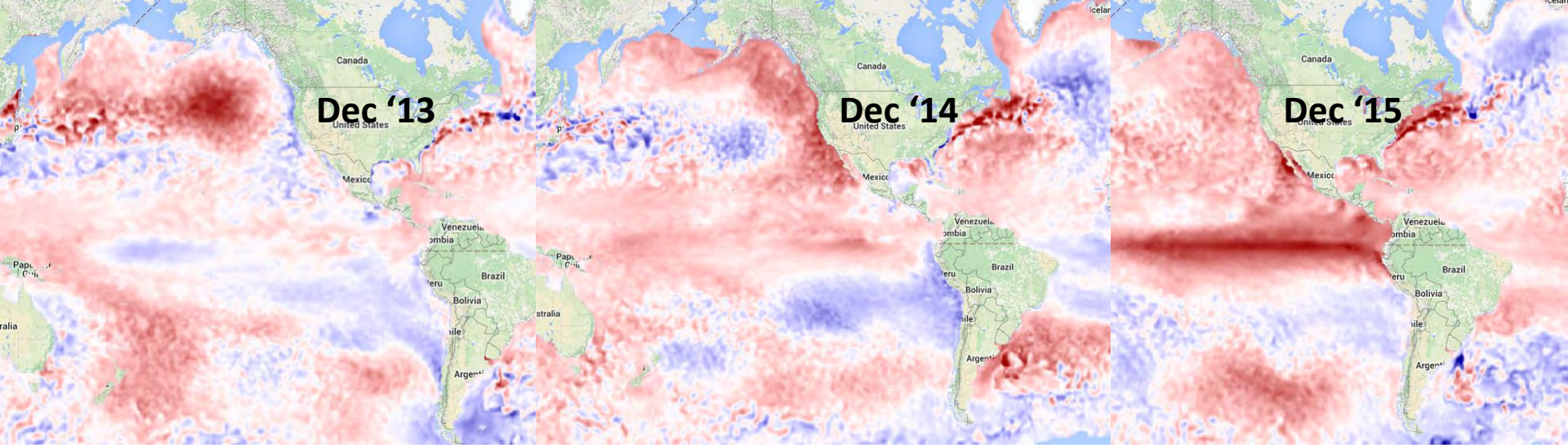


Understanding Marine Heatwaves in the Pacific Northwest

Jan Newton, University of Washington

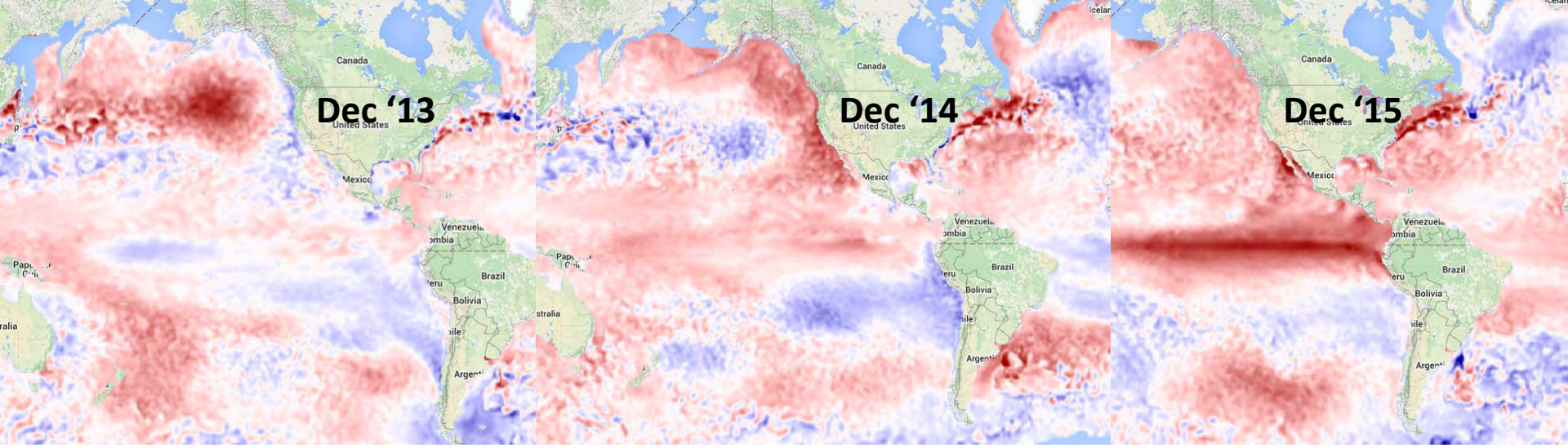
National Marine Sanctuaries Webinar Series:

24 April 2020

IOOS Integrated Ocean Observing System

NANOOS

UNIVERSITY of WASHINGTON



Understanding Marine Heatwaves in the Pacific Northwest

With much thanks and my acknowledgements to:
Toby Garfield, Stephanie Moore, Dillon Amaya, Hillary Scannell, Nick Bond, Beth Curry

Outline

- What is a marine heatwave?
- What do we know about them?
  - Mechanisms
- What are some of the biological effects?
- What happens in the nearshore?

What is a Marine Heatwave ?

A marine heatwave is defined a when seawater temperatures:

- exceed a seasonally-varying threshold (90th percentile)
- for at least 5 consecutive days.

Hobday, A. J. et al. (2016) *A hierarchical approach to defining marine heatwaves*, Prog. Ocean., 141, pp. 227-238, 10.1016/j.pocean.2015.12.014

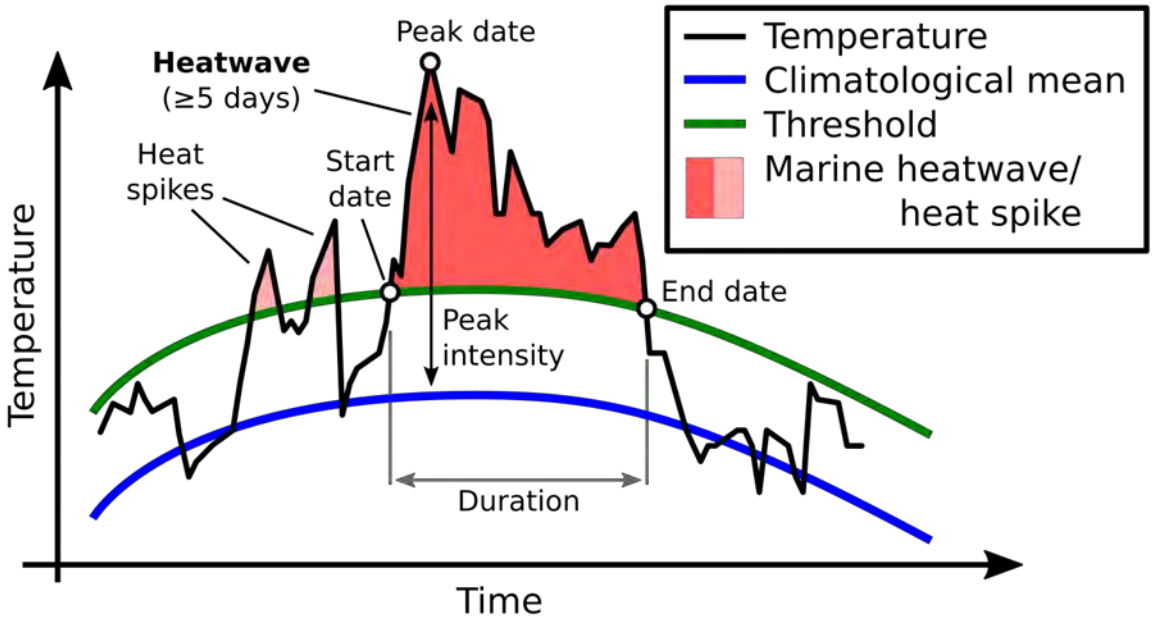
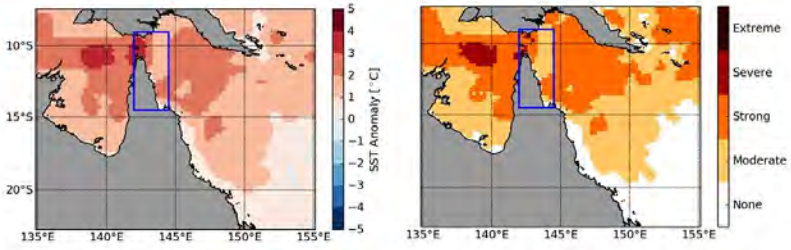
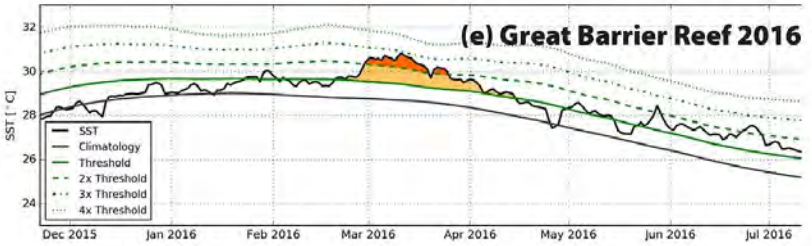


