Tracking Ocean Temperature Extremes with Multidimensional Image Processing

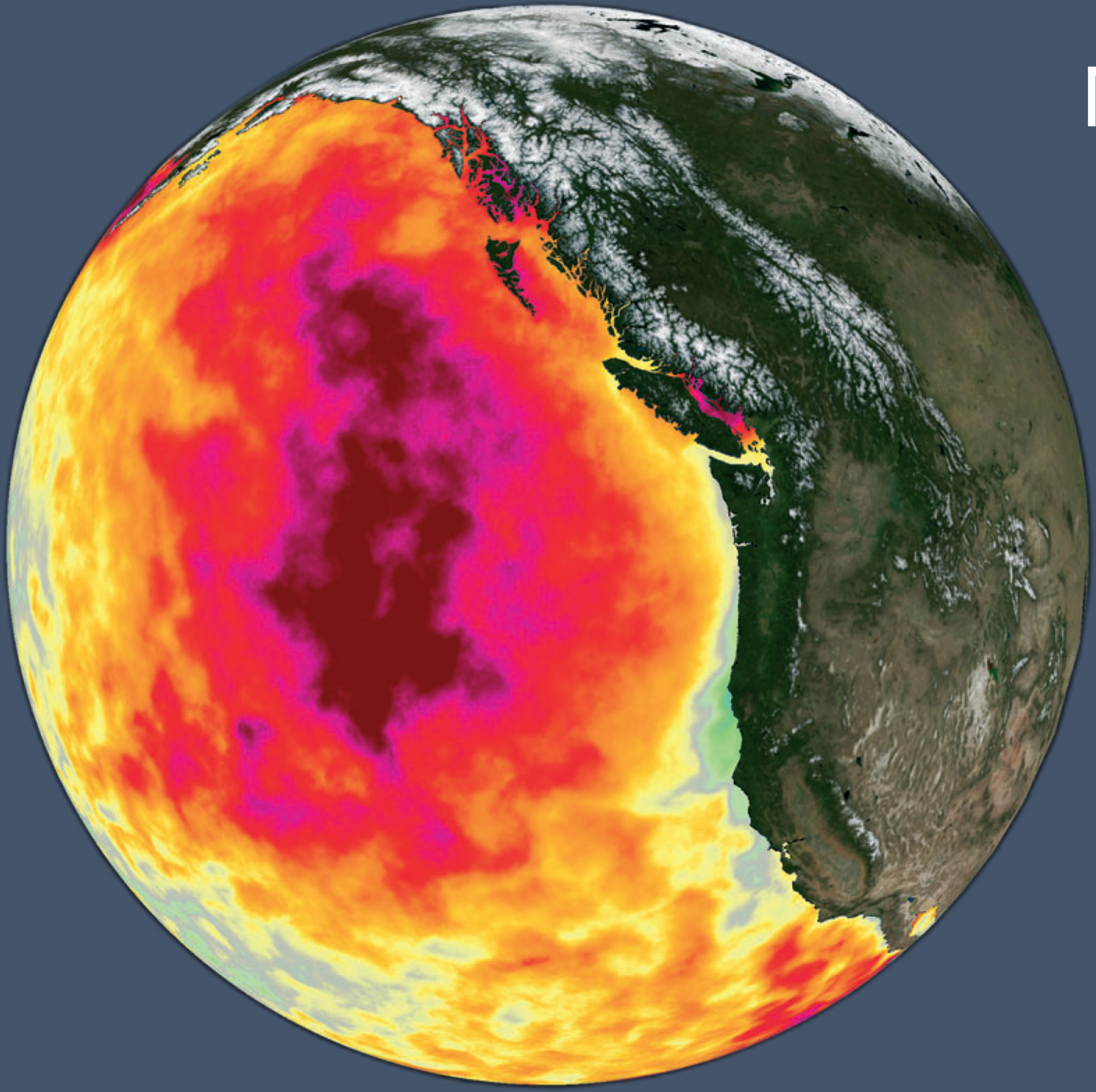
Hillary Scannell, PhD

Postdoctoral Research Scientist – Columbia University, New York, NY

Jupiter Intelligence « October 14, 2021

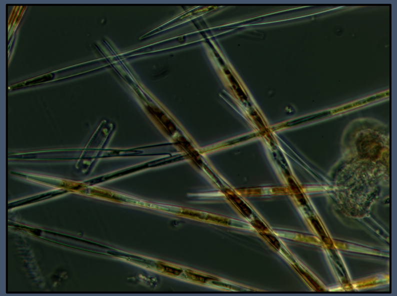
“The Blob” – May 2015

Sea Surface Temperature Anomalies

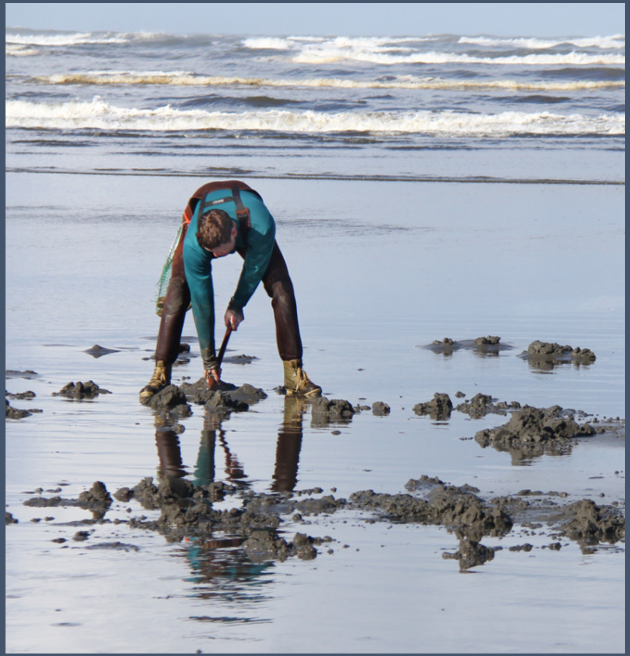


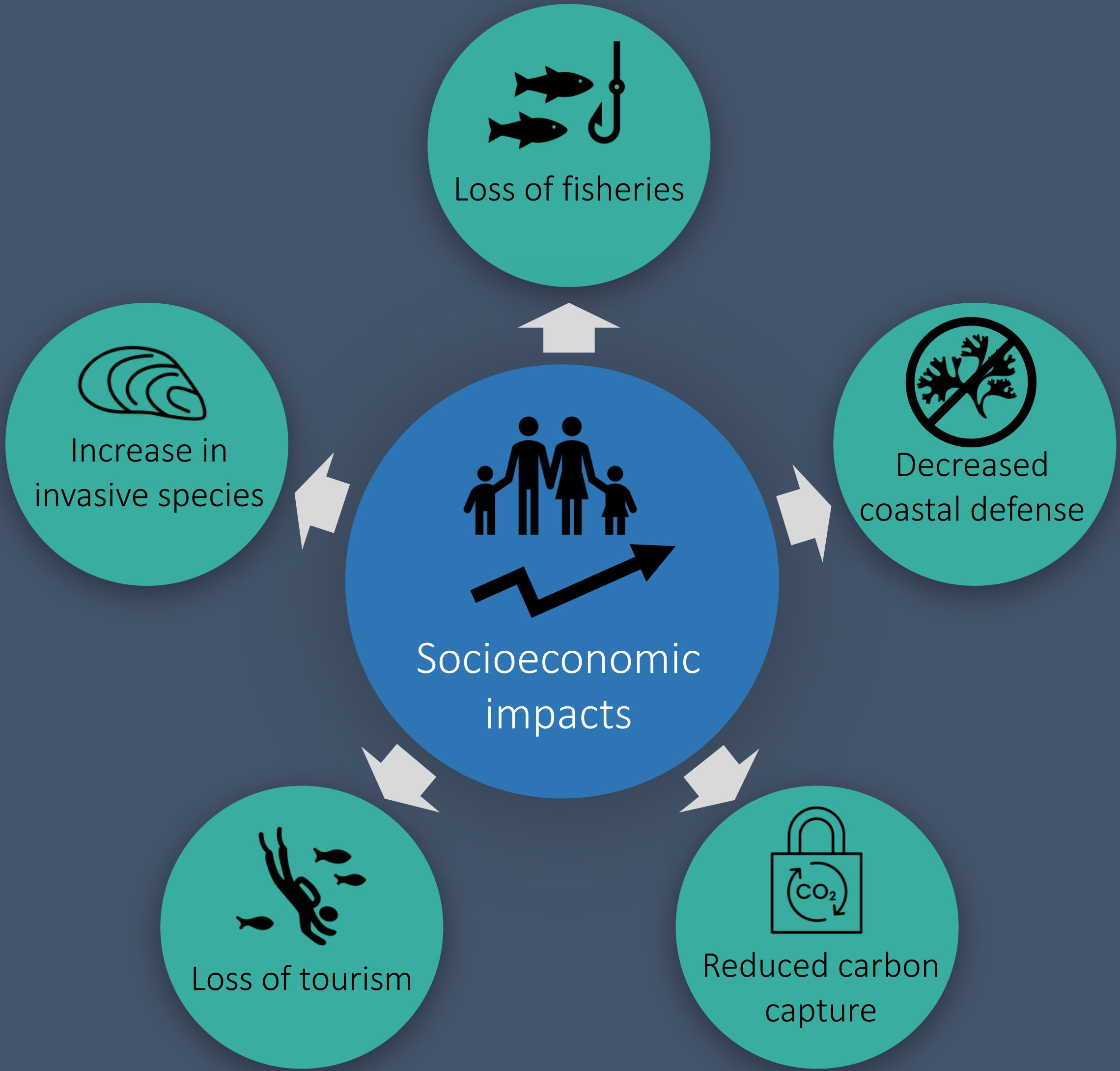
Marine Heatwaves

prolonged
discrete
anomalously
warm water
events



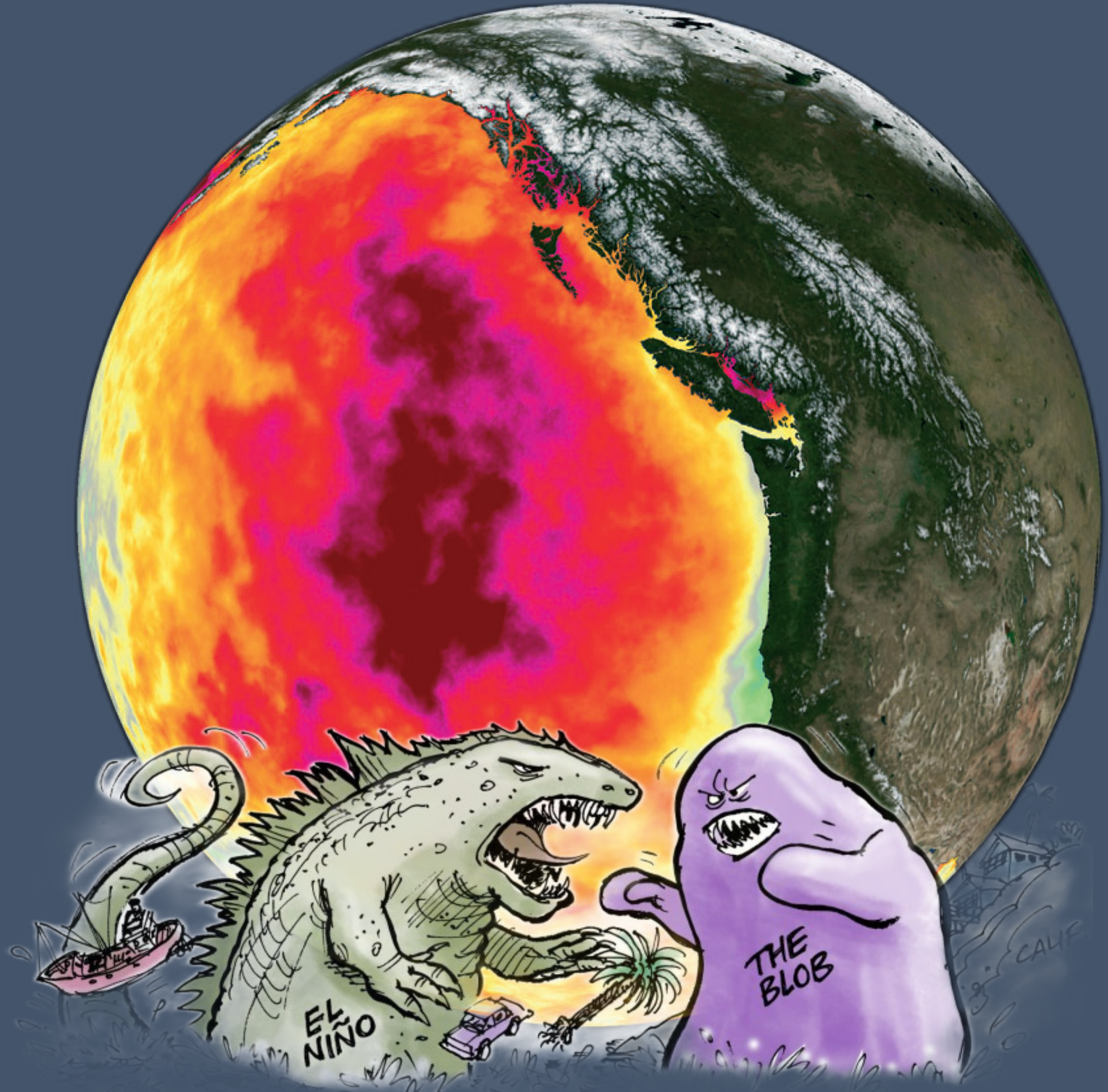
Marine heatwaves cause significant socioeconomic impacts…

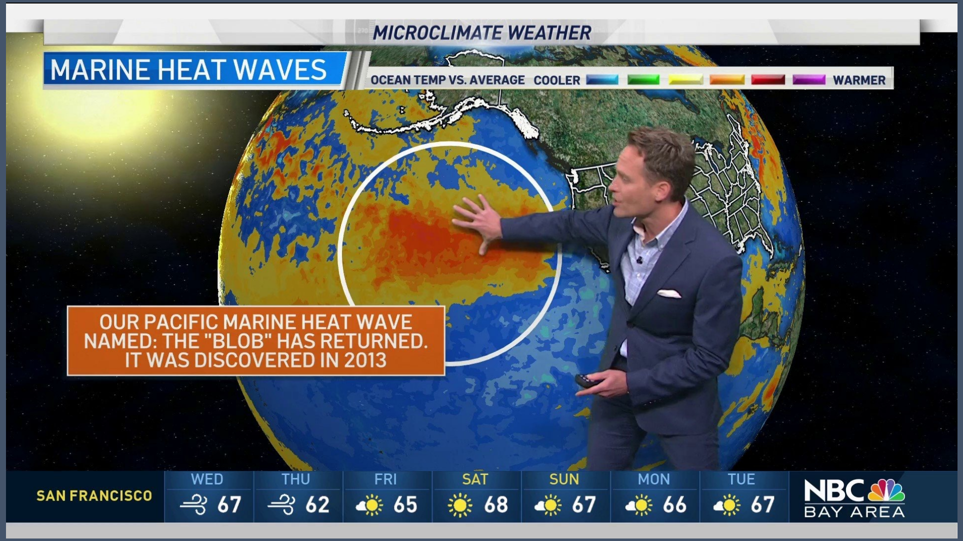




“The Blob” – May 2015

Sea Surface Temperature Anomalies

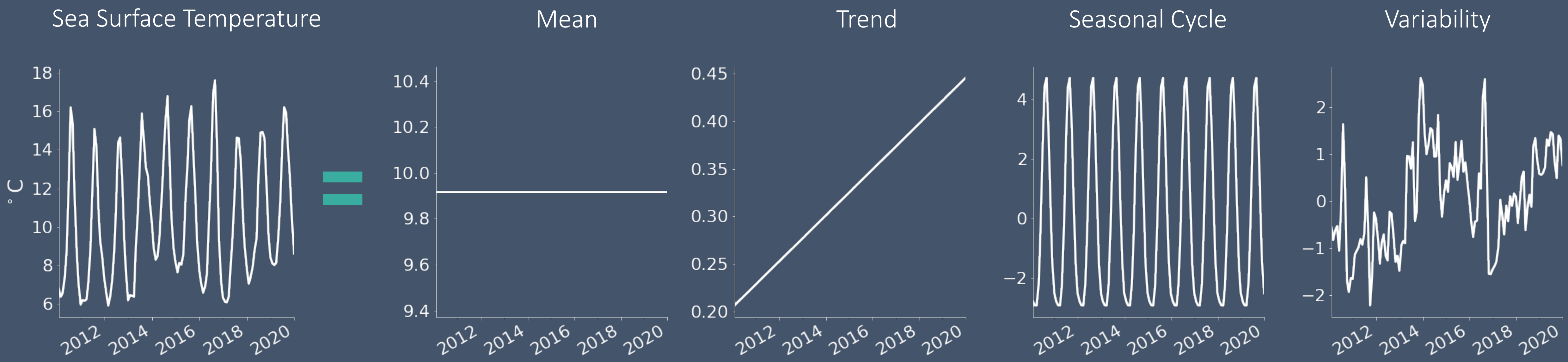





‘Warm blob’ in Pacific Ocean linked to weird weather across the U.S.

