'discrete' as referring to a well-defined start and end point, with gaps between events having to be greater than 2 days to qualify as separate events.[4]

References & Acknowledgments

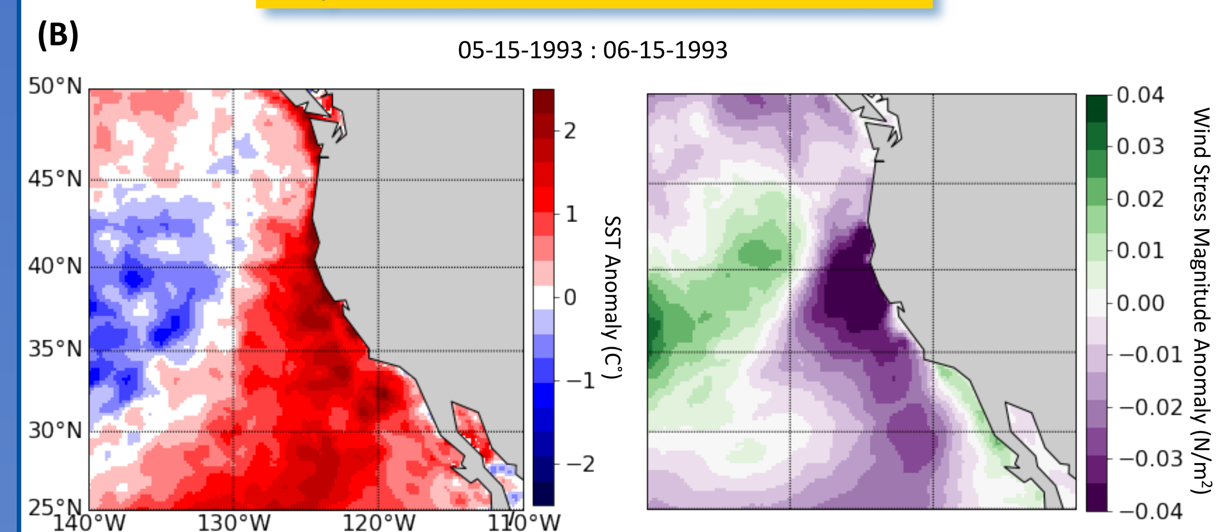
1. Canada Meteorological Center. 2012. GHRSST Level 4 CMC0.2deg Global Foundation Sea Surface Temperature Analysis (GDS version 2). Ver. 2.0. PO.DAAC, CA, USA. Dataset accessed [2019-02-11] at https://doi.org/10.5067/GHCMC-4FM02.
2. Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS). https://cds.climate.copernicus.eu/cdsapp#!/home
3. Fewings, M. R. and K. S. Brown (2019), Regional Structure in the Marine Heat Wave of Summer 2015 Off the Western United States, *Frontiers in Marine Science*, 6, doi:10.3389/fmars.2019.00564.
4. Hobday, A. J., L. V. Alexander, S. E. Perkins, D. A. Smale, S. C. Straub, E. C. J. Oliver, J. A. Benthuysen, M. T. Burrows, M. G. Donat, M. Feng, N. J. Holbrook, P. J. Moore, H. A. Scannell, A. Sen Gupta, and T. Wernberg (2016), A hierarchical approach to defining marine heatwaves, *Progress in Oceanography*, 141, 227-238, doi:10.1016/j.pocean.2015.12.014.
5. Paek, H., J. Yu, and C. Qian (2017), Why were the 2015/2016 and 1997/1998 extreme El Niños different? *Geophysical Research Letters*, 44(4), 1848-1856, doi:10.1002/2016GL071515.

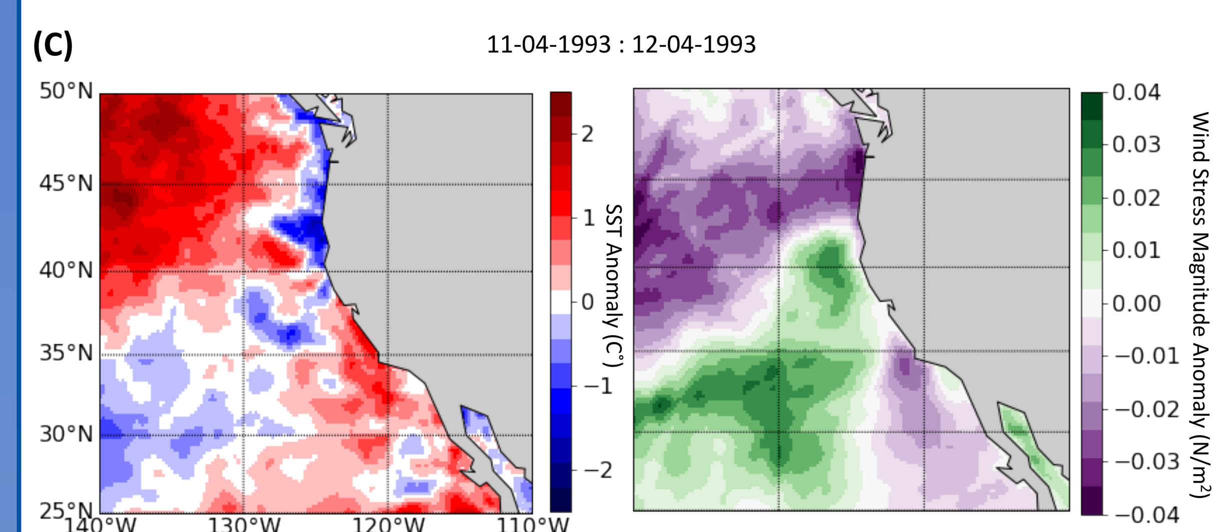
- This work was funded by NASA Ocean Vector Winds Science Team grant 80NSSC18K1611 and the University of Delaware School of Marine Science and Policy.