Figure from www.marineheatwaves.org

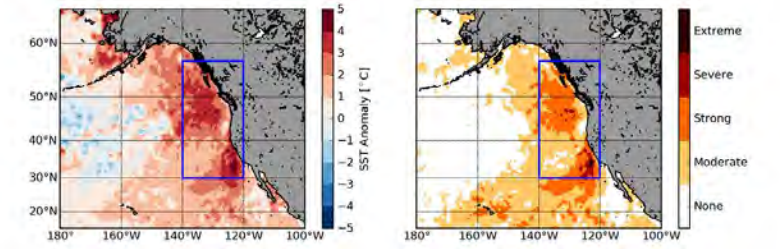
Marine Heatwave Classification

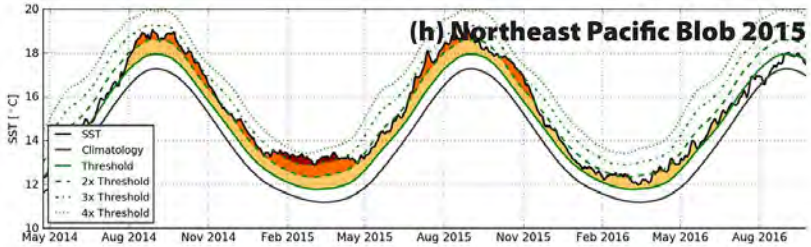
Strong



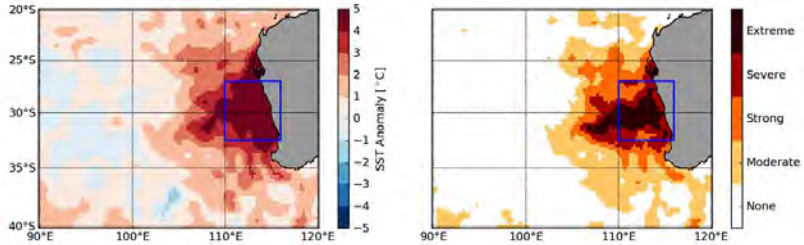


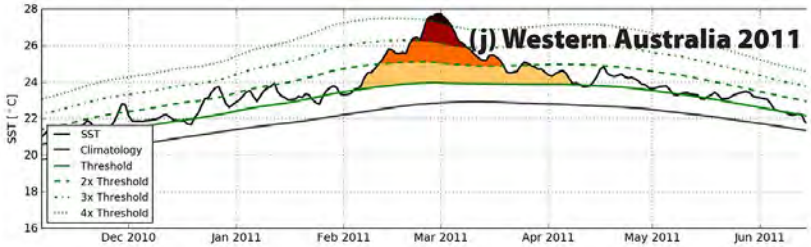
Severe





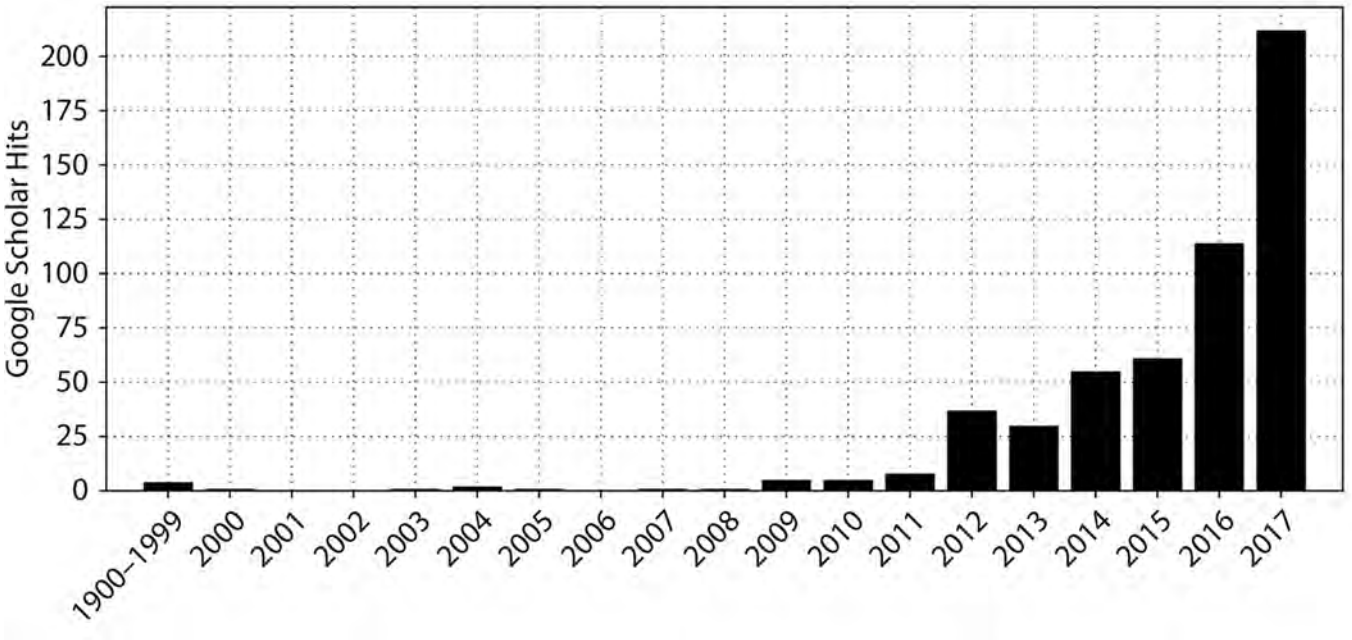
Extreme





Source: Hobday et al. 2018

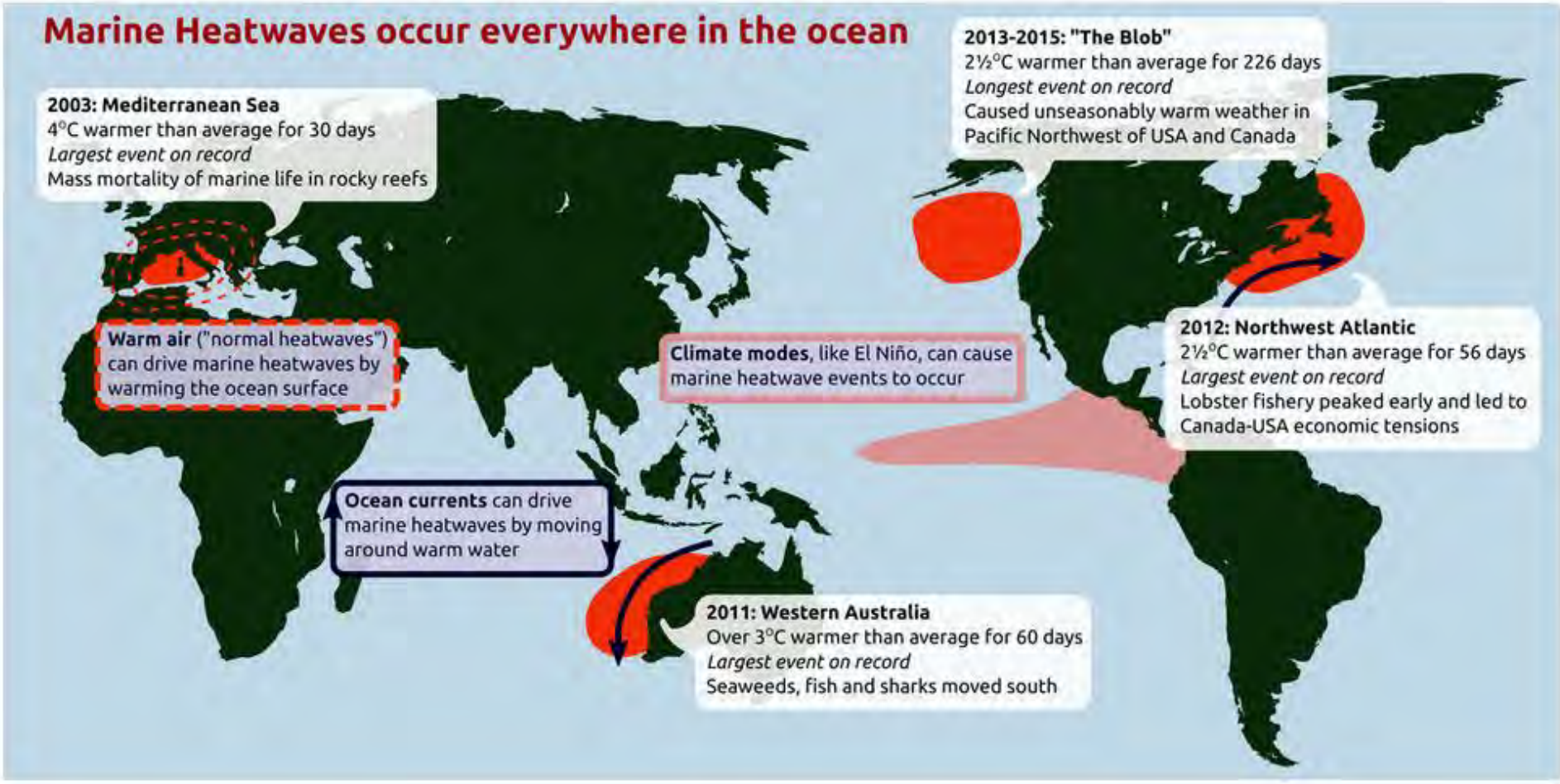
Relatively new



Frequency of publications returned from a Google Scholar search based on the search terms “marine heatwave” and “marine heat wave.” Note the first bin (1999) contains all records for the period 1900–1999.

Source: Hobday et al. 2018

Marine Heatwaves: Global Features



www.marineheatwaves.org

What can cause a MHW ?

"Drivers" that can

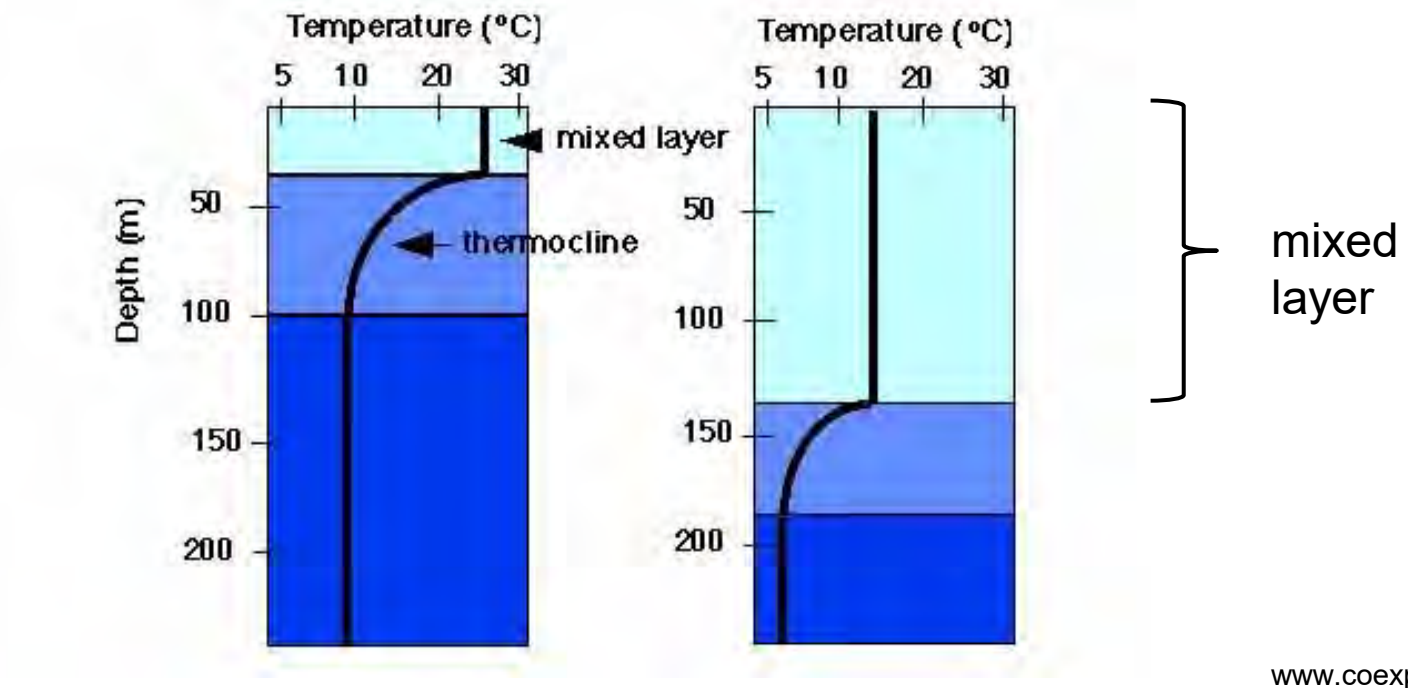
- force locally, through processes affecting the mixed layer temperature budget
- act to modulate MHW occurrences from regional or remote sources, climate modes
- act to modulate MHW occurrences via atmospheric and/or oceanic teleconnection processes.

Source: Holbrook et al., 2019

What can cause a MHW ?