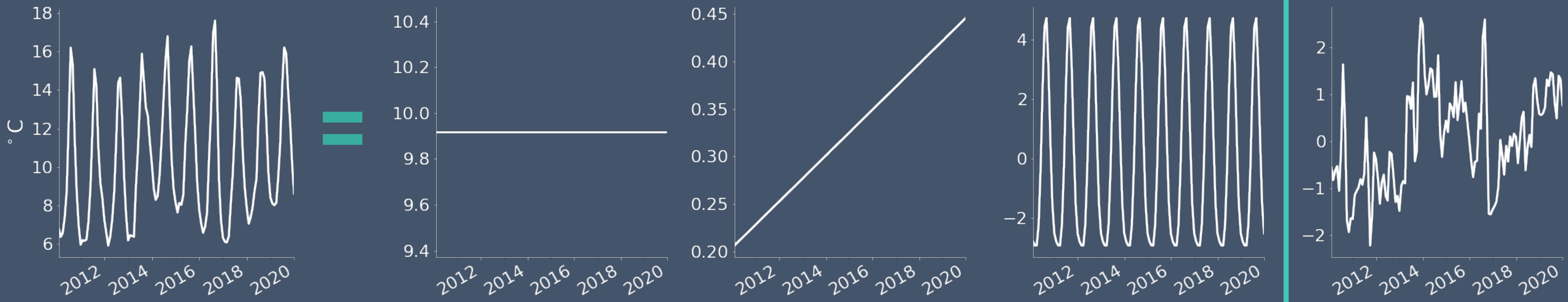
UW NEWS

Characterization of Marine Heatwaves



Characterization of Marine Heatwaves

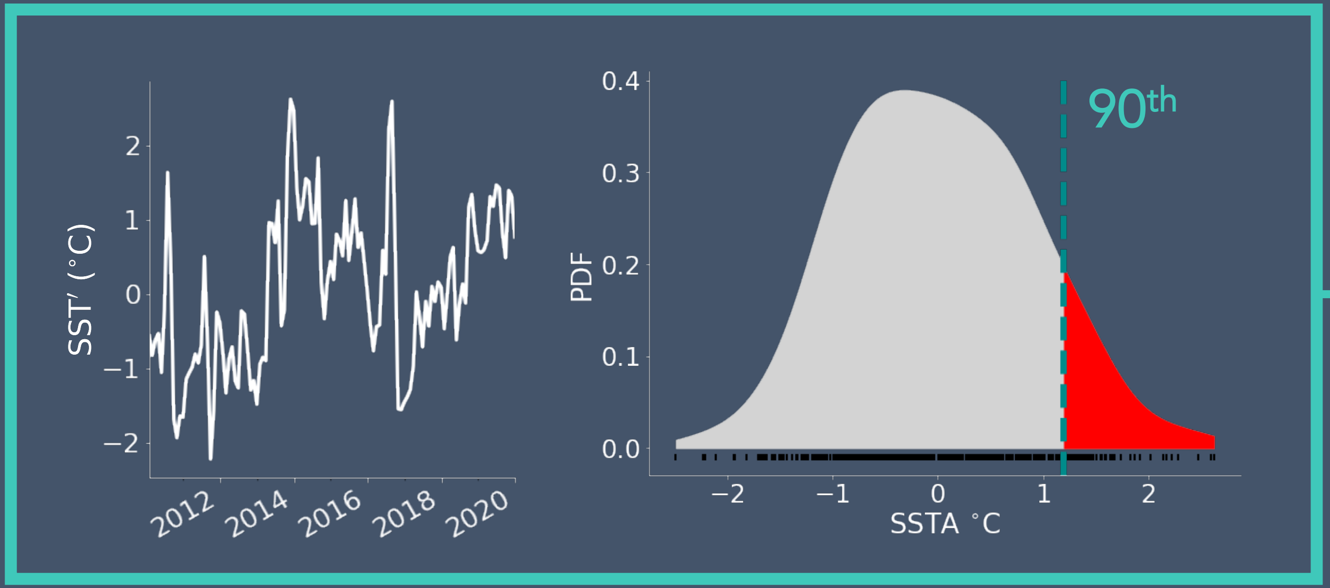
Sea Surface Temperature = Mean + Trend + Seasonal Cycle + Variability



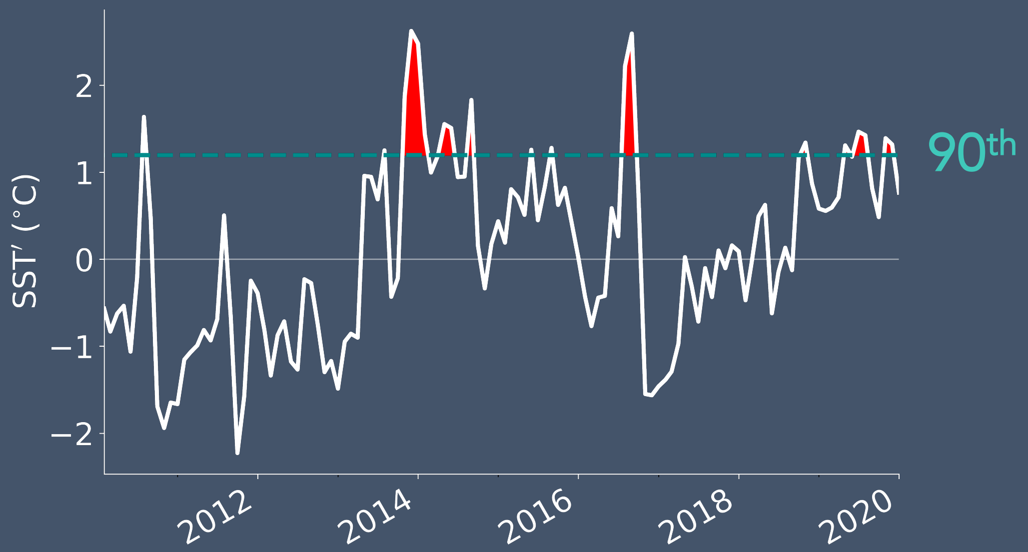
Characterization of Marine Heatwaves

Variability

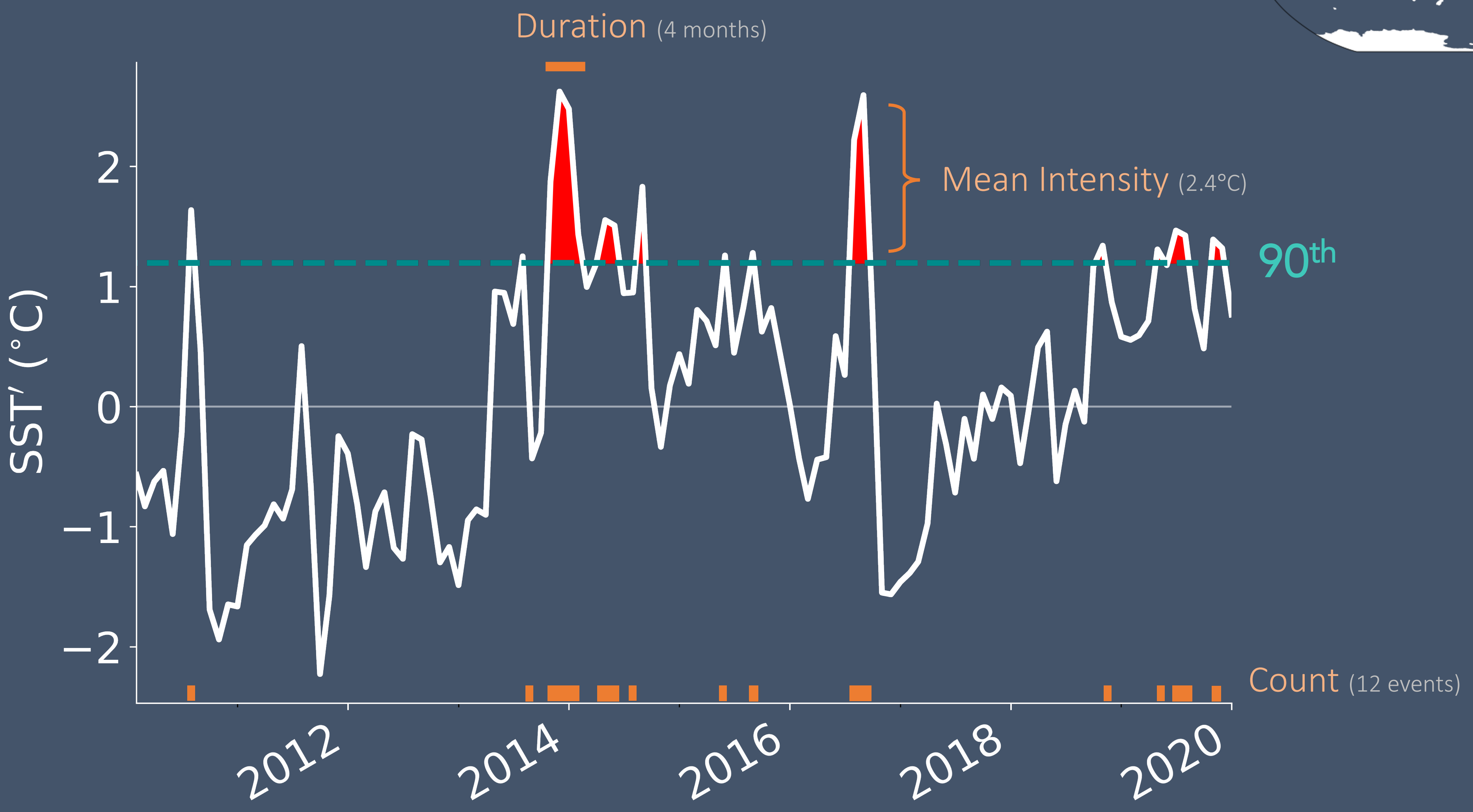
$$SST' = SST - (Mean\ + Trend\ + Seasonal\ Cycle)$$