Examples of Variability in the Along-shore Structure of MHW Events



July 2015-Like: Warm – Cold – Warm





Reverse of July 2015 pattern: Cold – Warm - Cold

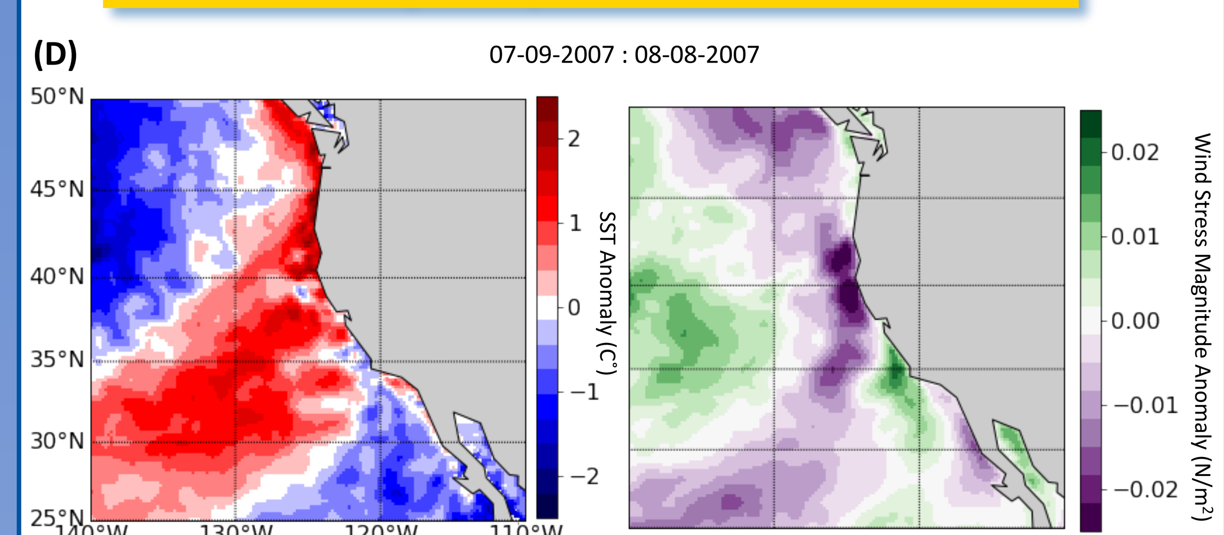


Figure: Composite anomalies for MHW events. (A) The July 2015 pattern, averaged over 15 days during the time the split structure was known to be occurring[3]. (B) and (C) July 2015-like dipole events. Both are monthly composite anomalies averaged over 30 days. (D) Cold – Warm – Cold event monthly composite anomaly averaged over 30 days.

- Significant along-shore variability was observed in most large MHW events in the CCS. While there were events the did resemble the split structure of July 2015 such as the two examples in the "July 2015-Like: Warm – Cold – Warm" category, there was far more variability within the alongshore structure of the study group of MHW events within the CCS.
- In most of the intense events, there is a general co-location of wind and SST anomalies, suggesting that, as observed during July 2015[3], wind forcing plays a key role in modulating these SST patterns. Strong wind anomalies such as the ones that were the predominant factor in July 2015[3] were observed during other MHWs, but other configurations were also observed. Work into the influence of wind anomalies in the heating of the MHWs is ongoing.
- For example, during the 1993 event, the dipole structure is shifted south, with a minimum SST anomaly and maximum wind anomalies in the same region where the opposite was true during July 2015.