"Drivers" that can

- force locally, through processes affecting the mixed layer temperature budget

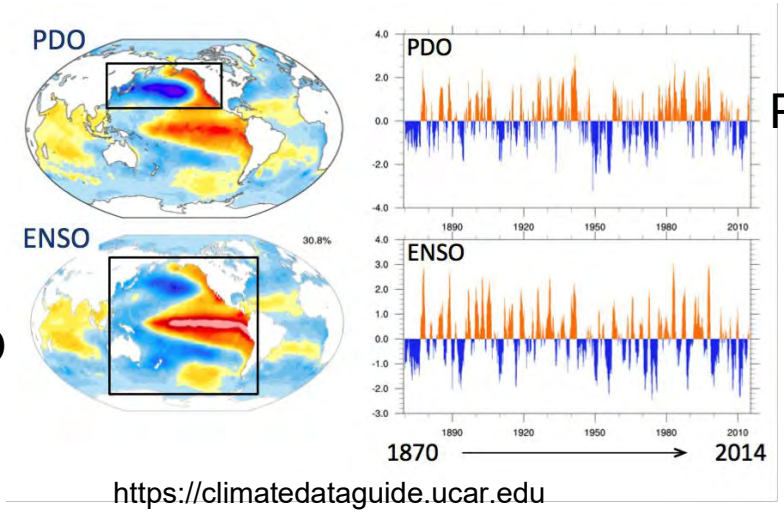


What can cause a MHW ?

"Drivers" that can

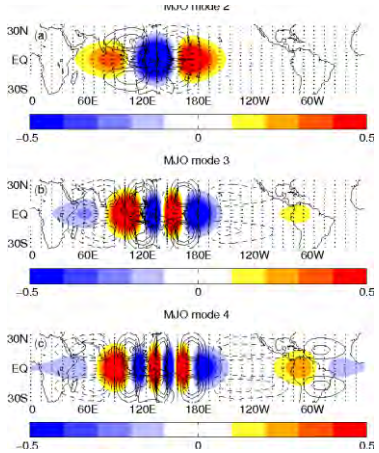
- act to modulate MHW occurrences from regional or remote sources, climate modes

e.g., El Niño comes to town…
but this isn't the only climate mode…



https://climatedataguide.ucar.edu

PDO



MJO

ENSO

& several others...

https://www.semanticscholar.org

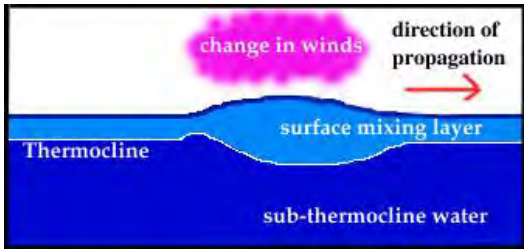
What can cause a MHW ?

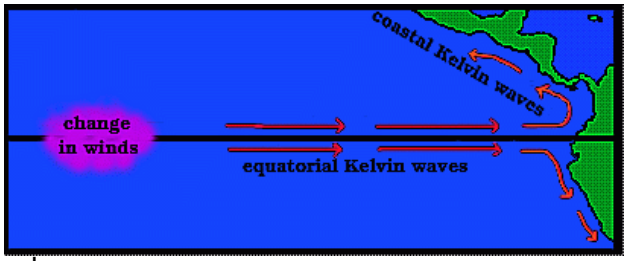
"Drivers" that can

- act to modulate MHW occurrences via atmospheric and/or oceanic teleconnection processes.

  Think jet stream, Kelvin waves…
  fluid flow is connected,
  and we have both ocean and atmosphere
  … teleconnection

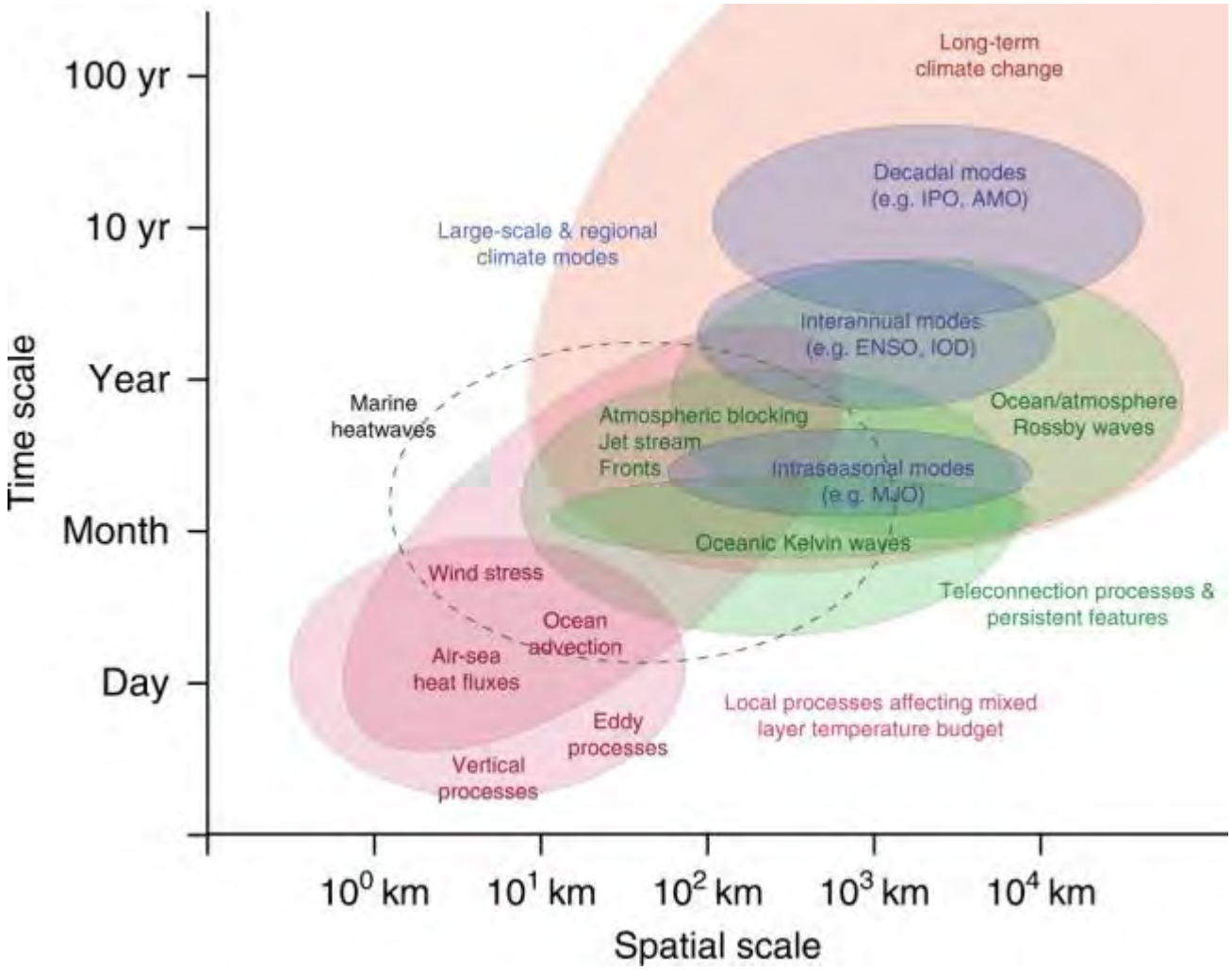
electroverse.net





www.oc.nps.edu

Complexity

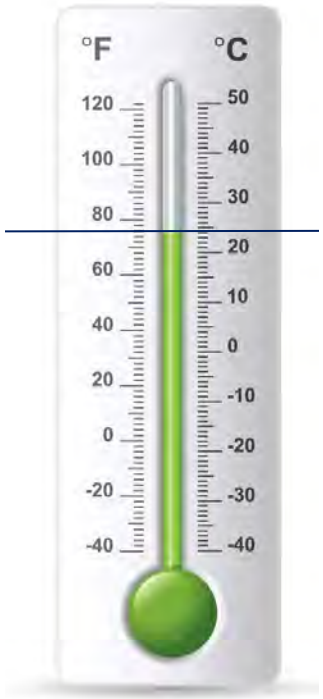


Schematic identifying the characteristic marine heatwave drivers and their relevant space and time scales. The black dashed line outlines the typical scales for MHWs.

Source: Holbrook et al., 2019

Anomaly and climatology

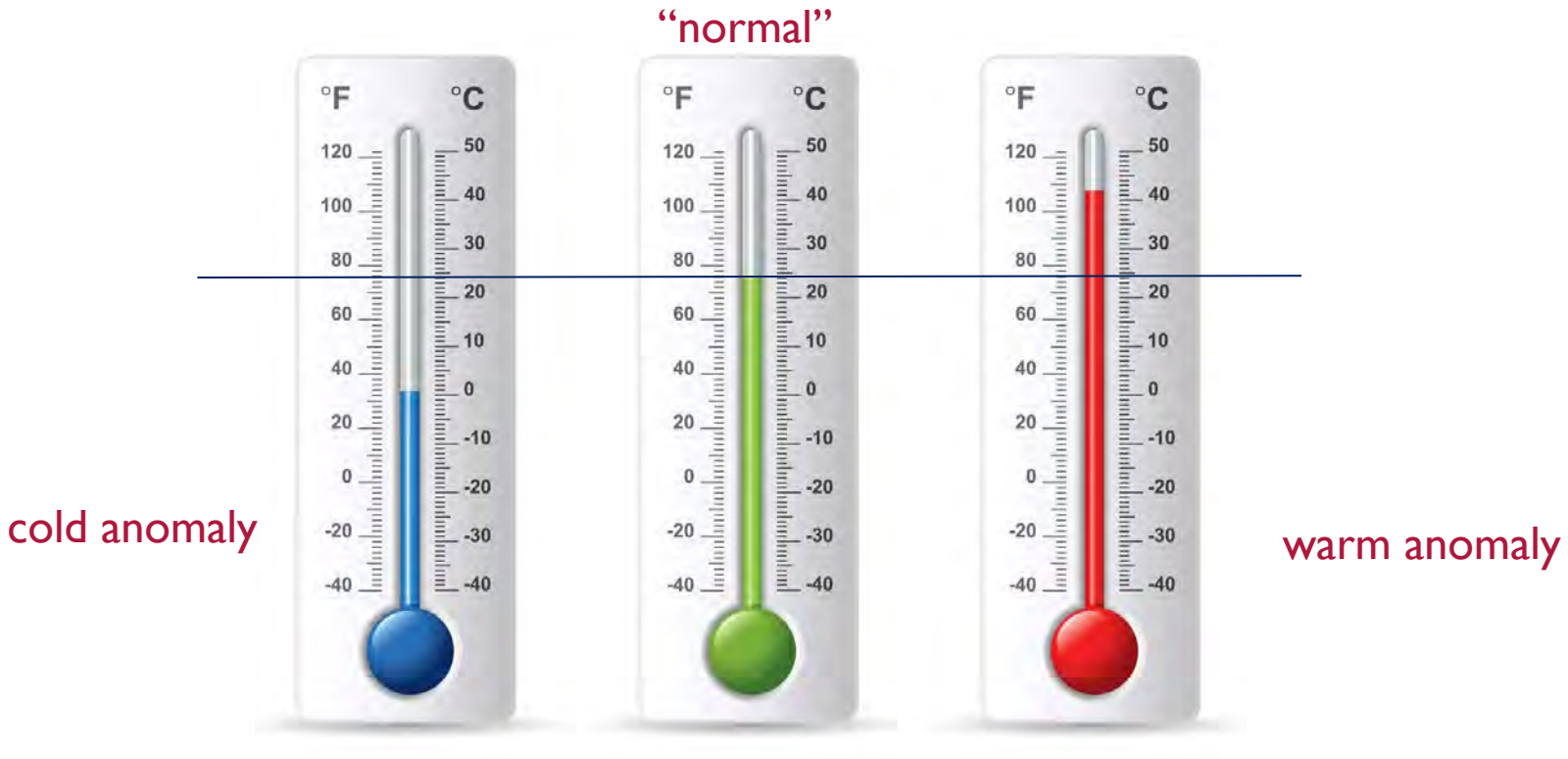
- Climatology = long term “normal”
- Anomaly = excursion from normal *(= obs - clim)*