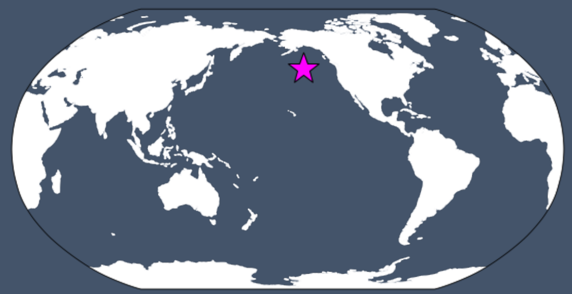


Marine Heatwaves > 90th percentile

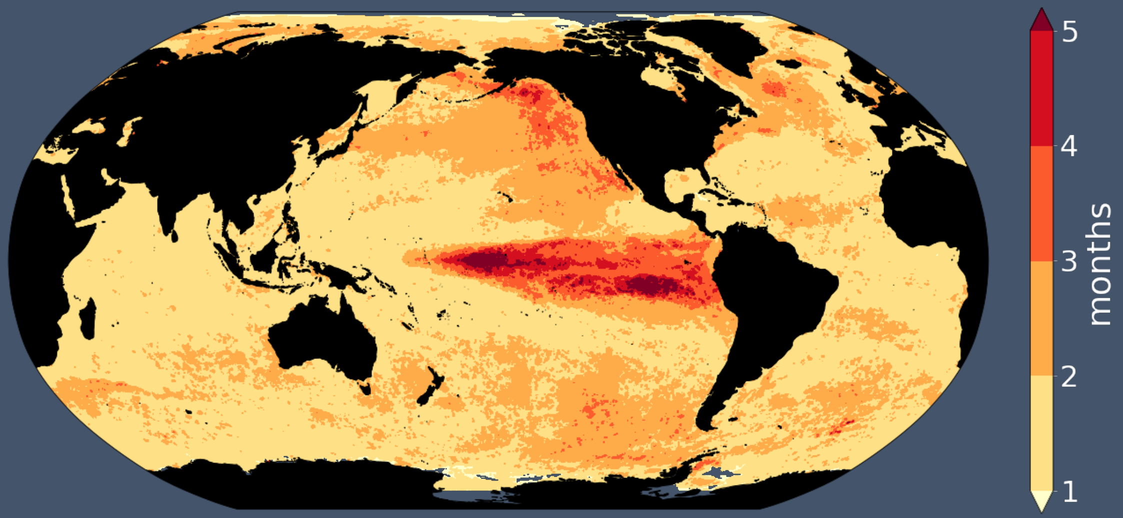


Characterization of Marine Heatwaves

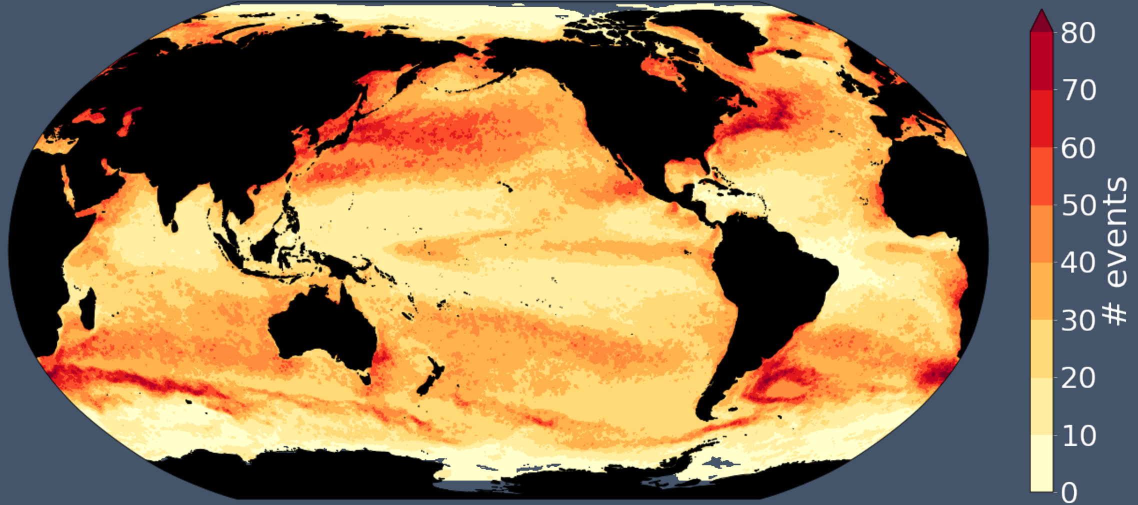




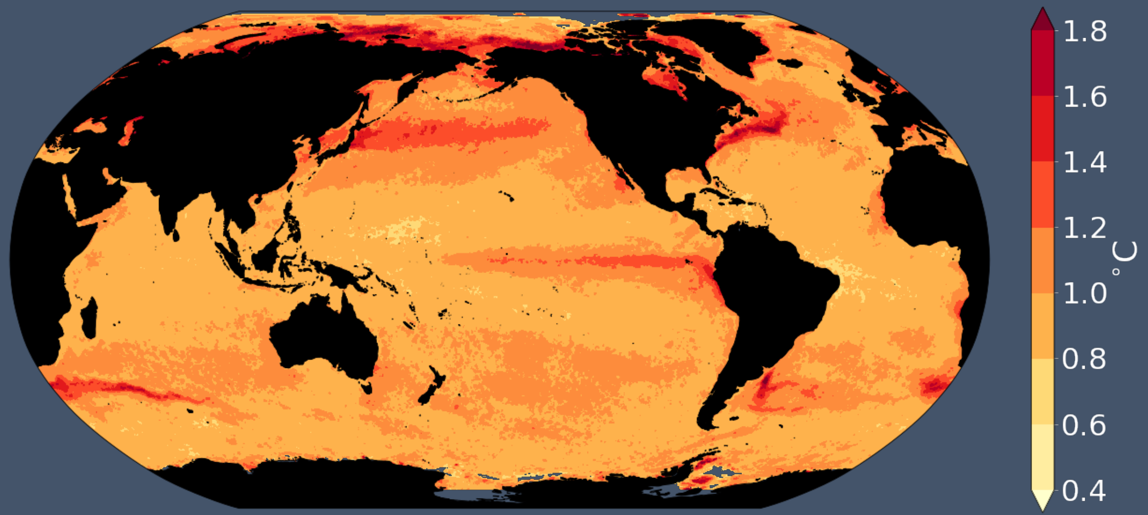
Average Duration



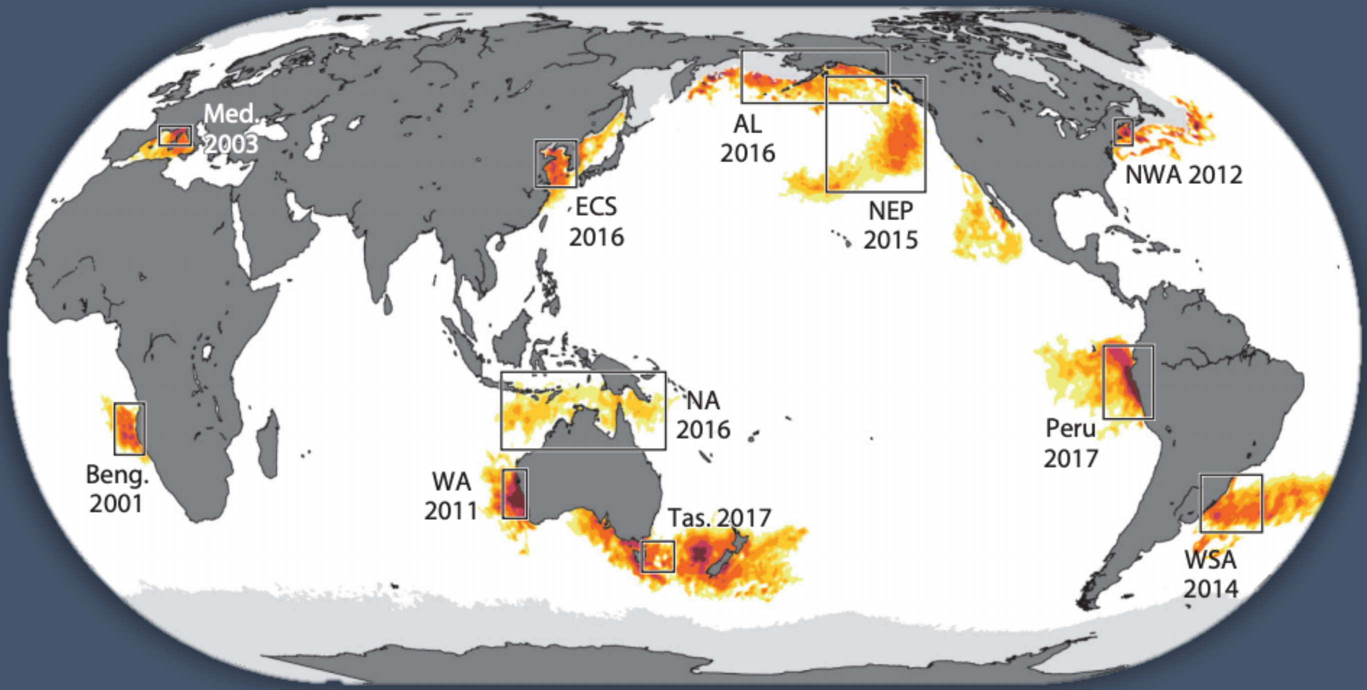
Total Event Count



Average Intensity

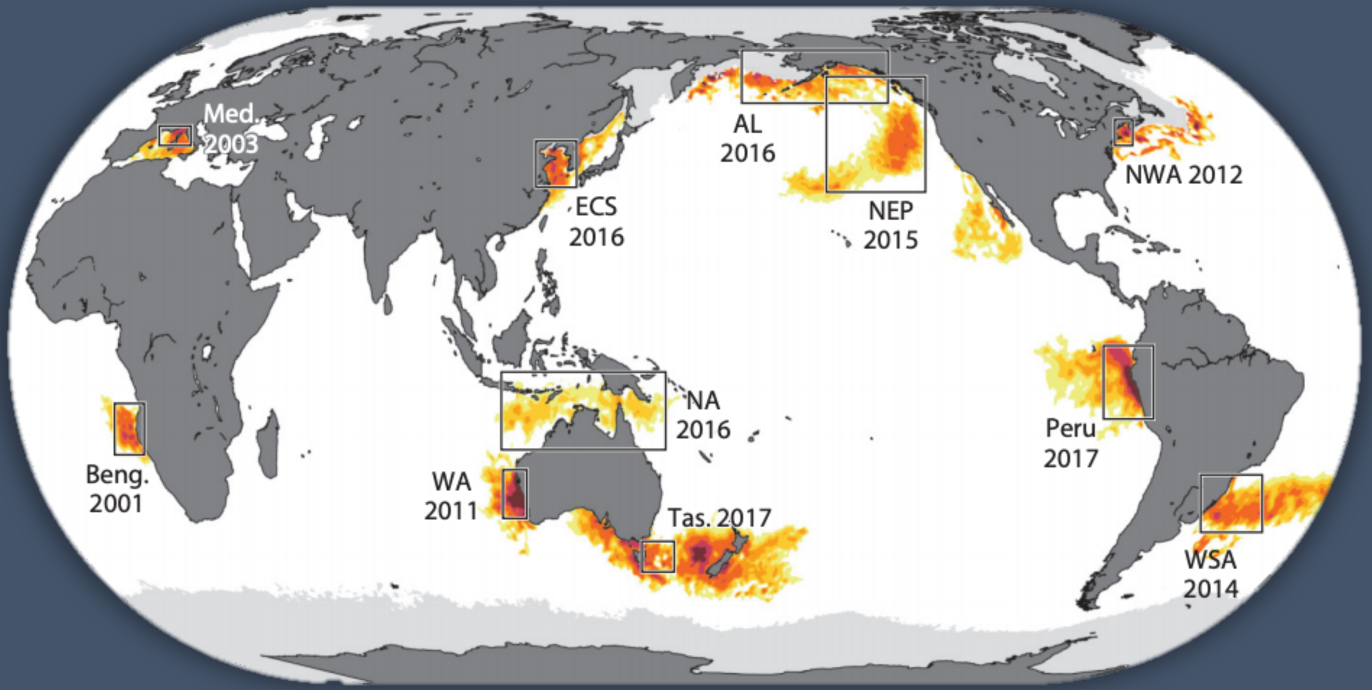


What does this characterization of marine heatwaves miss?

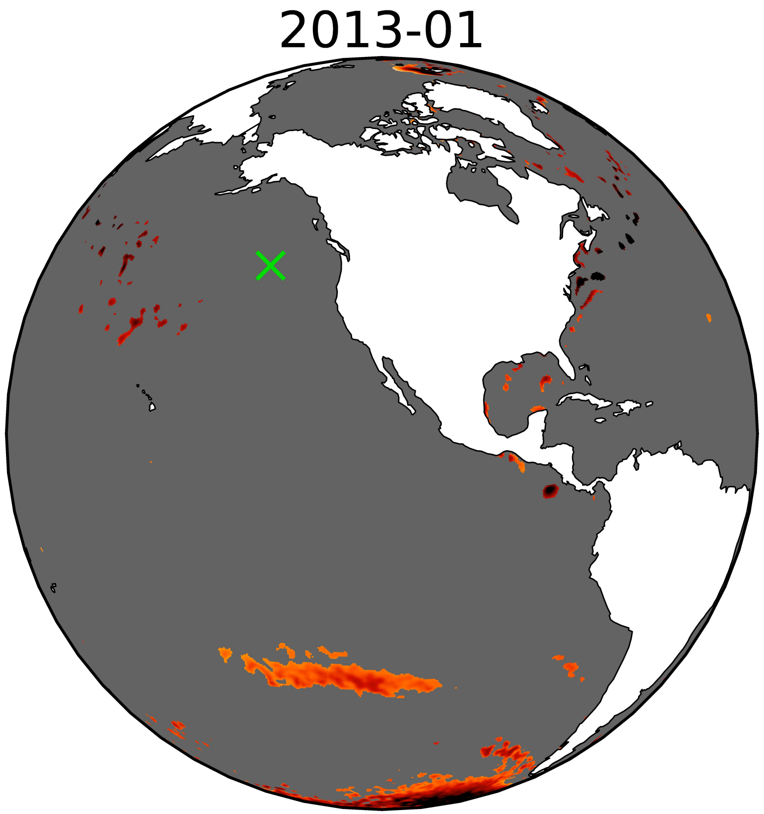


Oliver *et al.*, 2020

What does this characterization of marine heatwaves miss?

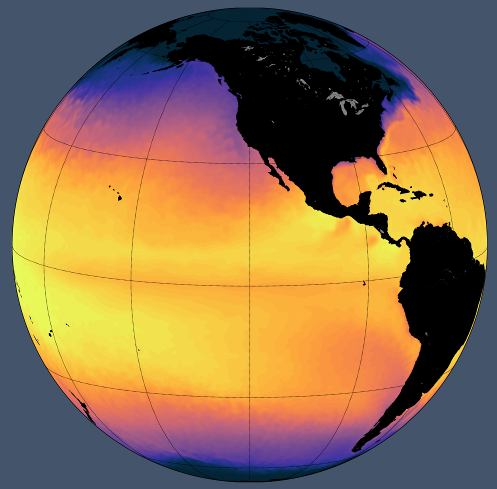


Oliver *et al.*, 2020



Marine heatwaves don't stay in one place!
They move throughout the ocean due to air-sea heat fluxes, ocean heat transport, and/or remote teleconnections.

Ocetrac

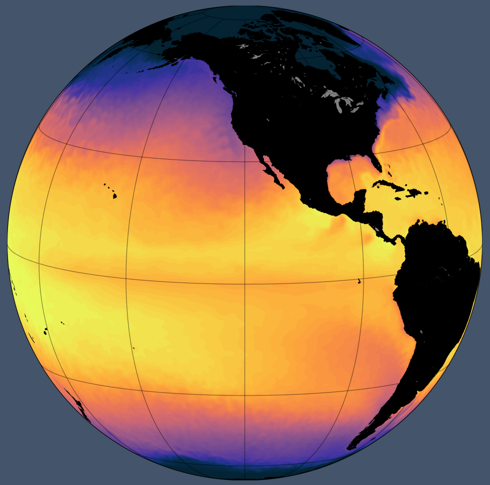


Optimum Interpolation Sea Surface Temperature v2.1

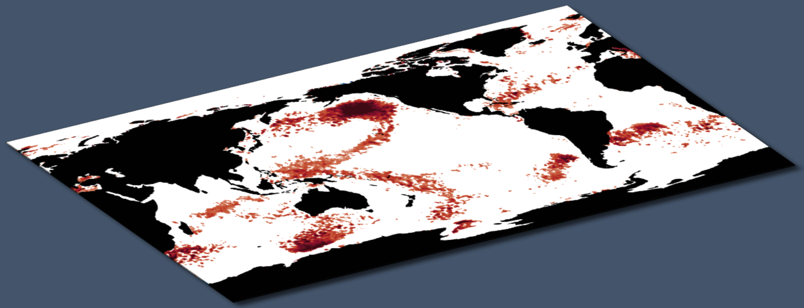
monthly means from September 1981 – present
0.25° longitude x 0.25° latitude grid

Ocetrac

Sea Surface Temperature



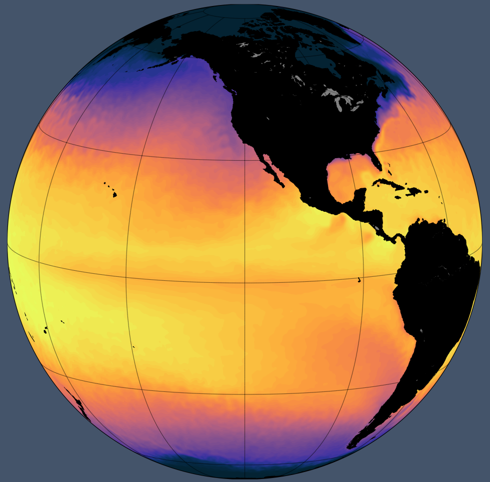
1. Feature extraction



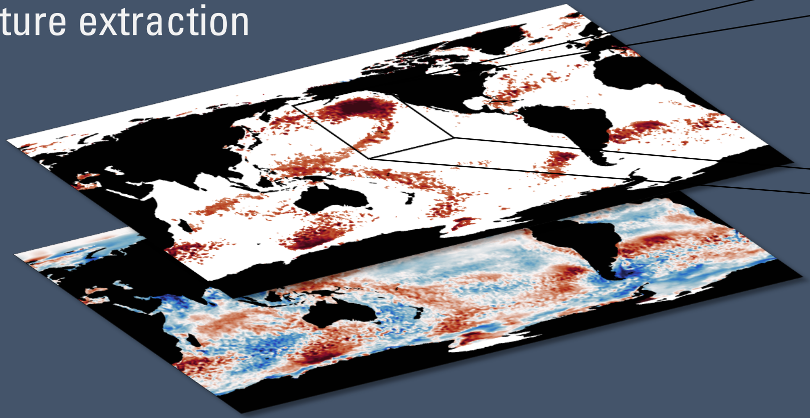
- The mean, seasonal cycle, and trend is computed between 1982–2020 and removed from the sea surface temperature.
- Anomalies are standardized by the local standard deviation.
- Marine heatwave candidates are defined when the sea surface temperature exceeds the local 90th percentile.