Seasonality of MHWs in the CCS

- A majority of events begin in the fall(SON)/spring(MAM) (13/16 events) and end in the fall/summer(JJA) (12/16 events). Exceptions include the 2013-16 MHW, which began in December, and the 1996-98 MHW which ended in April, which was associated with a strong ENSO event.
- We found that 8/16 events had average peaks that occurred in the summer months, 4 events had peaks that occurred in the spring months, and the final 4 events had peaks that occurred in the fall. No events had average peaks that occurred in the winter months (DJF).
- Local maximum intensity had a similar pattern to that seen in the average peaks (not shown). 10/16 events experienced their local maximum intensities in the summer; for 5 events it occurred in the fall months. There was one outlier event (2002-3 MHW) for which the local maximum occurred in December; its average peak occurred in the fall.
- The two largest events and thus peaks were from the from the 1996-98 MHW and the 2013-16 MHW. Their peaks were the end of May and mid July, respectively.
- There were five events that overlapped at least partially with El Nino events. The 1996-98 and 2013-16 MHWs both coincided with two of the strongest El Nino events on record[5]. The 1991-92 event, 2002-2003 event and the 2009 event also coincided with El Nino events.

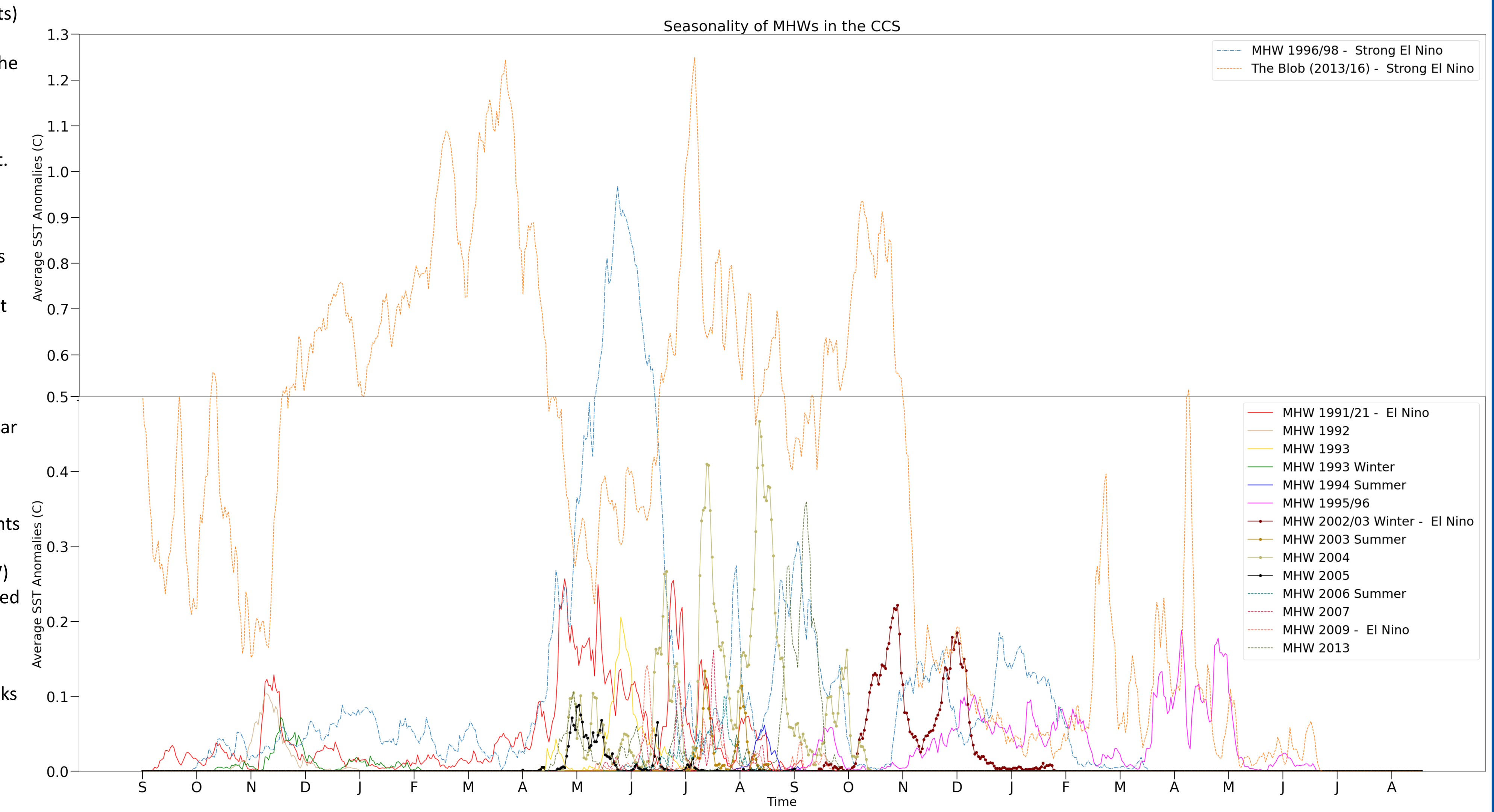


Figure: SST anomalies averaged over entire gridded area (25˚N to 50˚N, 110˚W to 140˚W) for each individual MHW. Each MHW is then plotted on the same graph from September year 1 to September year 3, to understand the seasonality and comparative average SST anomalies. Average peaks refer to maximum intensity of SST anomalies averaged over entire grid during a MHW event. Local maximum refers to maximum intensity of the SST anomaly at a single point in entire grid during a MHW event.