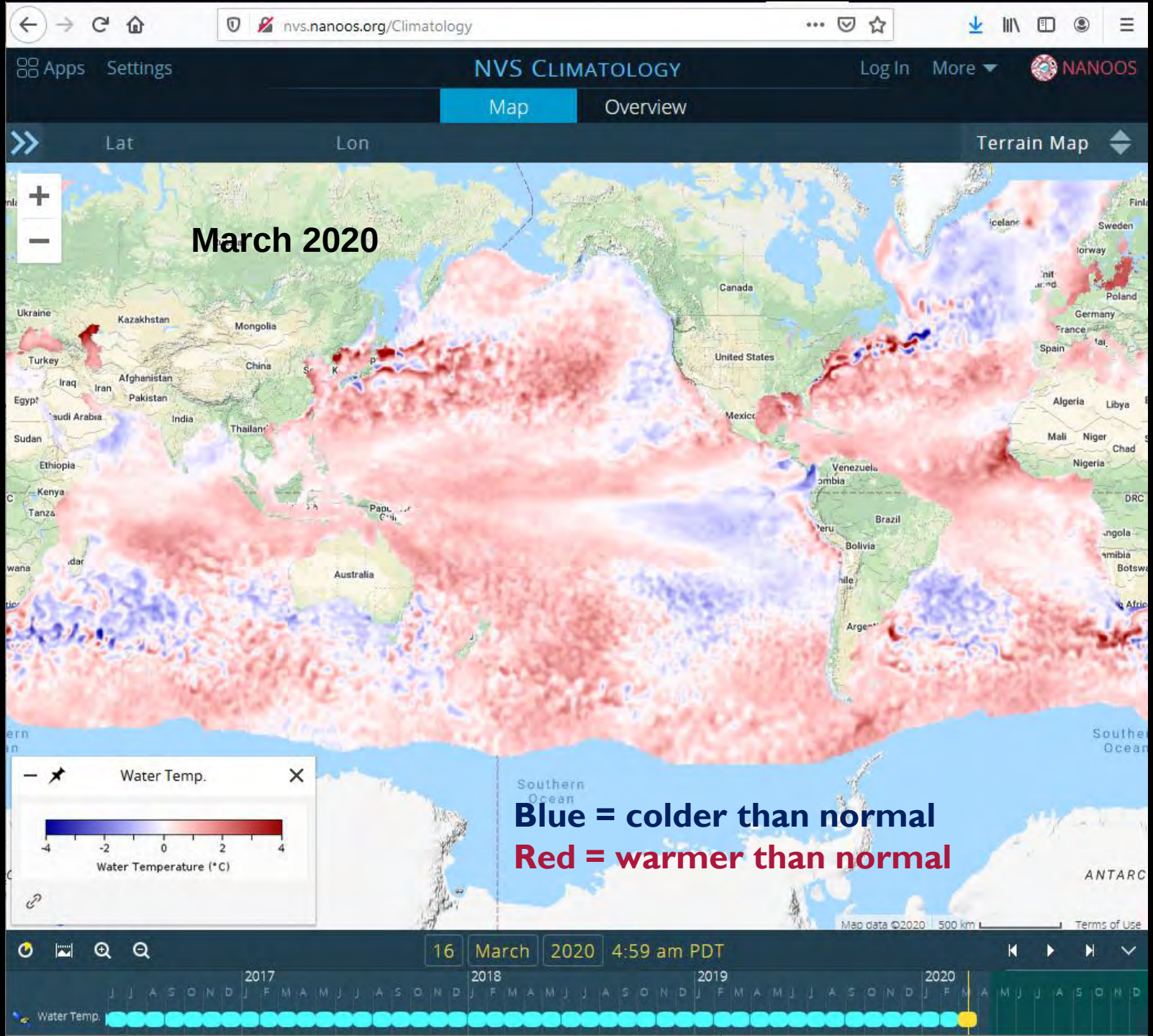


“normal”

Anomaly and climatology

- Climatology = long term “normal”
- Anomaly = excursion from normal *(= obs - clim)*




nvs.nanoos.org/Climatology
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NVS CLIMATOLOGY
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More
NANOOS
Map
Overview
Lat
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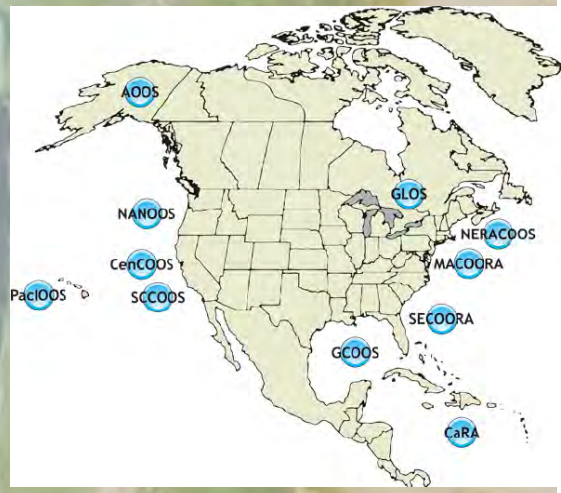
Terrain Map
March 2020
Water Temp.
-4
-2
0
2
4
Water Temperature (°C)
Blue = colder than normal
Red = warmer than normal
Map data ©2020
500 km
Terms of Use
16
March
2020
4:59 am PDT
2017
2018
2019
2020
Water Temp.



Northwest Association of Networked Ocean Observing Systems

The Integrated Ocean Observing System (IOOS)
Regional Association for the Pacific NW

www.nanoos.org

IOOS
Integrated Ocean
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IOOS | Integrated Ocean Observing System

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NANOOS Visualization System

NVS provides easy access to observations, forecasts, data, and visualizations.

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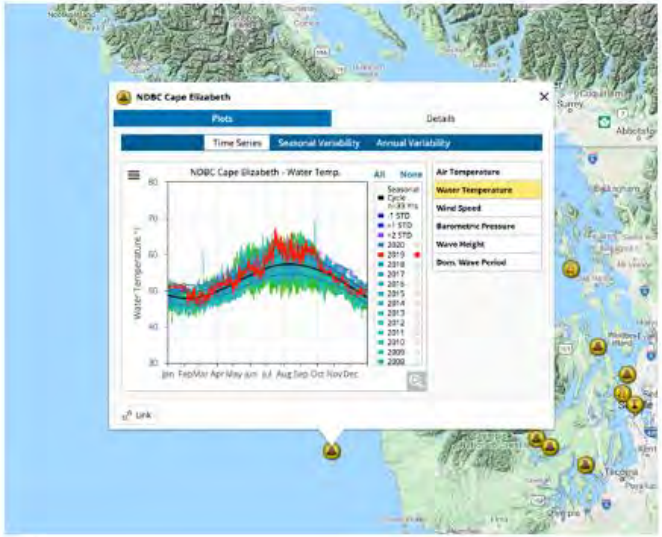


How Different Are Conditions?

New dynamic plotting capabilities have been added to the NVS Climatology app. Users can now explore year-to-year differences for a variety of data sets including water temperature and wave height. This makes comparing the two recent marine heat waves or comparing to other years easy. Click on the "+" in the lower right corner to expand the plot, then highlight any year in red by clicking the bubble next to the year. As always, use the comment link to let us know what you think of this new functionality.

How to Track Anomalies | Visit the NVS Climatology App

Go

New CDIP Wave Buoy in NANOOS Region

Go

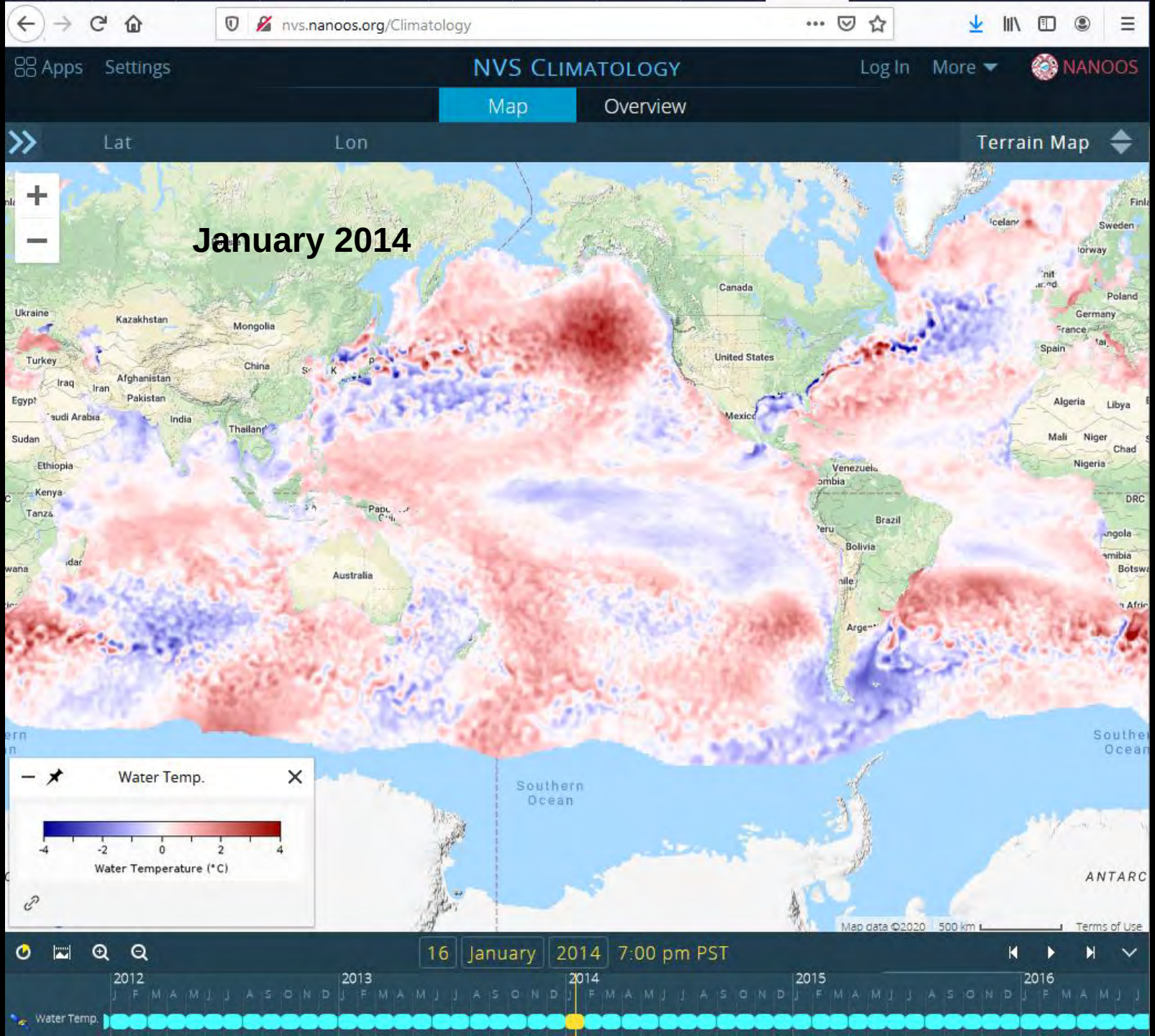
How Different Are Conditions?