Ocetrac

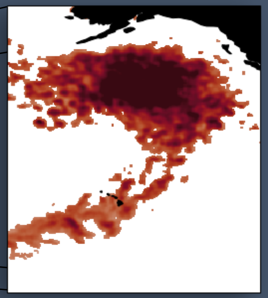
Sea Surface Temperature



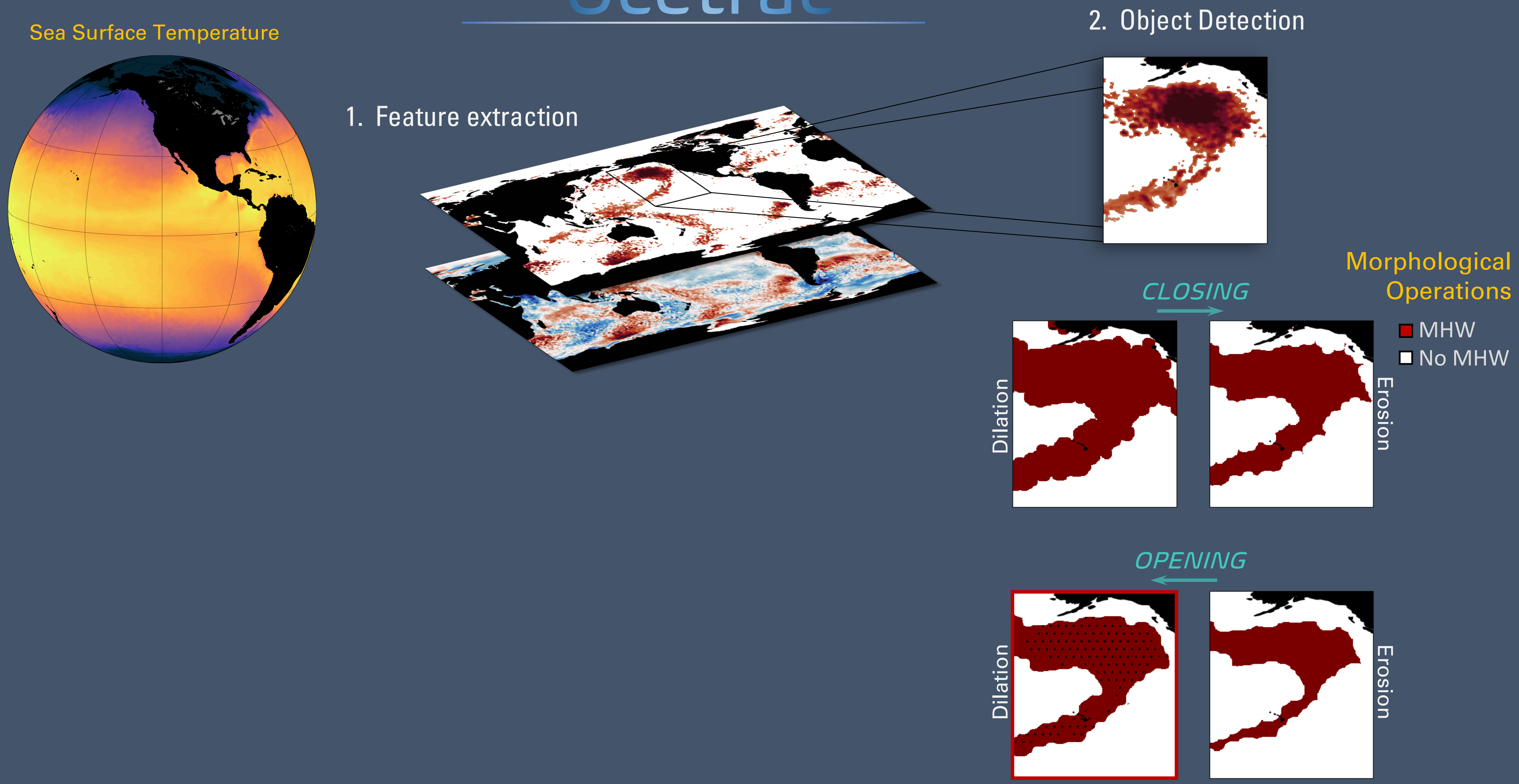
1. Feature extraction



2. Object Detection

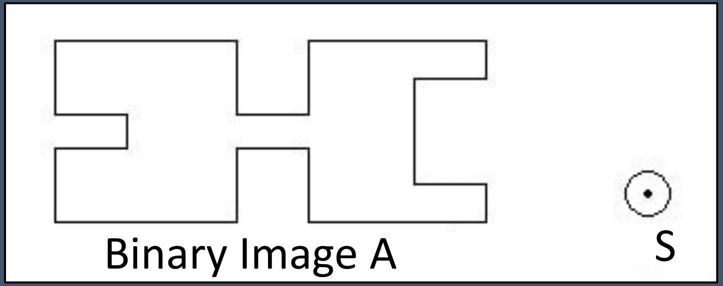


Ocetrac



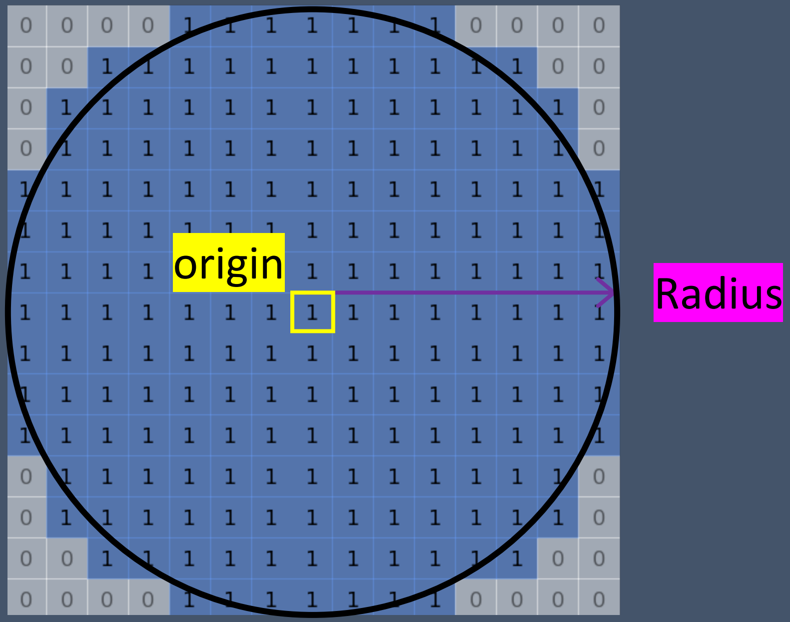
Sea Surface Temperature
1. Feature extraction
2. Object Detection
Morphological Operations
CLOSING
OPENING
MHW
No MHW
Dilation
Erosion
Dilation
Erosion

Morphological Operations

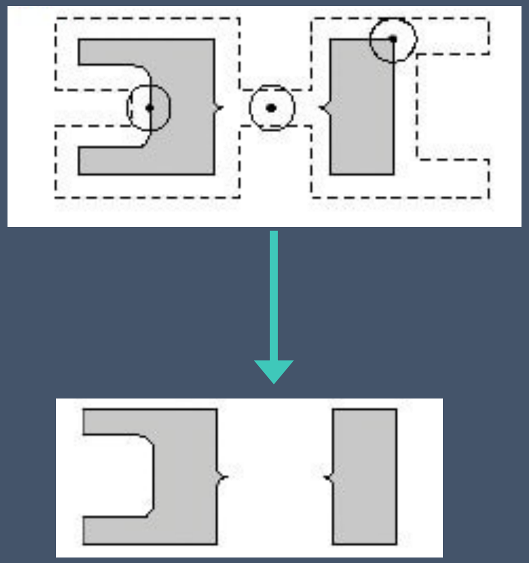


Structuring Element (S)

used to probe the input image

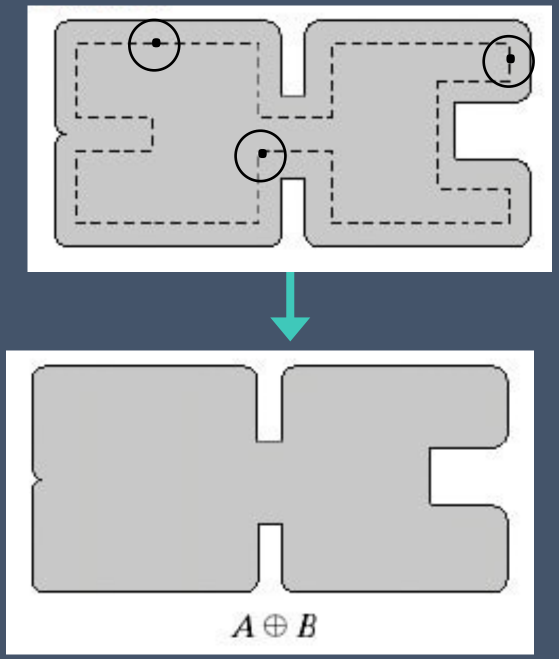


Erosion $A \ominus S$



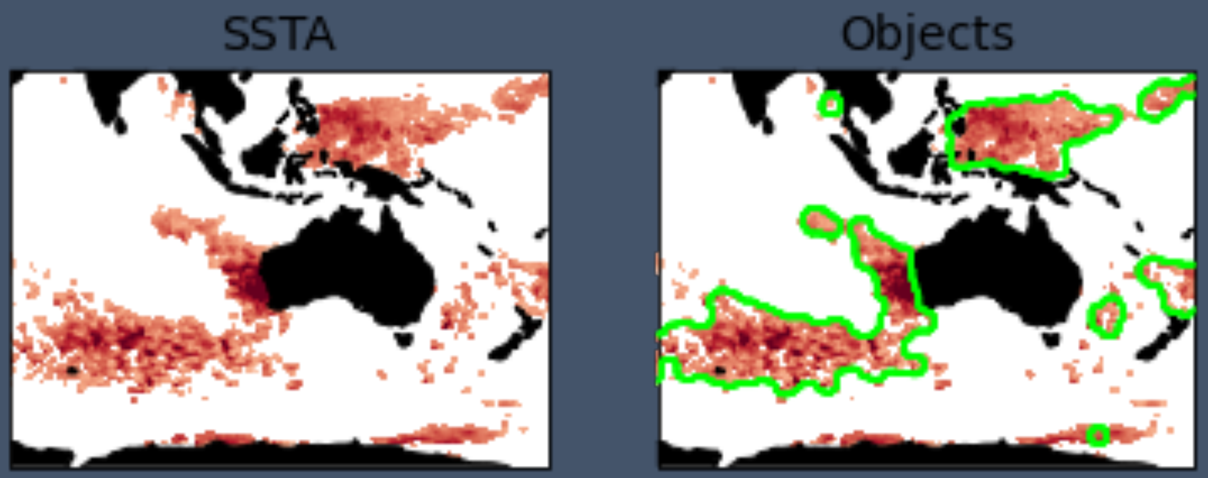
Shrinks features; removes bridges, branches, and protrusions.

Dilation $A \oplus S$



Growing features and filling small holes

Opening and closing removes small features and smooth the borders of larger features