Evolution of the Along-Shore Structure of MHW Events

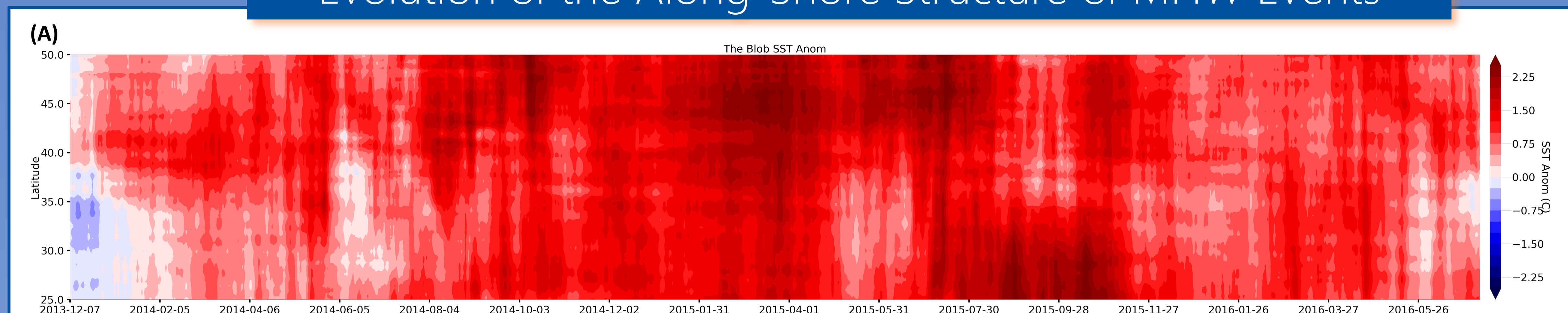
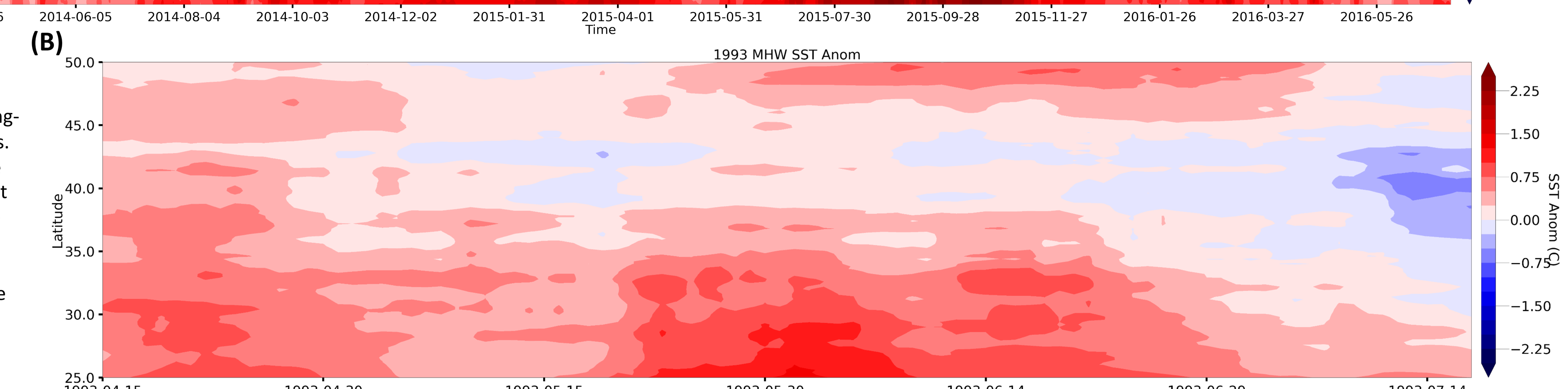


Figure: SST anomalies were averaged zonally to get daily along-shore (along a latitude line) slices. Each slice represents a day in the event. Variability along the extent of the slice displays the structure of the anomalies for that day. Compacted into one figure this then displays the evolution of the along-shore and temporal structure of the SST anomalies during an event.



- SST Anomalies during 2013-16 (A) were primarily positive, except for the very beginning. If SST anomalies were not anomalous positive they hovered close to zero. This is however not the case with all MHW events. (B) and (C) are the two examples of other events with strong along-shore variability: Throughout the evolution of both MHWs, positive and negative anomalies are prominent features of the events.