Go

National Weather Service Assets Added to NVS

Go

NANOOS Presentation for NOAA West Watch Tracks Marine Heat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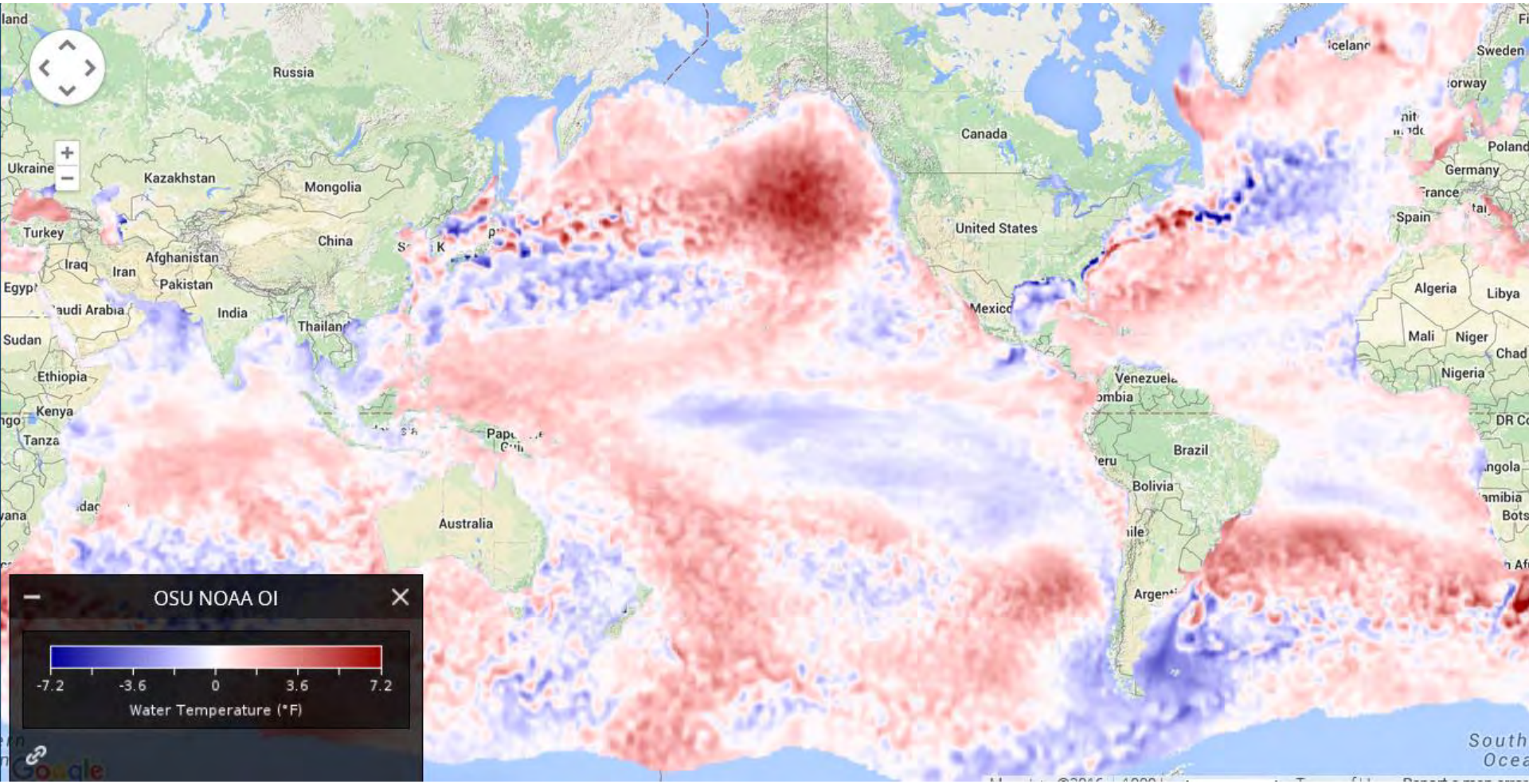
Terrain Map
January 2014
Water Temp.
-4
-2
0
2
4
Water Temperature (°C)
Southern Ocean
Map data ©2020
500 km
Terms of Use
16
January
2014
7:00 pm PST
2012
2013
2014
2015
2016
Water Temp.

“the blob”

Named by Nick Bond, WA State Climatologist

- Was not so much of a warming, but a lack of cooling
- Ridiculously resistant ridge of high pressure over Gulf of Alaska 2013-2014
- Weak Aleutian Low yields weak winds, minimal storms, reduced cooling from mixing → warm anomaly

The view in early 2014…

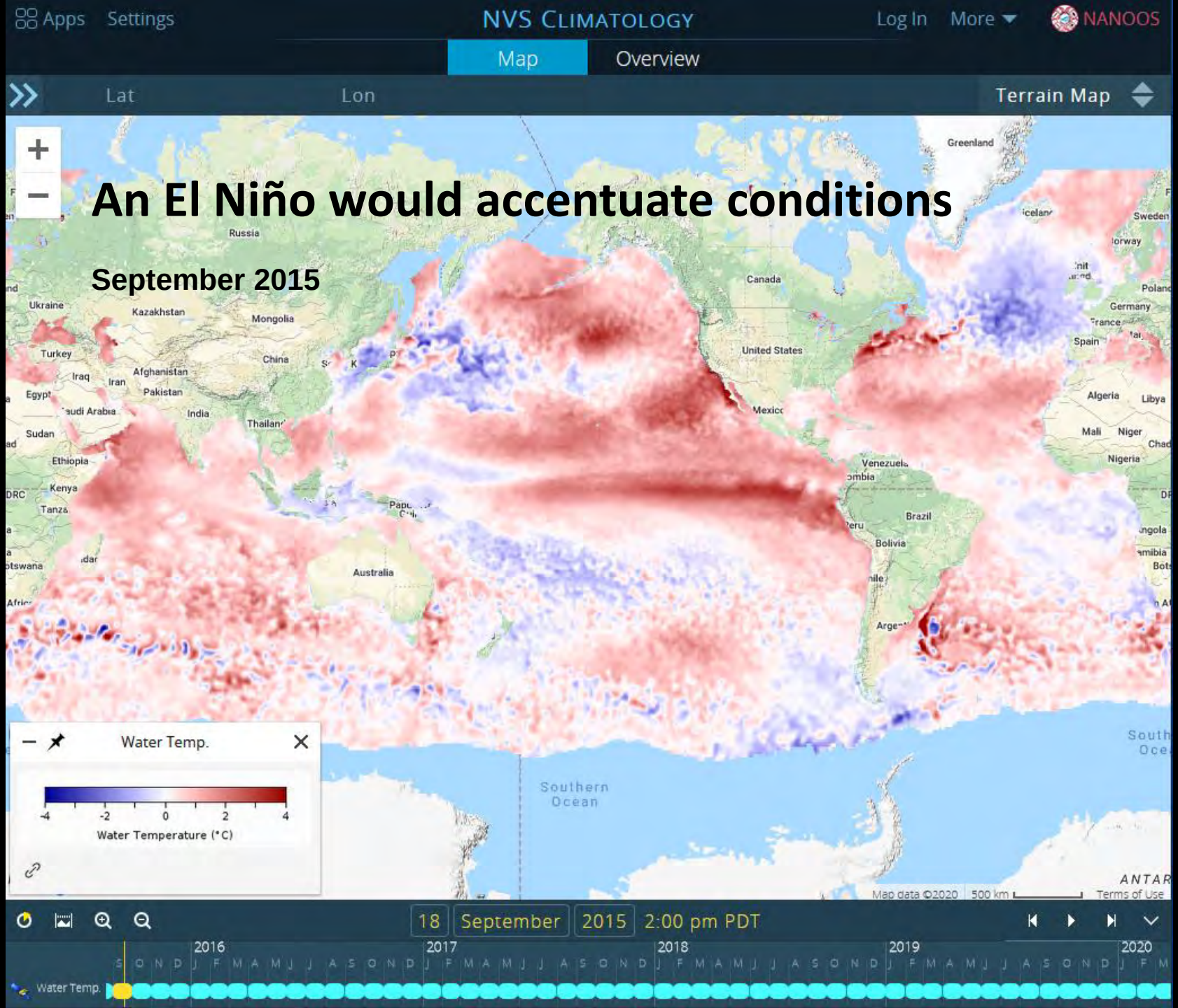


What we didn't know in 2014…

- An El Niño would accentuate conditions
- The blob would go deep and persist
- The blob would enter coastal waters with different dynamics

- What biological effects would occur ?