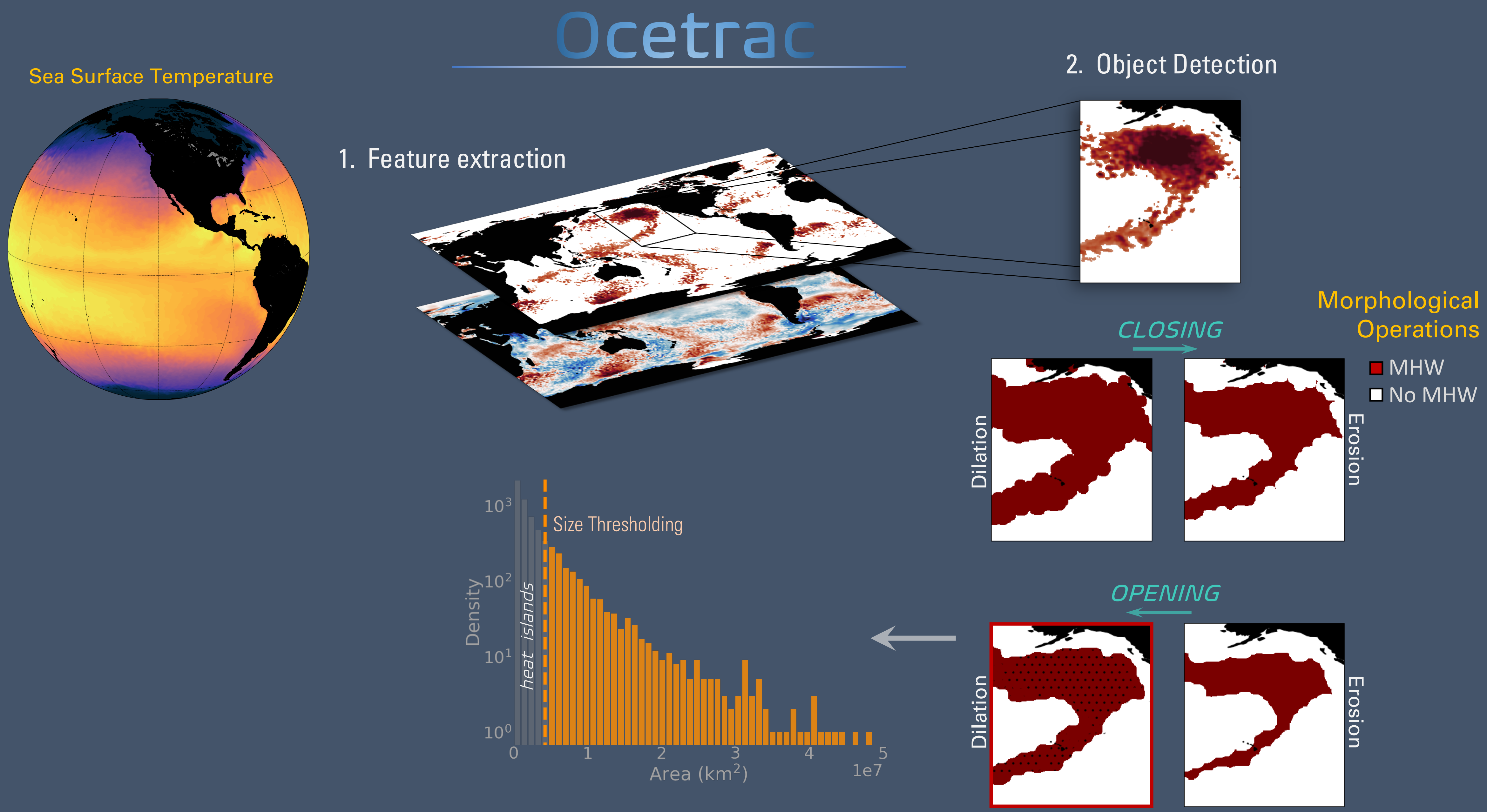


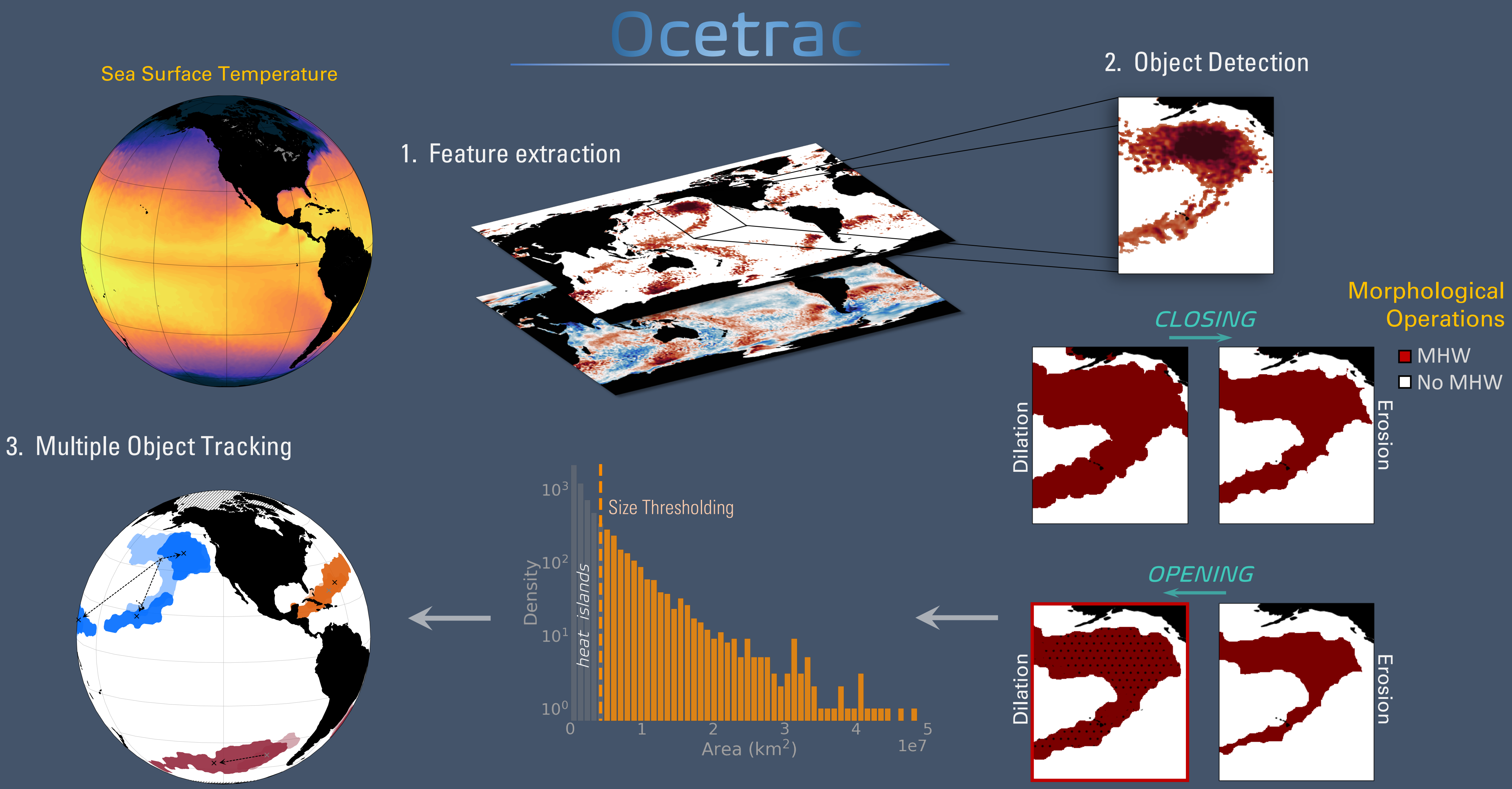
Closing

Opening

Fills small holes within features

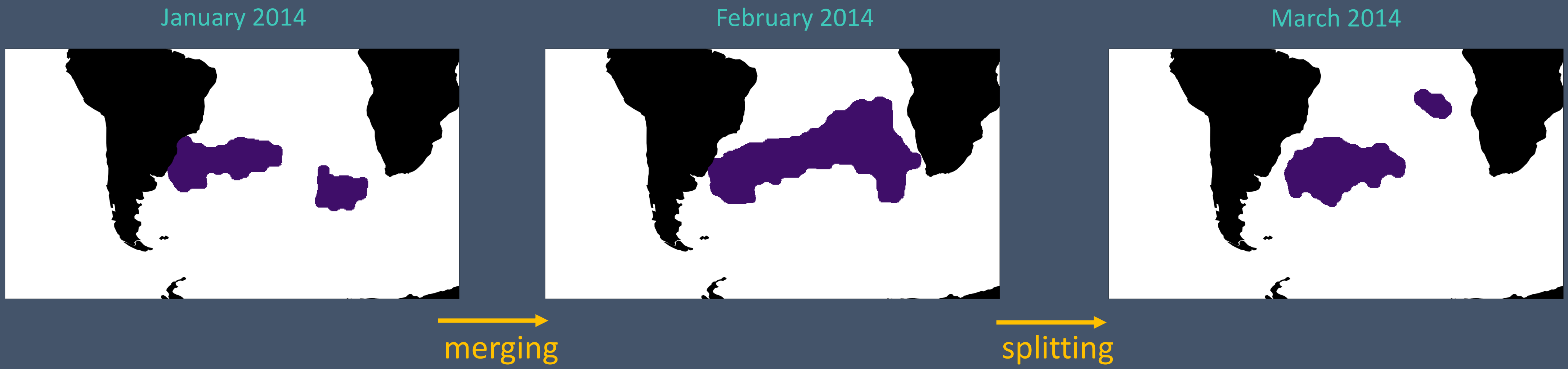
Eliminates small features


Ocetrac
Sea Surface Temperature
1. Feature extraction
2. Object Detection
Morphological Operations
CLOSING
MHW
No MHW
Dilation
Erosion
OPENING
Dilation
Erosion
Size Thresholding
heat islands
Density
10^3
10^2
10^1
10^0
0
1
2
3
4
5
1e7
Area (km^2)


Ocetrac
Sea Surface Temperature
1. Feature extraction
2. Object Detection
Morphological Operations
CLOSING
MHW
No MHW
Dilation
Erosion
OPENING
Dilation
Erosion
3. Multiple Object Tracking
Size Thresholding
heat islands
Density
Area (km²)
1e7

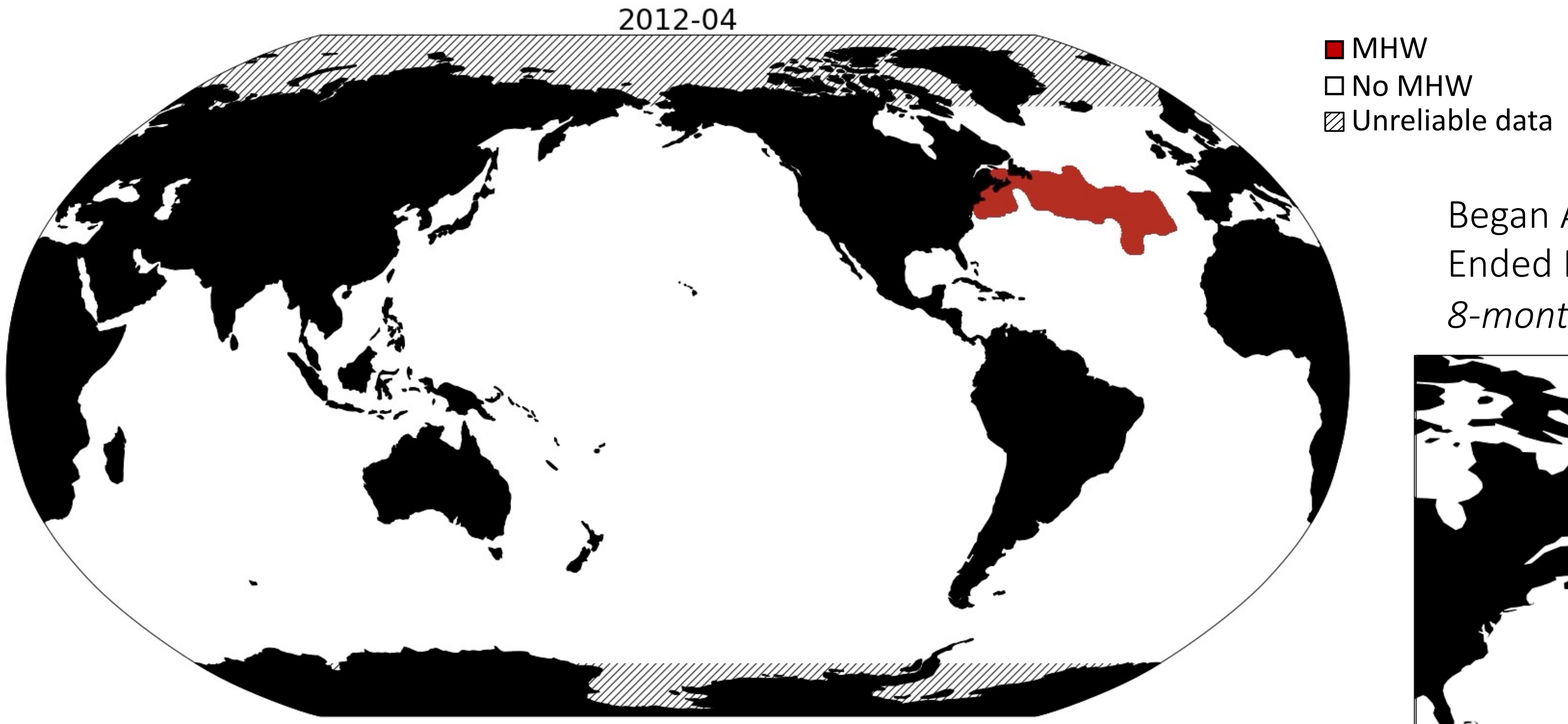
Multiple Object Tracking

- Marine heatwaves are connected when they share a surface in either longitude, latitude, or time
- Marine heatwaves may split or merge



2012 Gulf of Maine

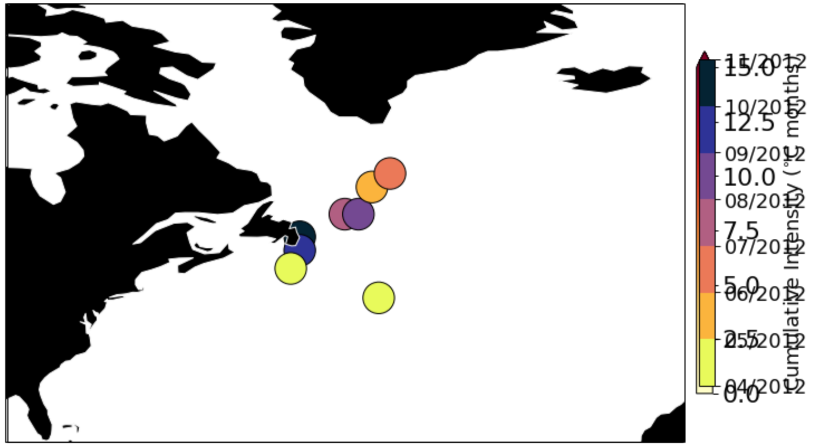
marine heatwave



Began April 2012

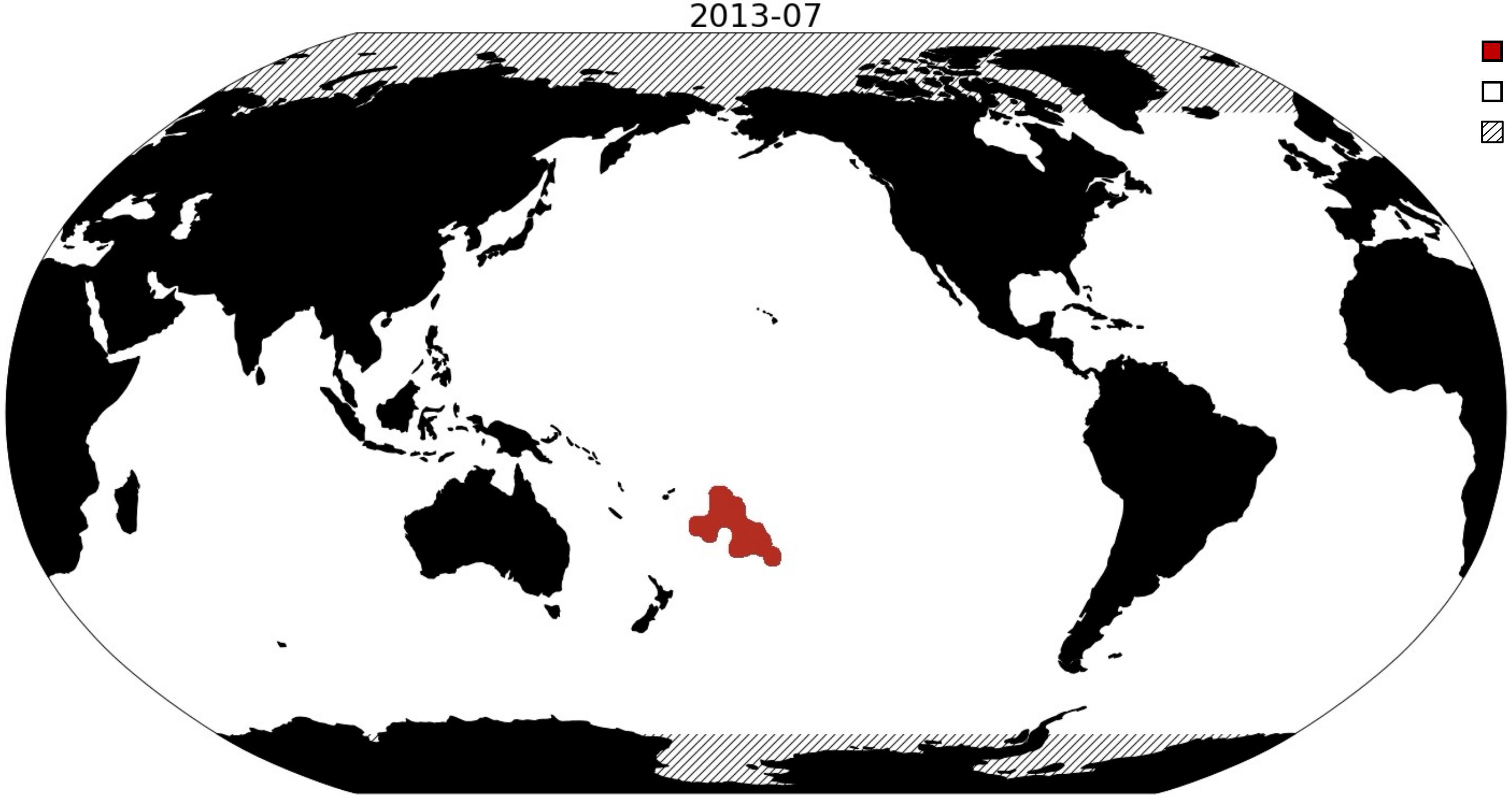
Ended Nov. 2012

8-month event

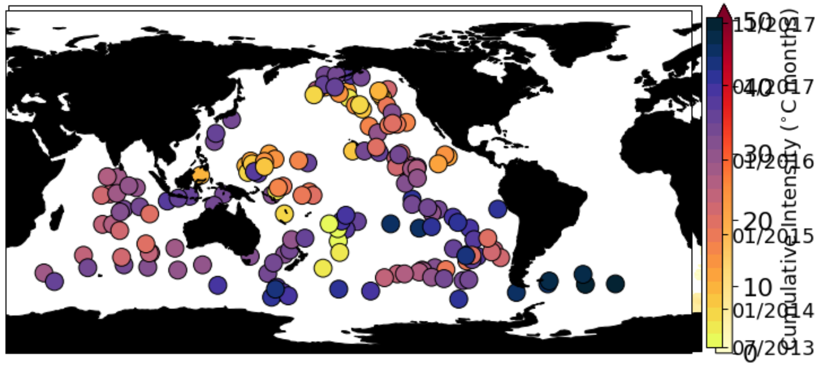


Global Evolution of "The Blob"