- We would see another MHW in less than 5 years in same area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Overview
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Lon
Terrain Map
An El Niño would accentuate conditions
September 2015
Water Temp.
-4
-2
0
2
4
Water Temperature (°C)
18
September
2015
2:00 pm PDT
2016
2017
2018
2019
2020
Water Temp.
Map data ©2020
500 km
Terms of Use

The blob would go deep and persist…

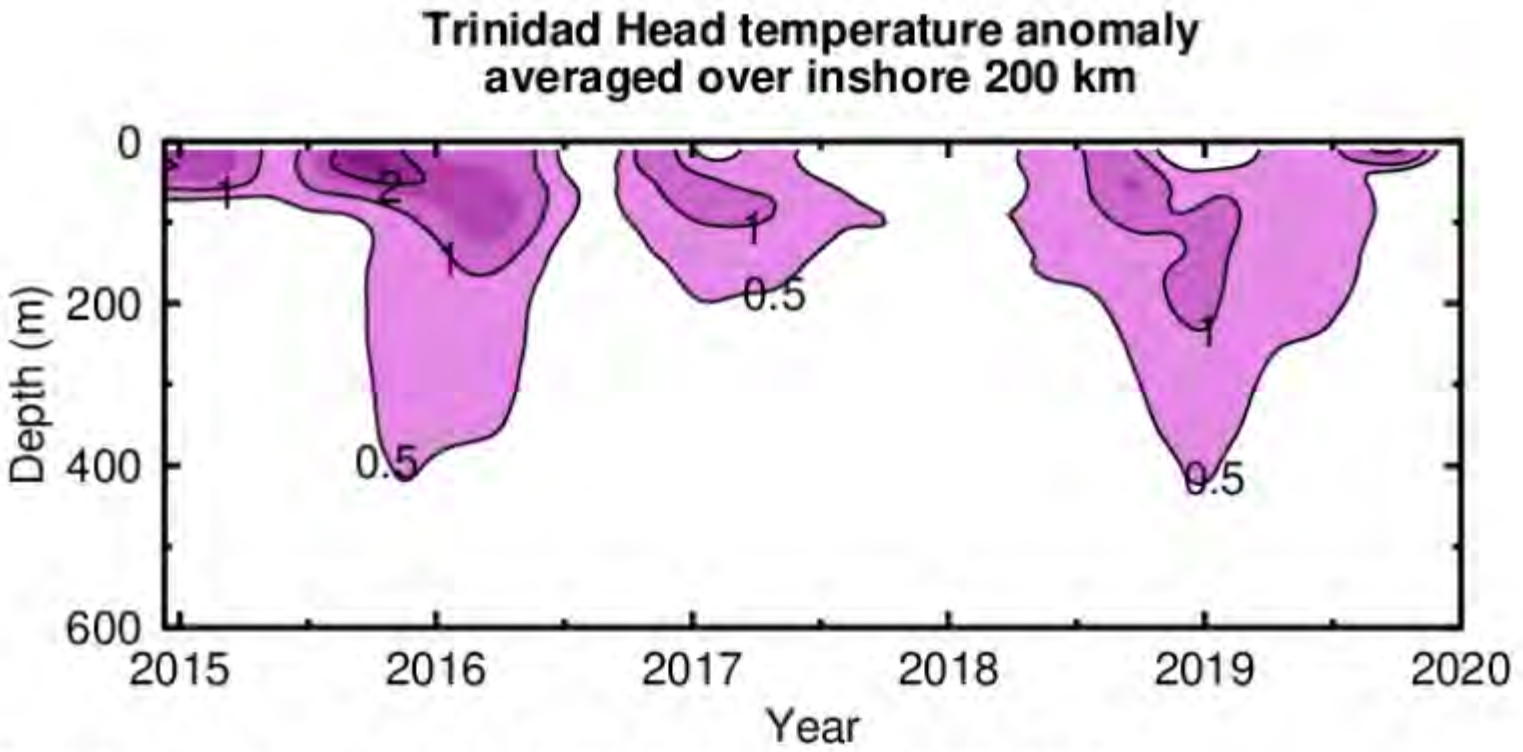
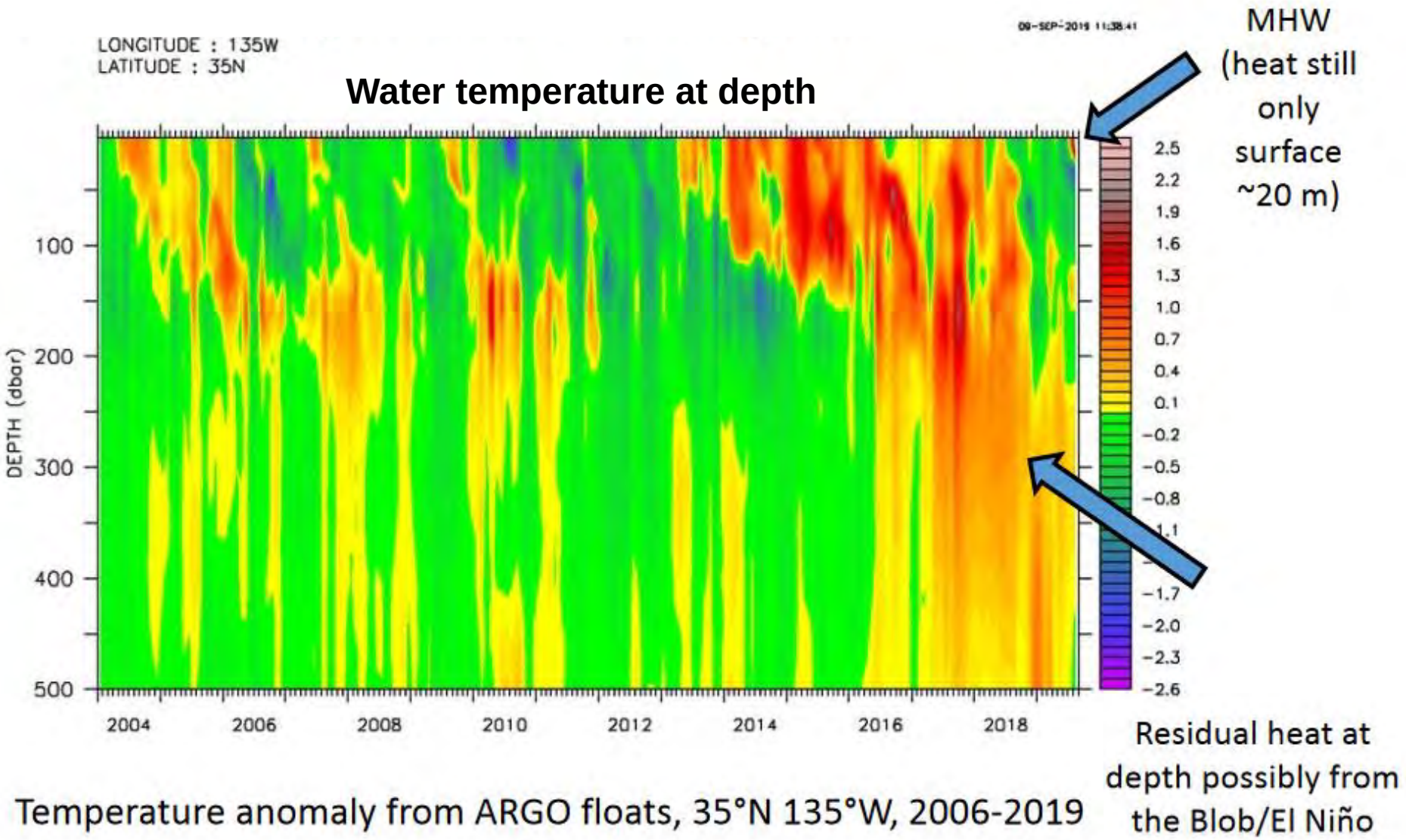


Figure 1: *Temperature anomaly from the Trinidad Head, CA (41° 3.5'N) glider line.*