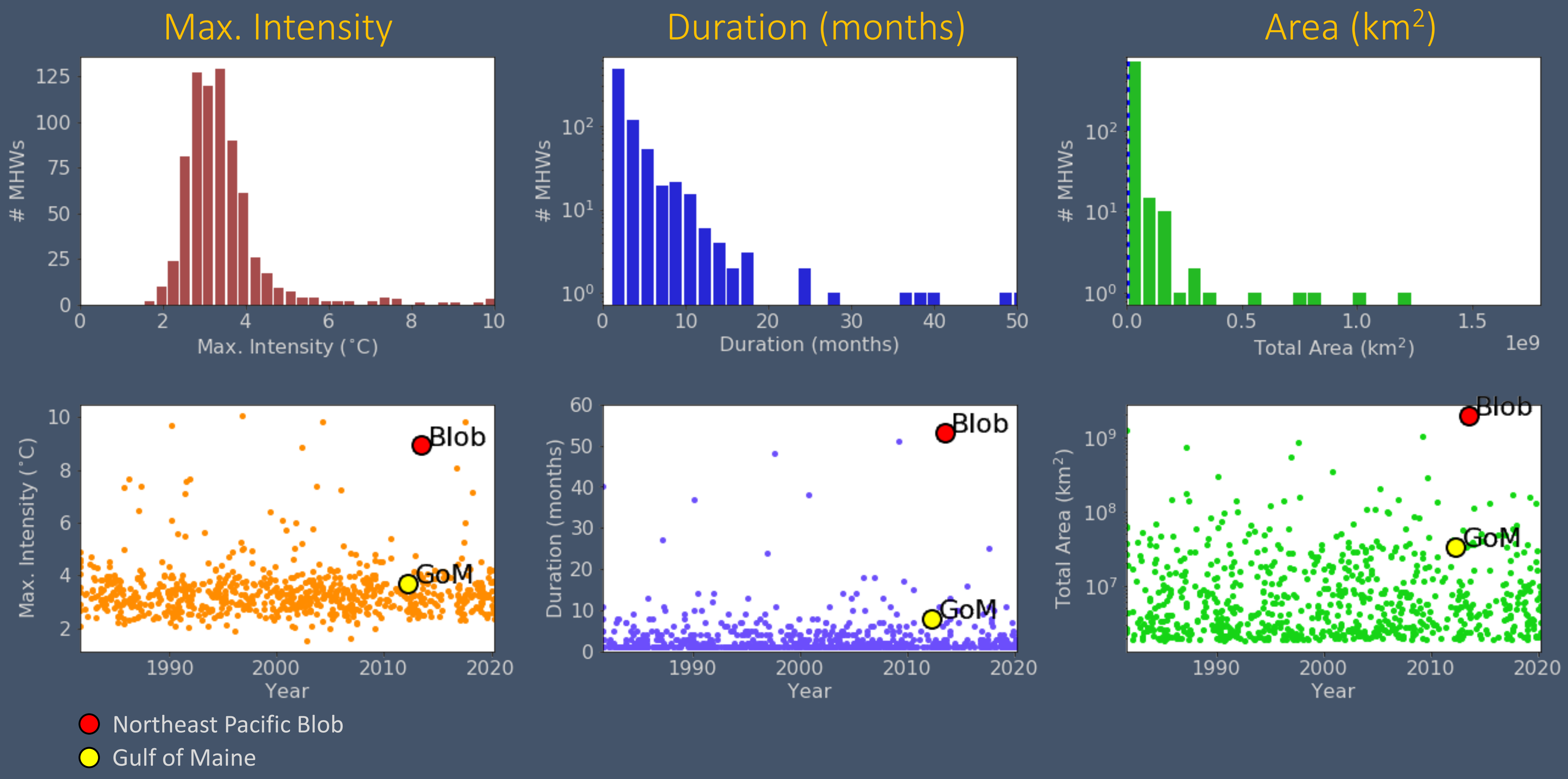
marine heatwave



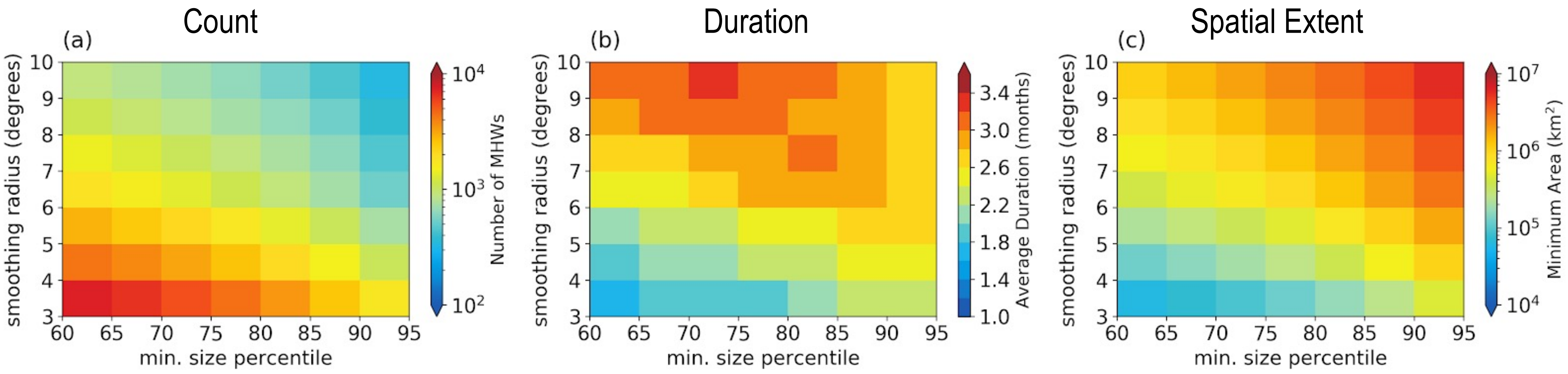
Began July 2013
Ended Nov. 2017
53-month event!



Global history and accounting of marine heatwaves



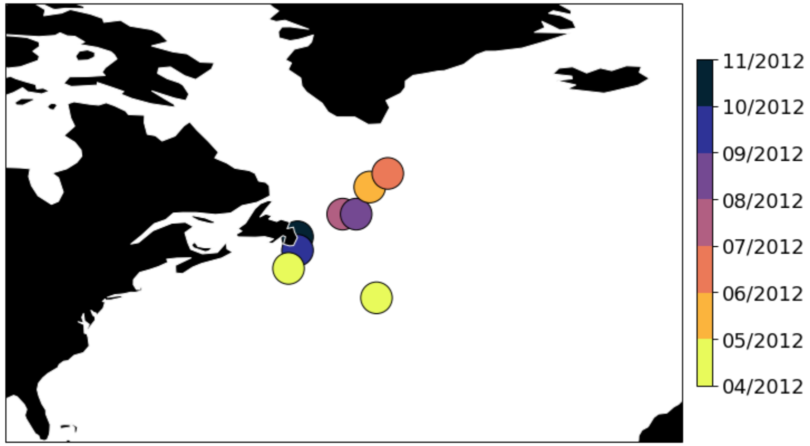
Sensitivity of structuring element shape & minimum size threshold on marine heatwave properties

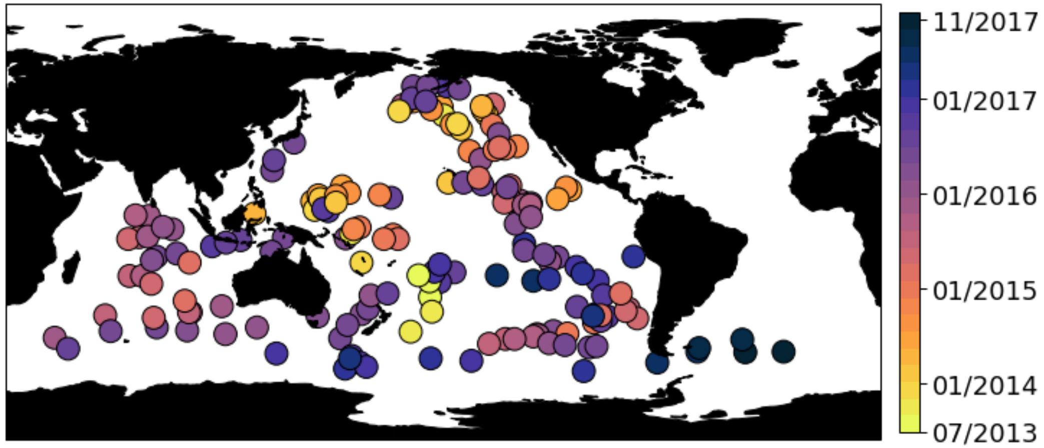


- Large radius values increase the connectedness of features in the binary images, resulting in fewer, but also larger marine heatwave events identified
- These well-connected marine heatwaves are also likely to persist for longer durations

What new insights does Ocetrac reveal about marine heatwaves?

- Two different types of marine heatwave patterns emerge: localized events that grow in place and globally connected events that are linked through the tropics
- Marine heatwaves with global connectivity tend to be longer lasting and more intense compared to localized events
- The tropics provide an important conduit for extremely large-scale and persistent marine heatwaves
- Marine heatwaves split and merge – connected in space and time

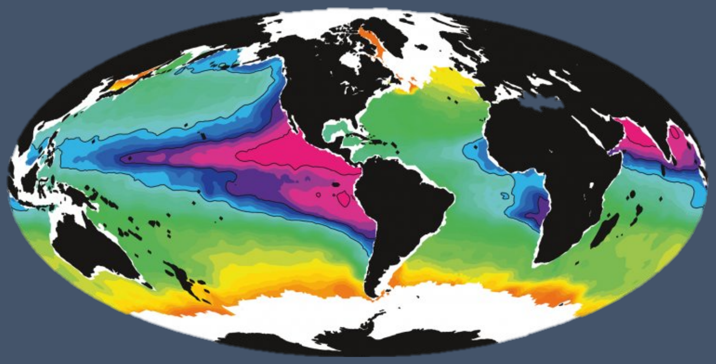




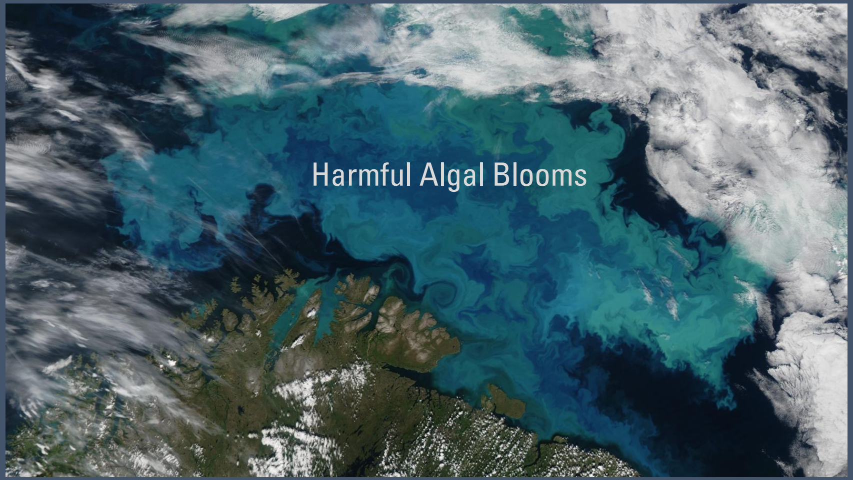
Ocetrac

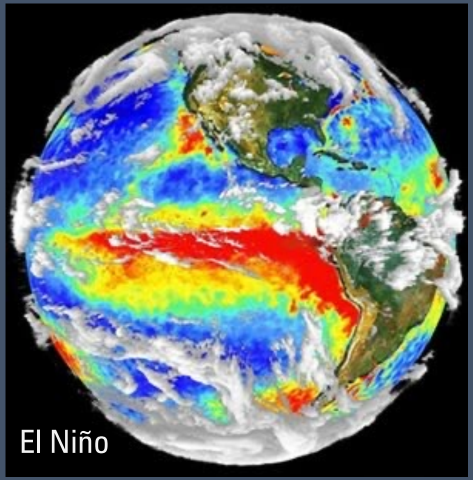
Why use Ocetrac?

- Overcomes the limitations of characterizing the complex spatial connectivity and temporal behavior of marine heatwaves as they evolve
- Enables the characterization of new spatial patterns and behaviors of some of the most dangerous marine heatwaves of the 21st Century
- Provides a new public catalog of observed marine heatwave metrics and trajectories
- New set of tools to probe other extreme phenomena



Oxygen Extremes





GORDON AND BETTY MOORE FOUNDATION

Advanced Study Program
Developing Scientific Leaders of the Future
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Contributors & Project Collaborators

Hillary Scannell (project lead) – Columbia University

Julius Busecke – Columbia University

Ryan Abernathey – Columbia University

Charles Stern – Columbia University

LuAnne Thompson – University of Washington

David John Gagne – NCAR CISL

Dan Whitt – NASA Ames

Ocetrac

Tests passing | codecov 93%

pypi v0.1.4 | conda-forge 340 | docs passing

https://ocetrac.readthedocs.io

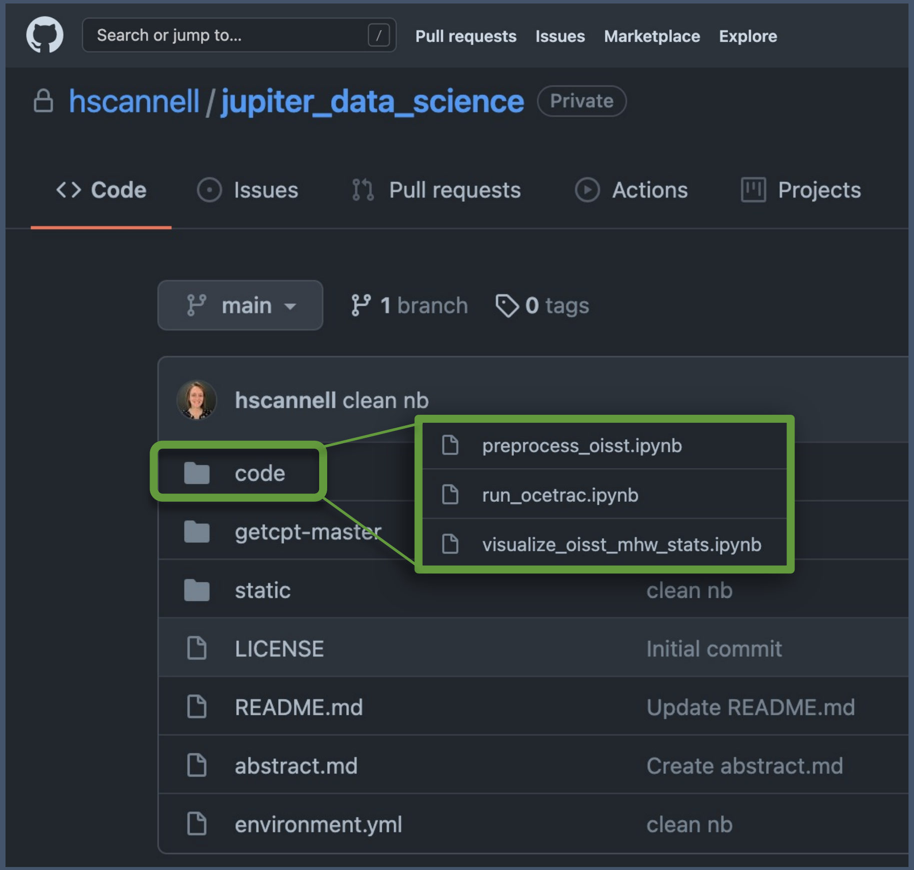
Featured Talks:

NASA Ames Earth Sciences Division Seminar – September 2, 2021

SciPy Conference – July 16, 2021

NCAR Climate & Global Dynamics Seminar – April 27, 2021

Data Science Tools

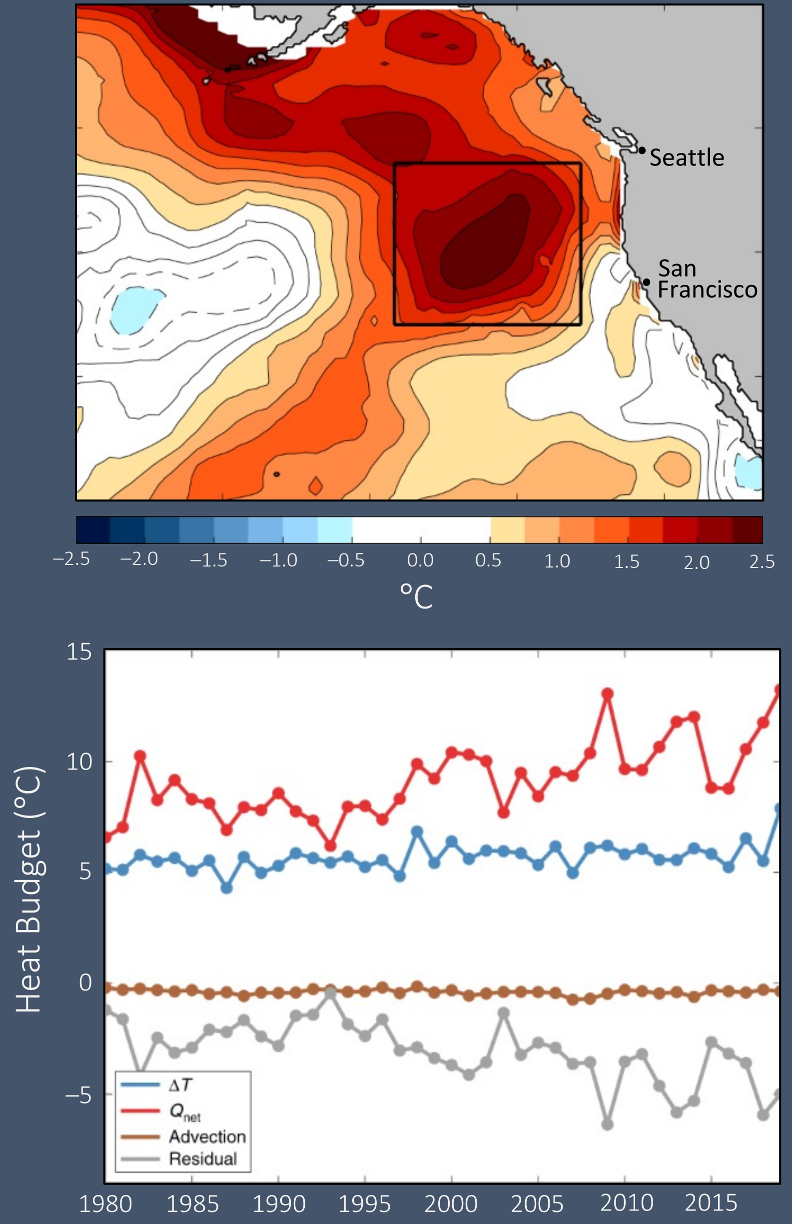


https://github.com/hscannell/jupiter_data_science

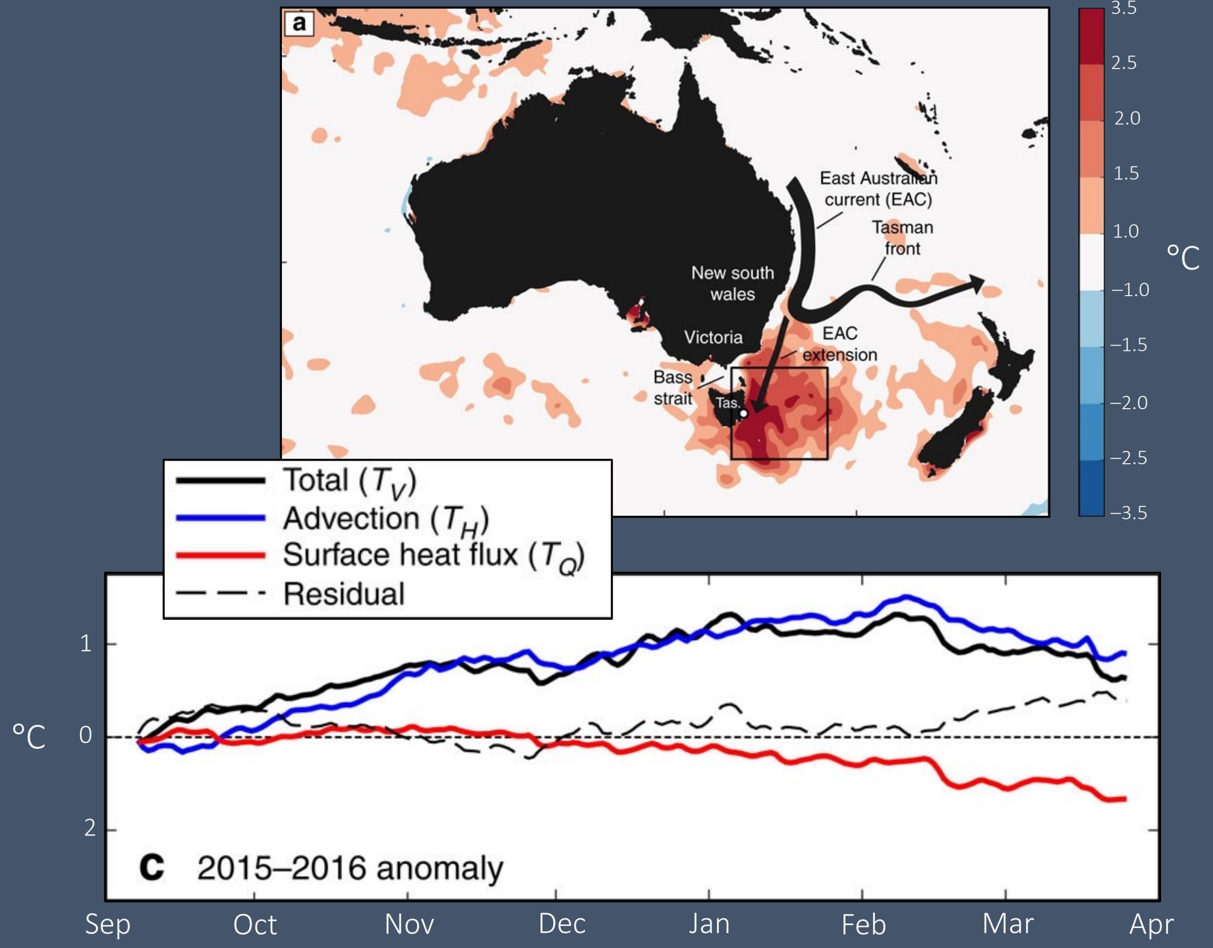
Data: (20 GB) DOI 10.5281/zenodo.5567687