Source: Barth, OSU

We would see another MHW in less than 5 years…



Slide from Toby Garfield, NOAA SWFSC

A new MHW but with some differences…

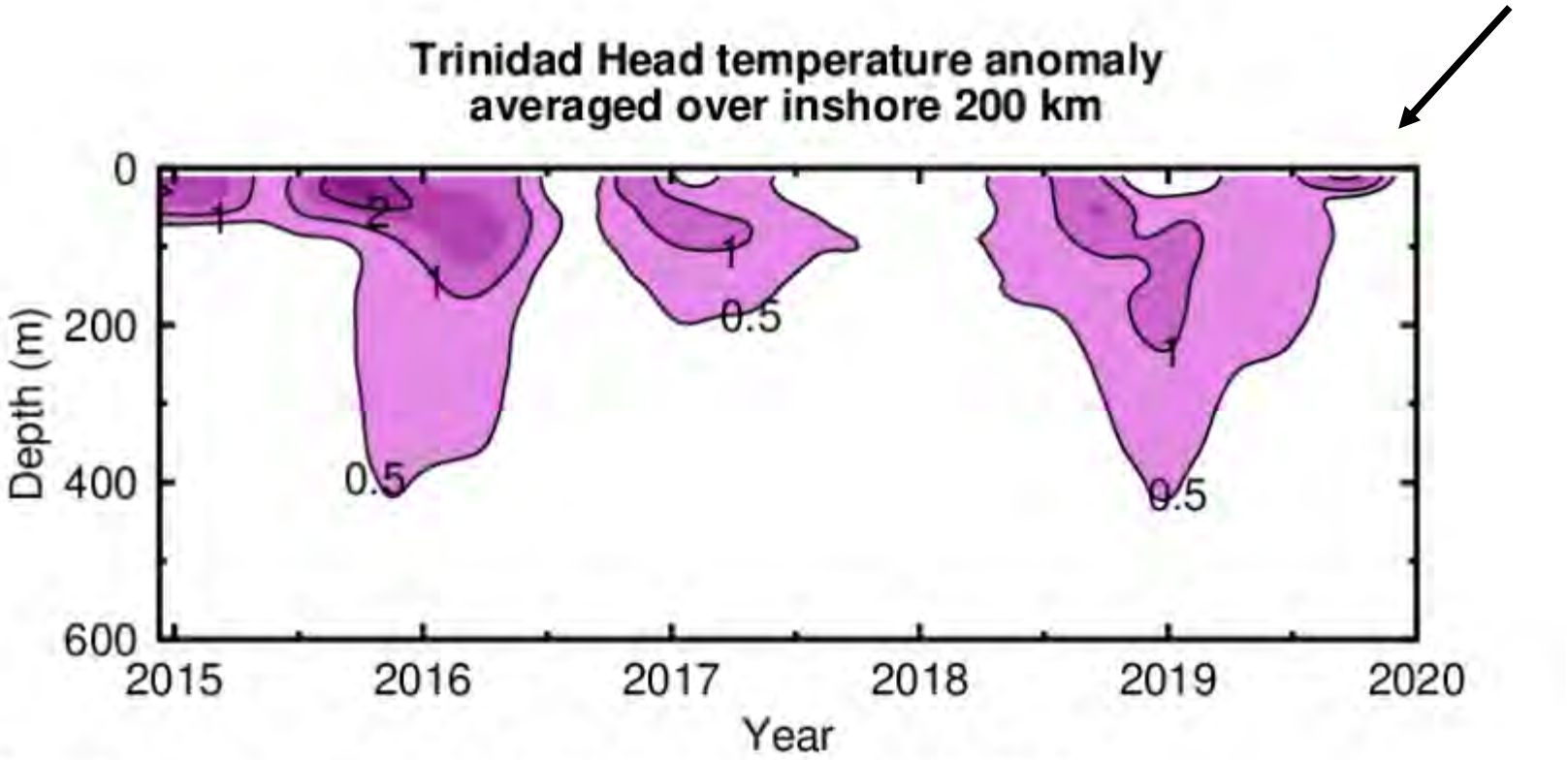


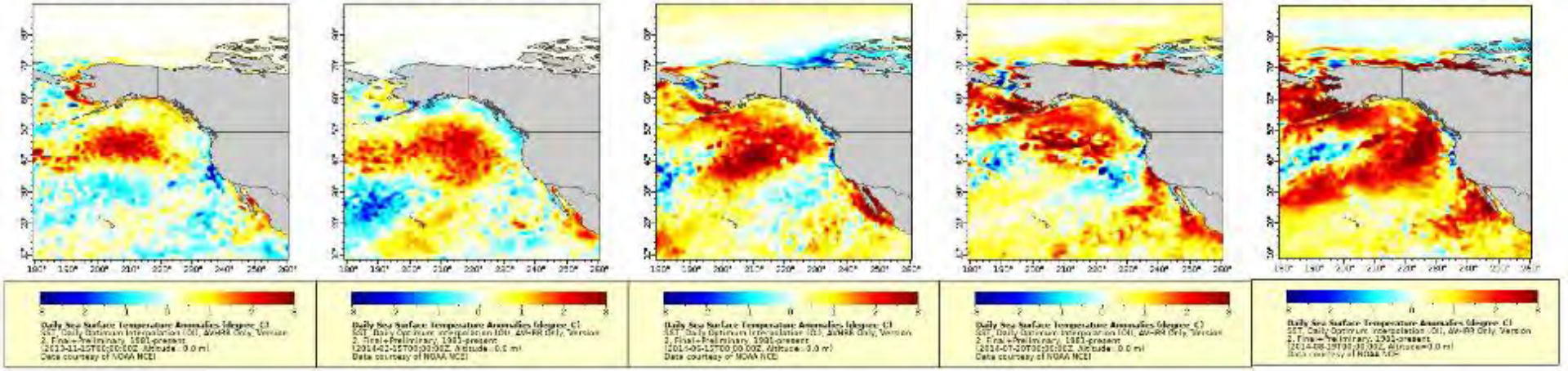
Figure 1: *Temperature anomaly from the Trinidad Head, CA (41° 3.5'N) glider line.*

Source: Barth, OSU

Current MHW vs. "The Blob": SST anomalies

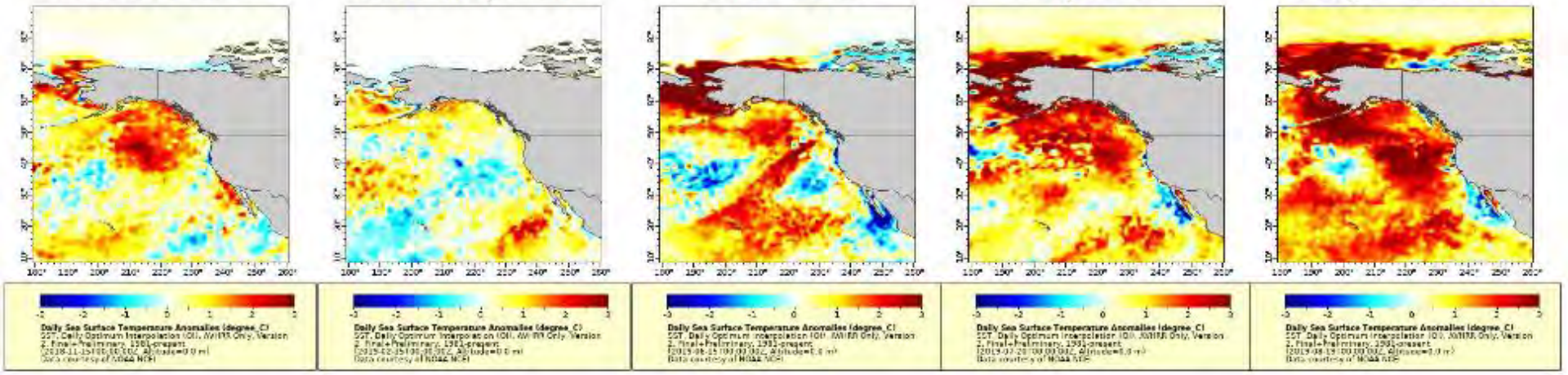
The Blob

October 2013 | February 2014 | June 2014 | July 2014 | Aug 19, 2014



Current MHW

October 2018 | February 2019 | June 2019 | July 2019 | Aug 19, 2019



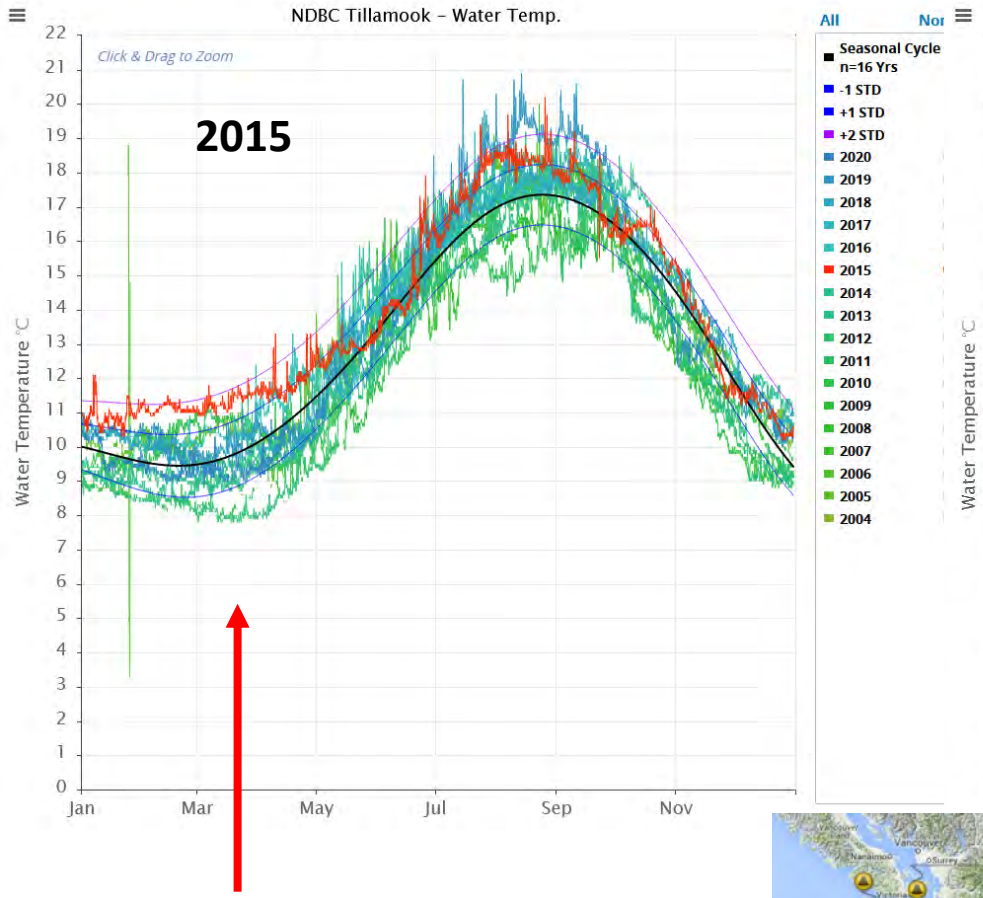
Slide from Toby Garfield, NOAA SWFSC

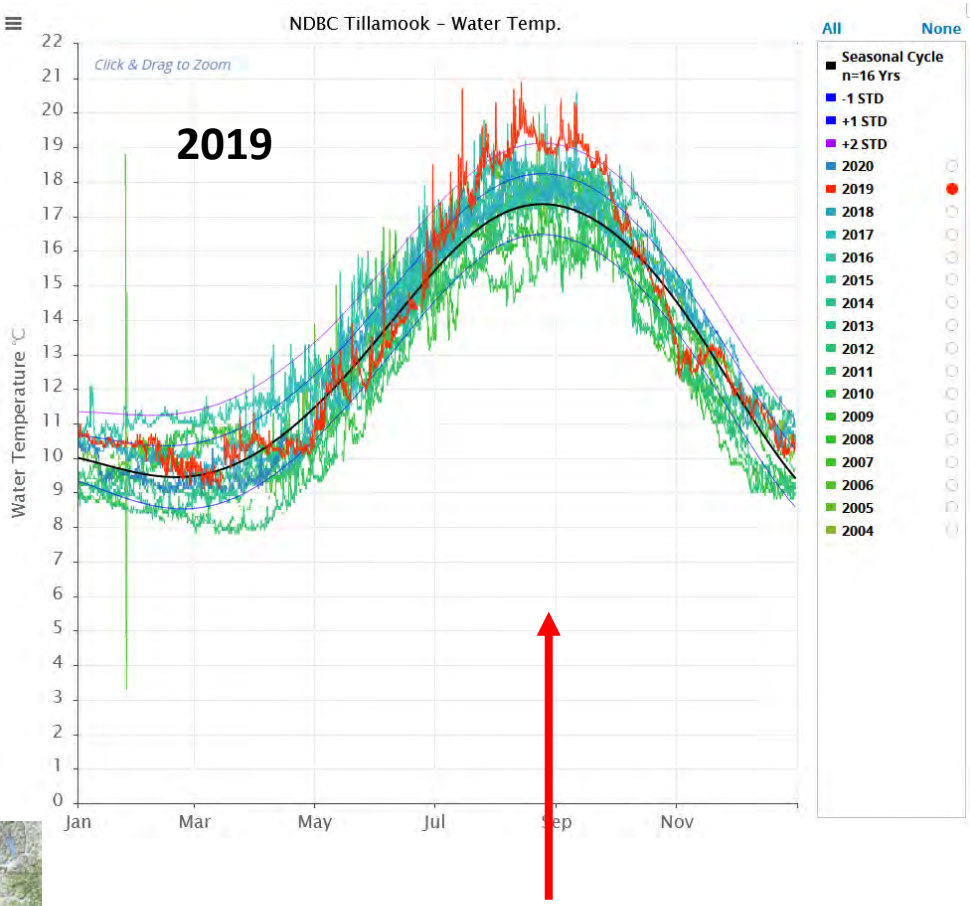
2013-2016 vs. 2019-2020

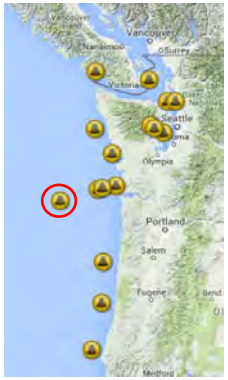
- 2013-14 winter genesis
- Very strong pressure ridge stalled, weakened the Aleutian low
- Reduced related winds
- Less mixing
- Lack of cooling, so surface heat accumulated

Source: Amaya et al. 2020

- 2019 summer genesis
- Prolonged weakening of N. Pacific high
- Reduced surface winds
- Less cooling/mixing
- Mixed layer depth shallows, heating constrained to narrow layer
- Summer cloud burn-off a positive feedback