Extra Slides

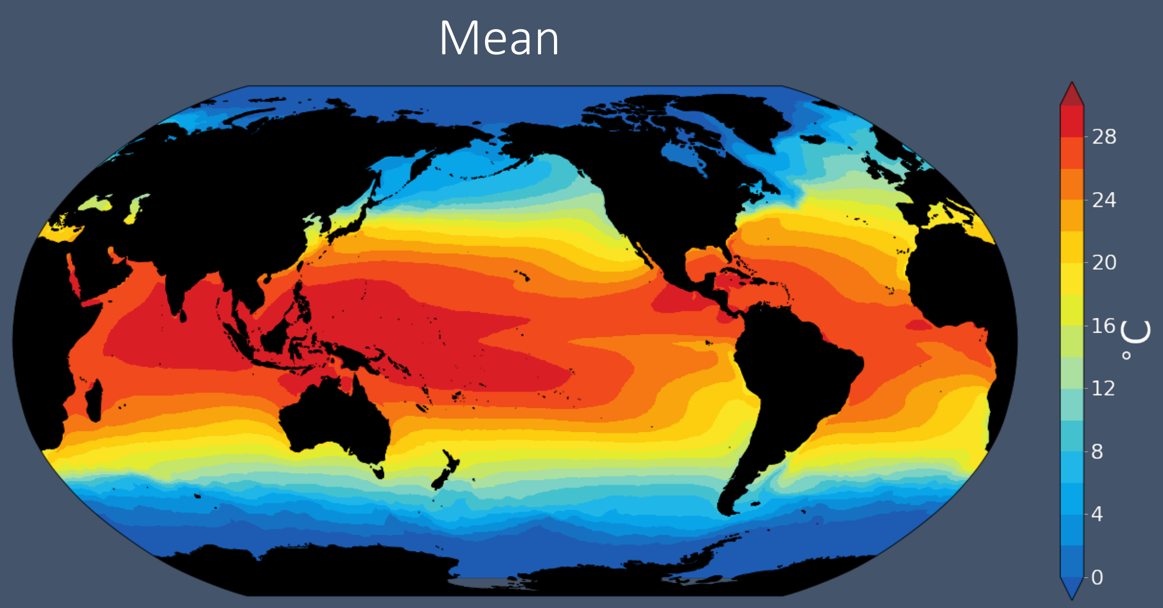
Fixed Heat Budget Analyses

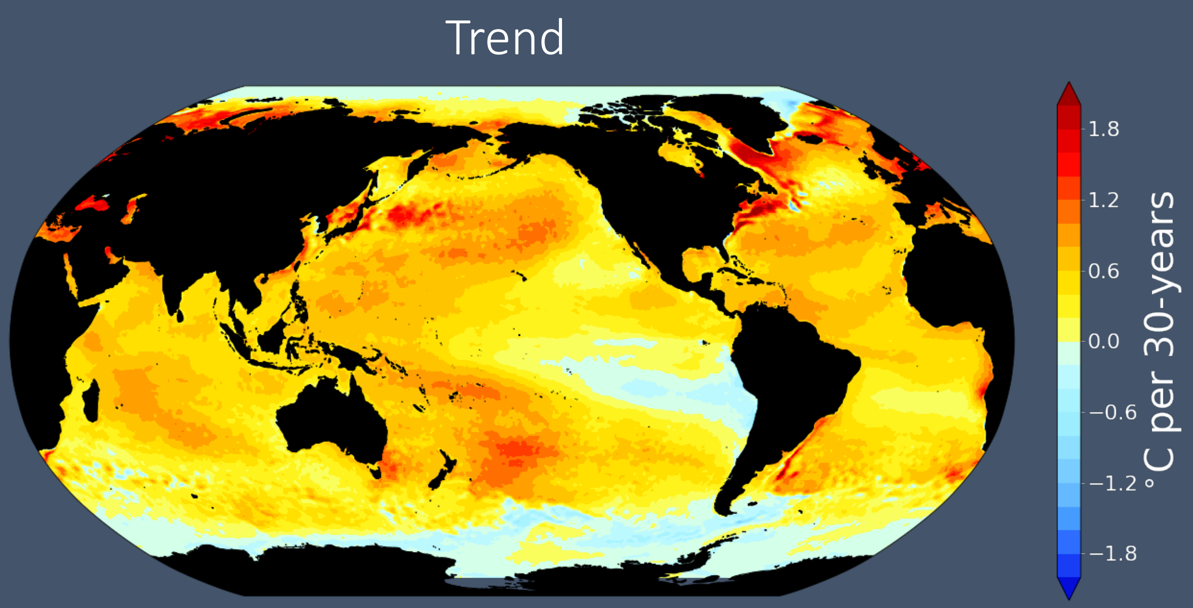


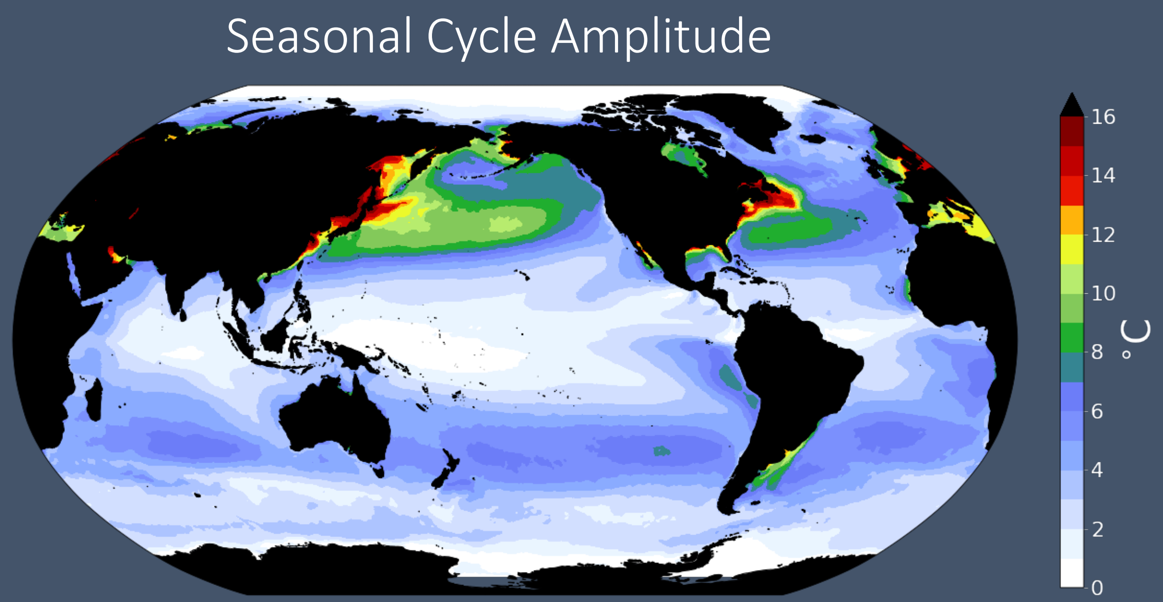
Amaya *et al.*, 2020

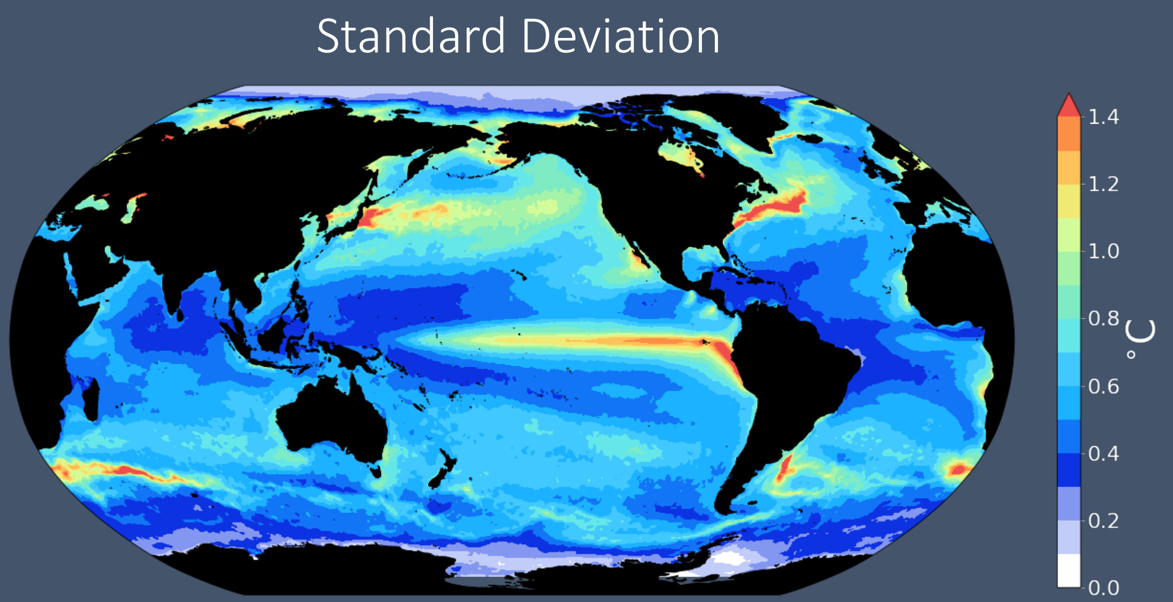


Oliver *et al.*, 2017

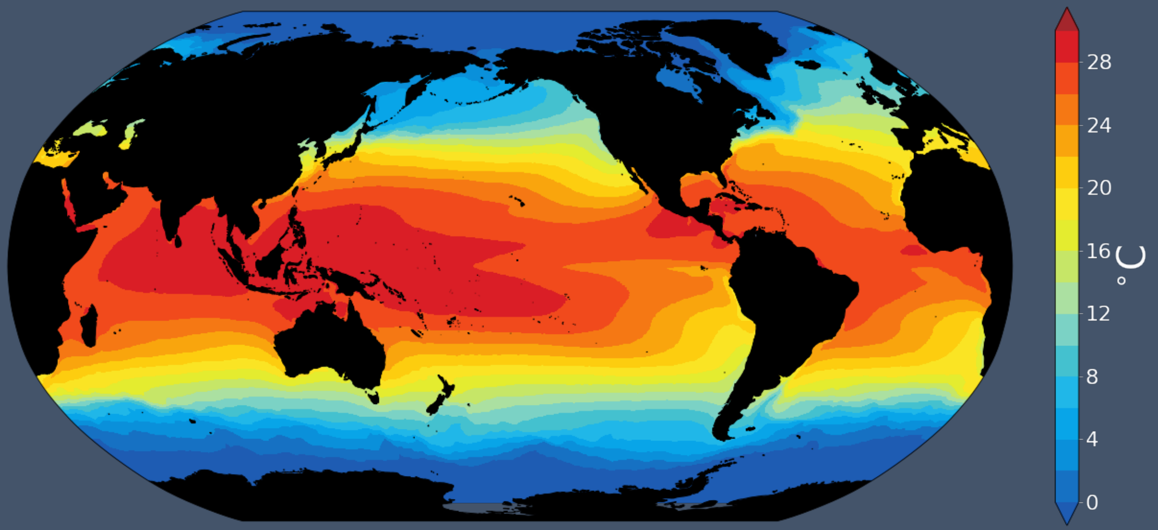

Mean
28
24
20
16
12
8
4
0
°C


Trend
1.8
1.2
0.6
0.0
−0.6
−1.2
−1.8
°C per 30-years

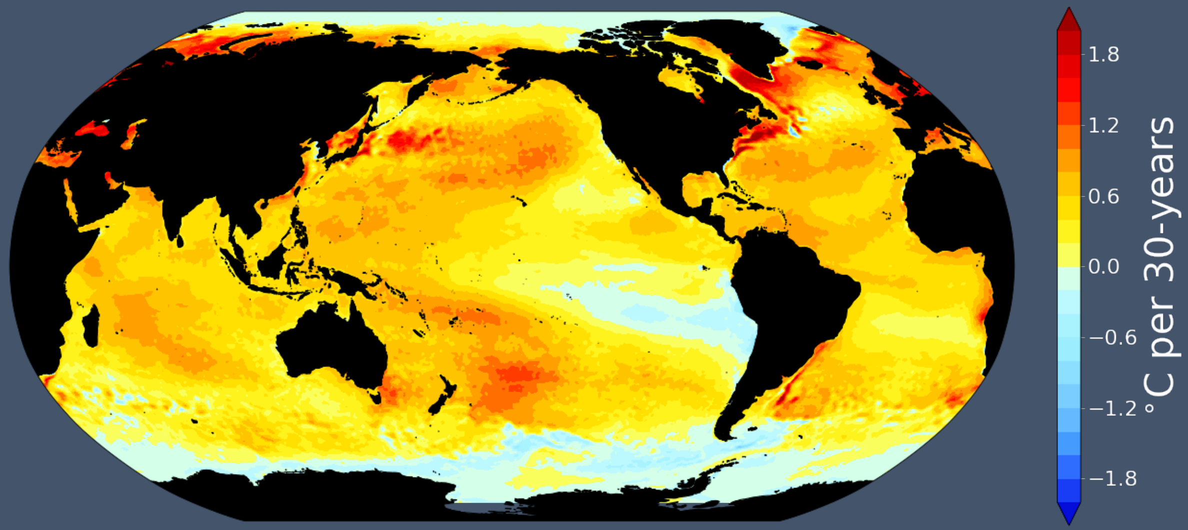

Seasonal Cycle Amplitude
16
14
12
10
8
6
4
2
0
°C


Standard Deviation
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
°C

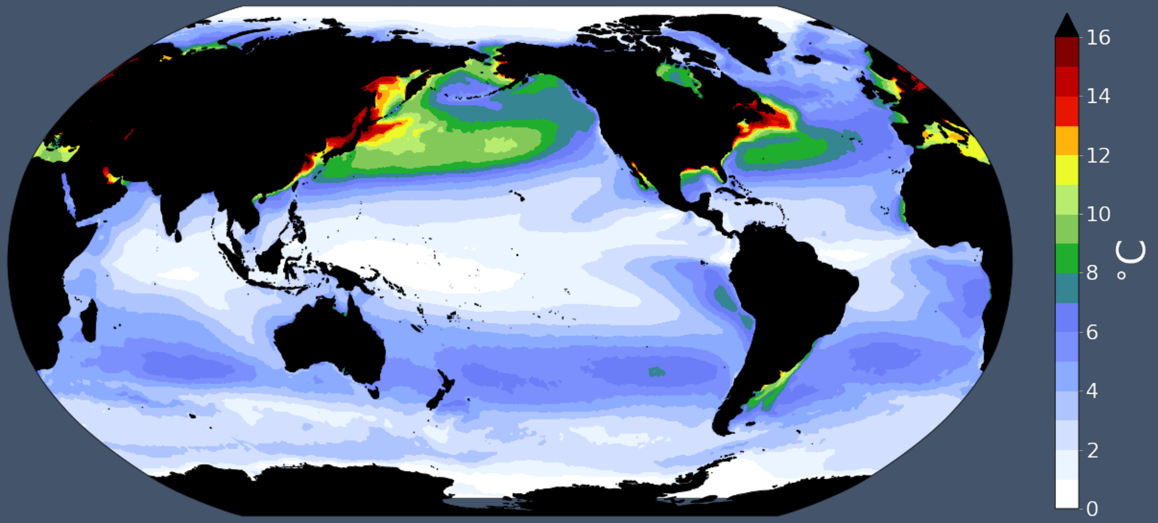
Mean



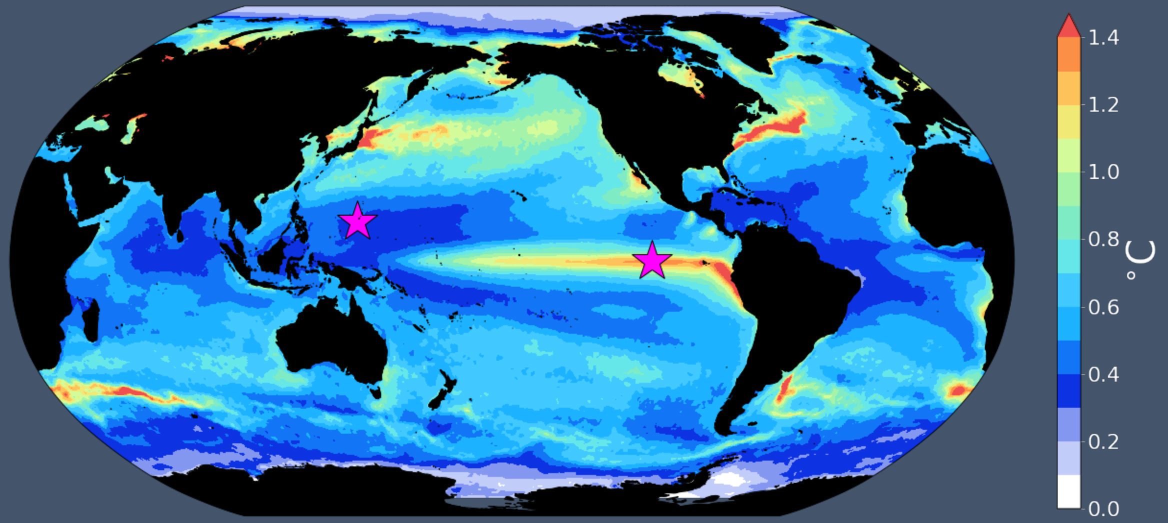
Trend



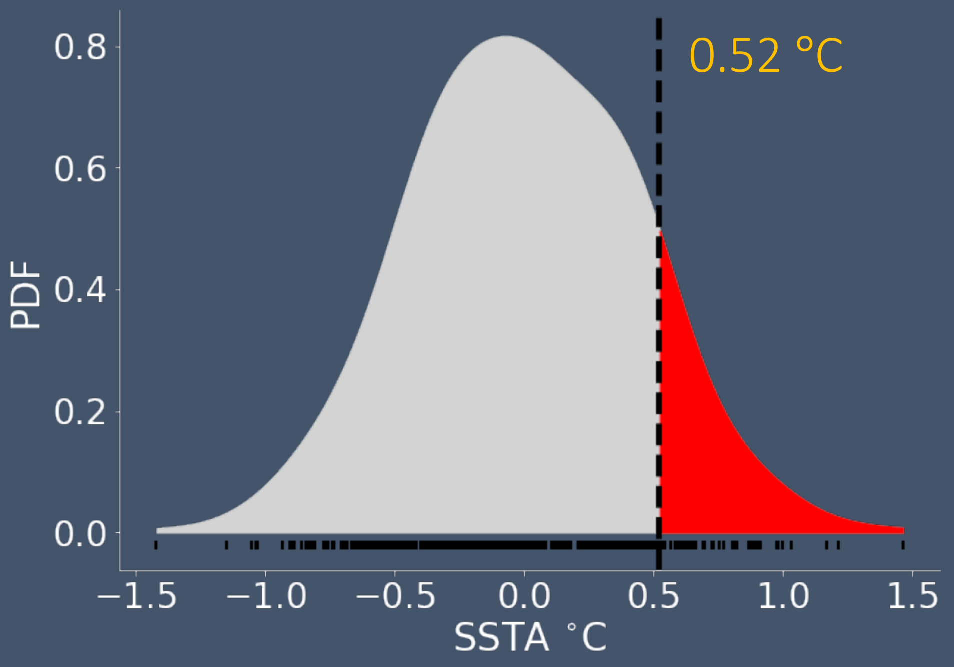
Seasonal Cycle Amplitude



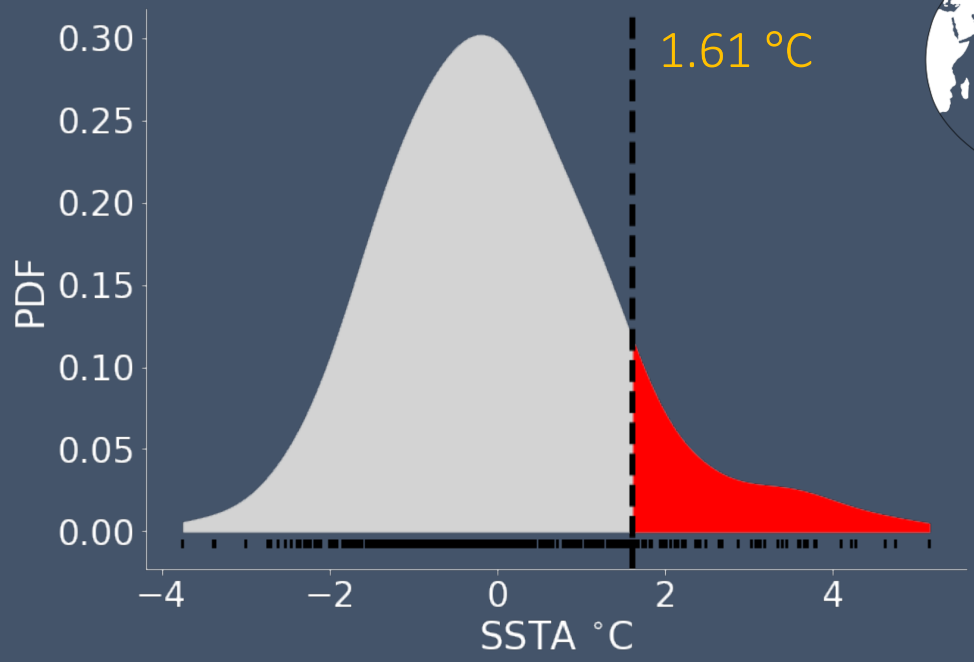
Standard Deviation

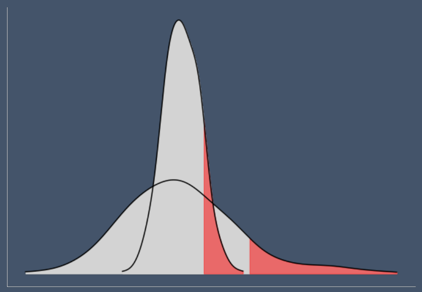


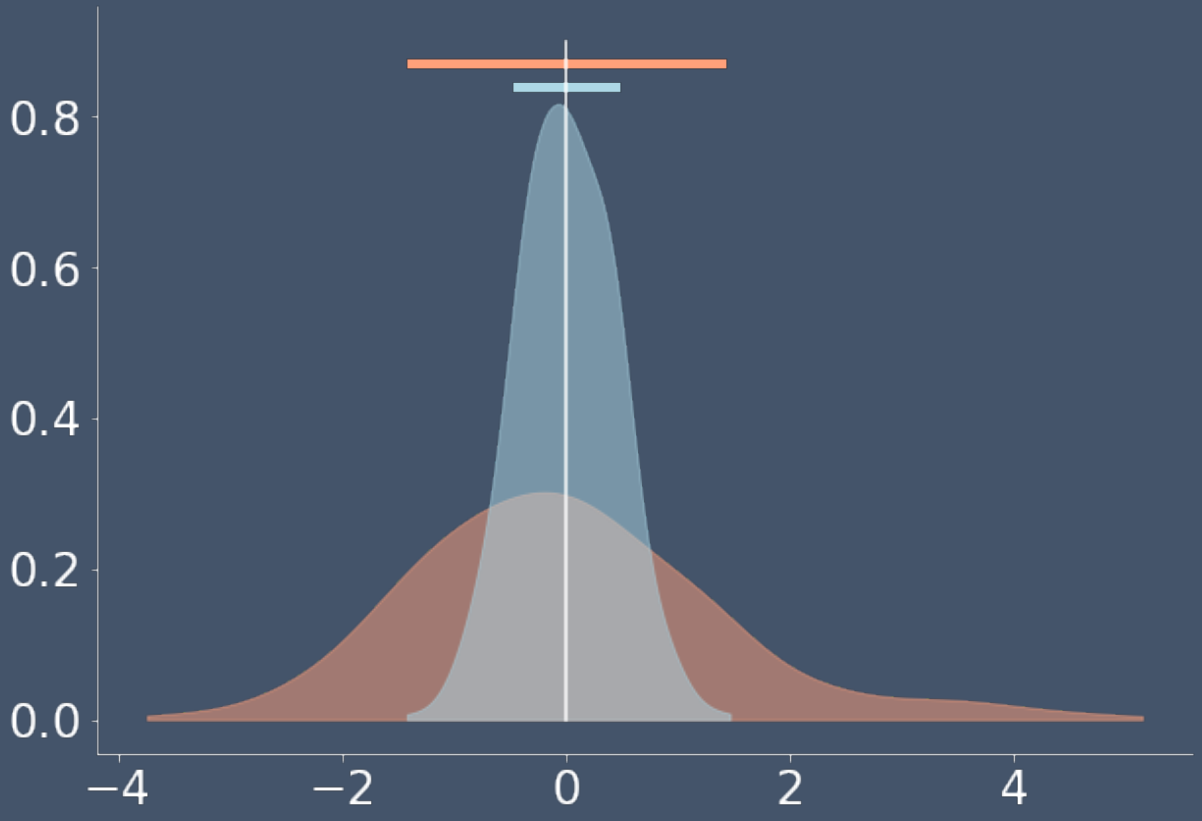
Western Tropical Pacific

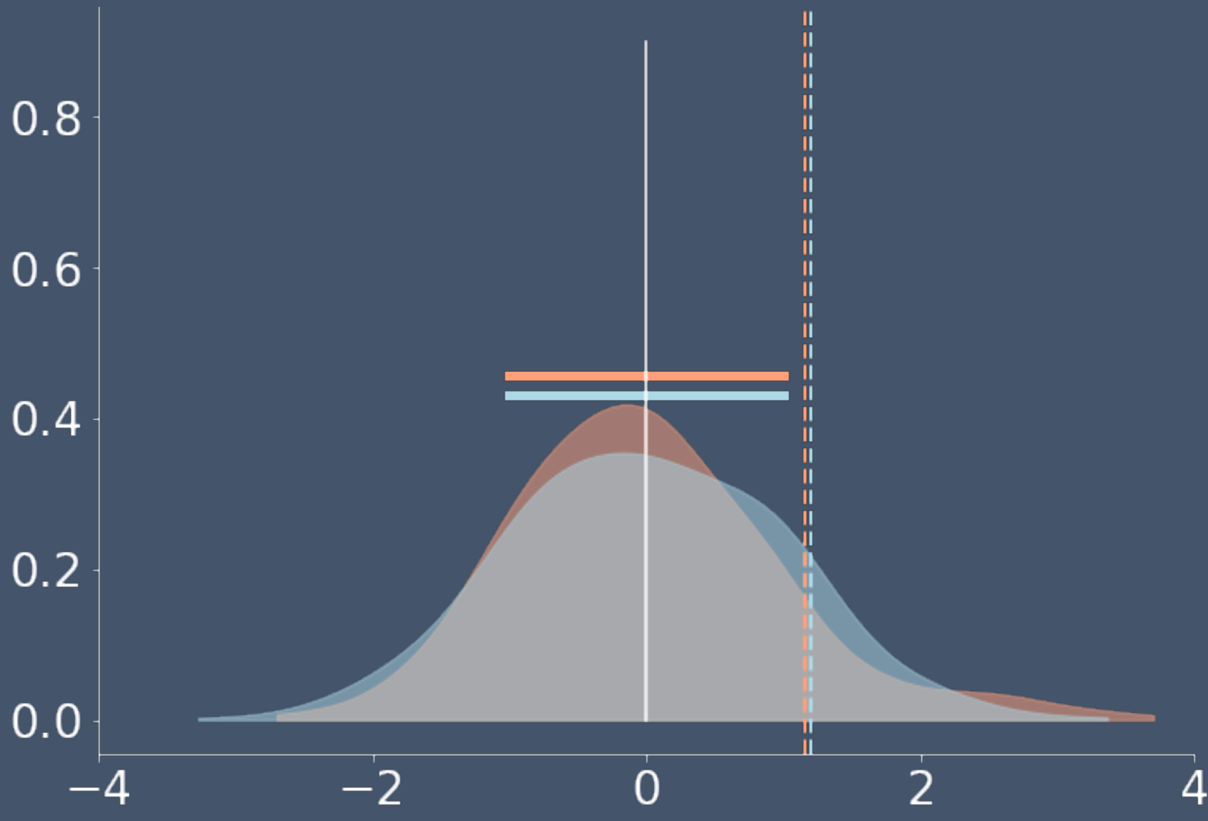


Eastern Equatorial Pacific









$$z = \frac{x - \mu}{\sigma}$$

Ocetrac