~1.5-2 degrees C
~3 months
Feb to May

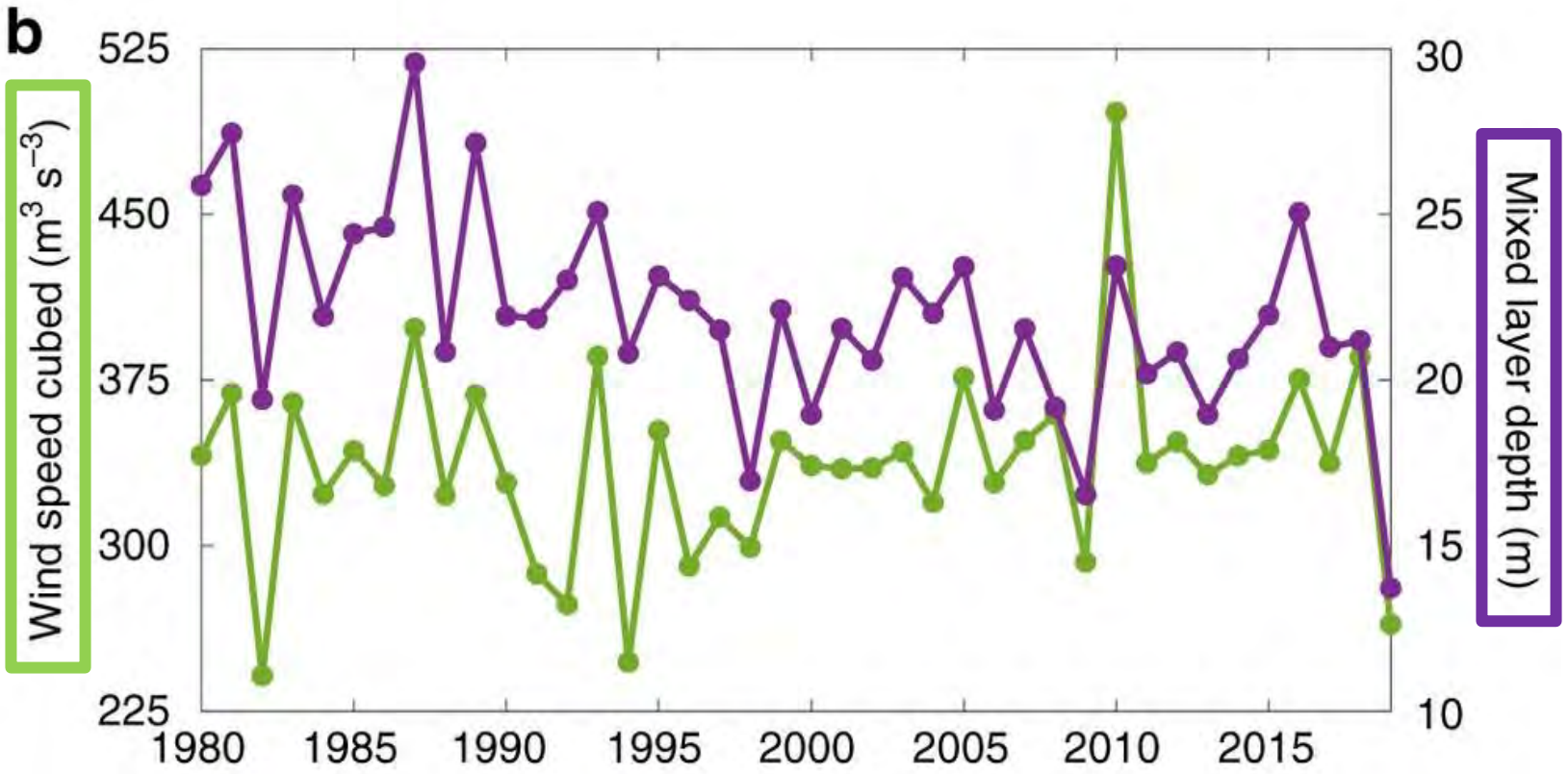
~2-3 degrees C
~3 months
July to Oct

How will things change ?

- The oceans are warming at an unprecedented rate. Sea surface temperatures have increased at a rate of nearly 0.6°C per century since 1880 (IPCC AR5).
- The Intergovernmental Panel on Climate Change (IPCC) 5th assessment report projects that the global ocean will continue to warm well into the 21st century. Warming in the upper ocean is projected to be between 0.6 - 2°C.

- Increase the heat = increase in risk of heatwave

- What about the North Pacific mixed layer depth?

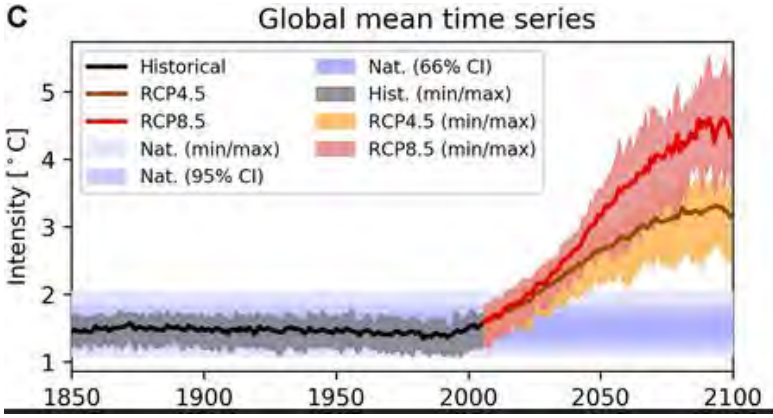


June–August (JJA)-averaged reanalysis wind speed cubed (green/left y-axis; m^3 s^{-3}) and mixed layer depth (purple/right y-axis; m) area-weighted averaged in black box seen in Fig. 1a. All time series are for the time period 1980–2019.

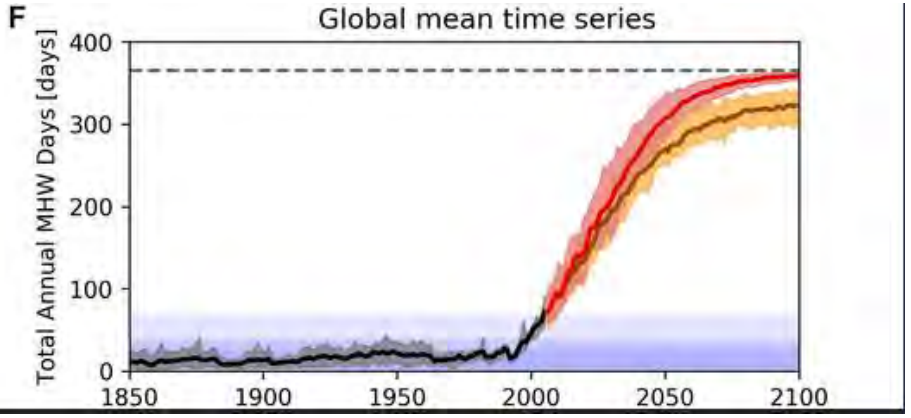
Amaya, D.J., Miller, A.J., Xie, S. *et al.* Physical drivers of the summer 2019 North Pacific marine heatwave. *Nat Commun* 11, 1903 (2020). https://doi.org/10.1038/s41467-020-15820-w

How will things change ?

Maximum Intensity (C)



Total Annual MHW Days



"Based on these projections we expect impacts on marine ecosystems to be widespread, significant and persistent through the 21st century."

Source: Oliver et al., 2019

What are MHW Effects ?

Also, consider: abrupt vs gradual change (Oliver et al. 2018)

- Alter ecosystem structure
- Alter habitat ranges
- Affect biodiversity
- Cause economic losses

For more, see Smale et al. 2019

MHWs have killed off kelp forests and coral, and produced significant impacts on marine ecosystems, fishing and aquaculture

Credit: https://english.kyodonews.net/news/2018/04/78ae9aeae8a9-one-third-of-great-barrier-reef-corals-killed-in-marir

Dungeness Crabbers Hit Hard By Algae Bloom On Washington Coast

By ASHLEY AHEARN · 18 HOURS AGO

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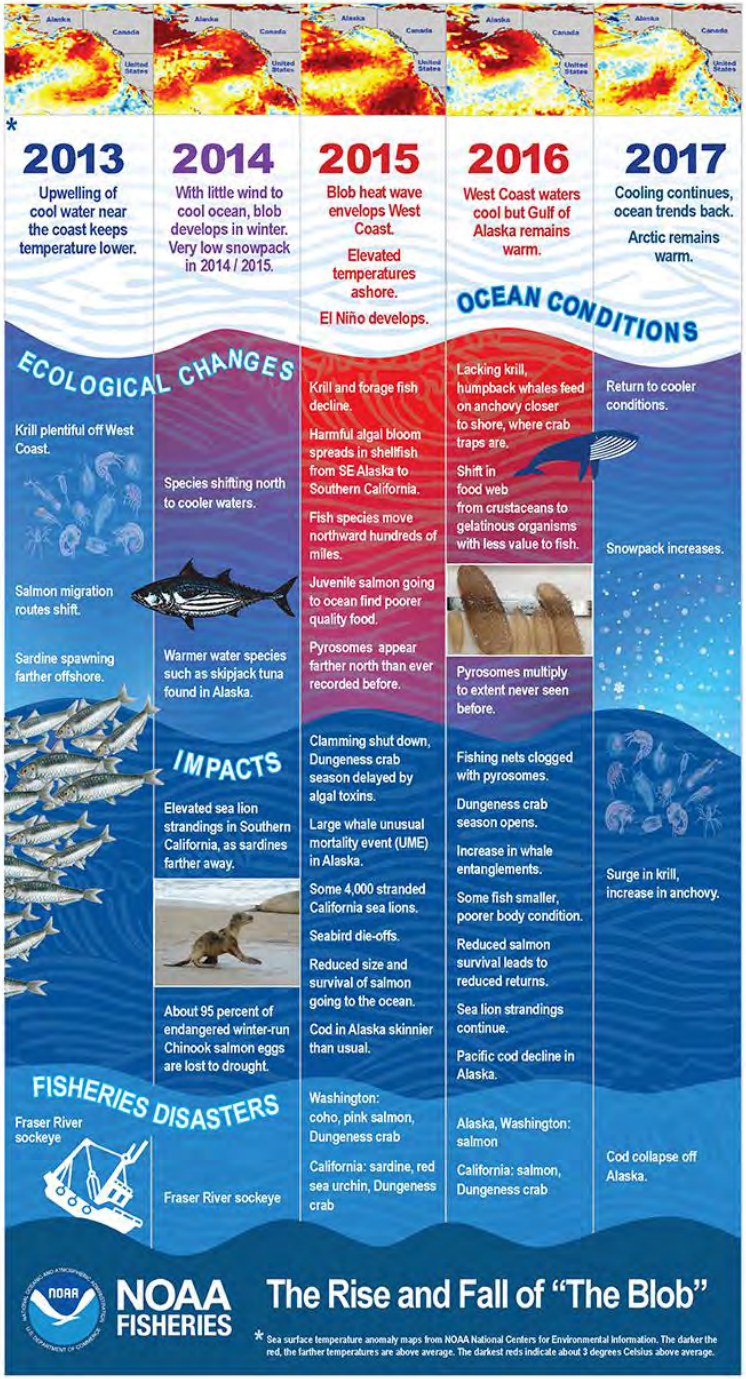
Crabber Tom Petersen would rather have his crab pots on the floor of the Pacific, but a toxic algae bloom has prompted health officials to close the south Washington coast to commercial and recreational crabbing.

Credit: Photograph: D. Derickson/COASST

Credit: Bennett, Santana-Garcon and Wernberg

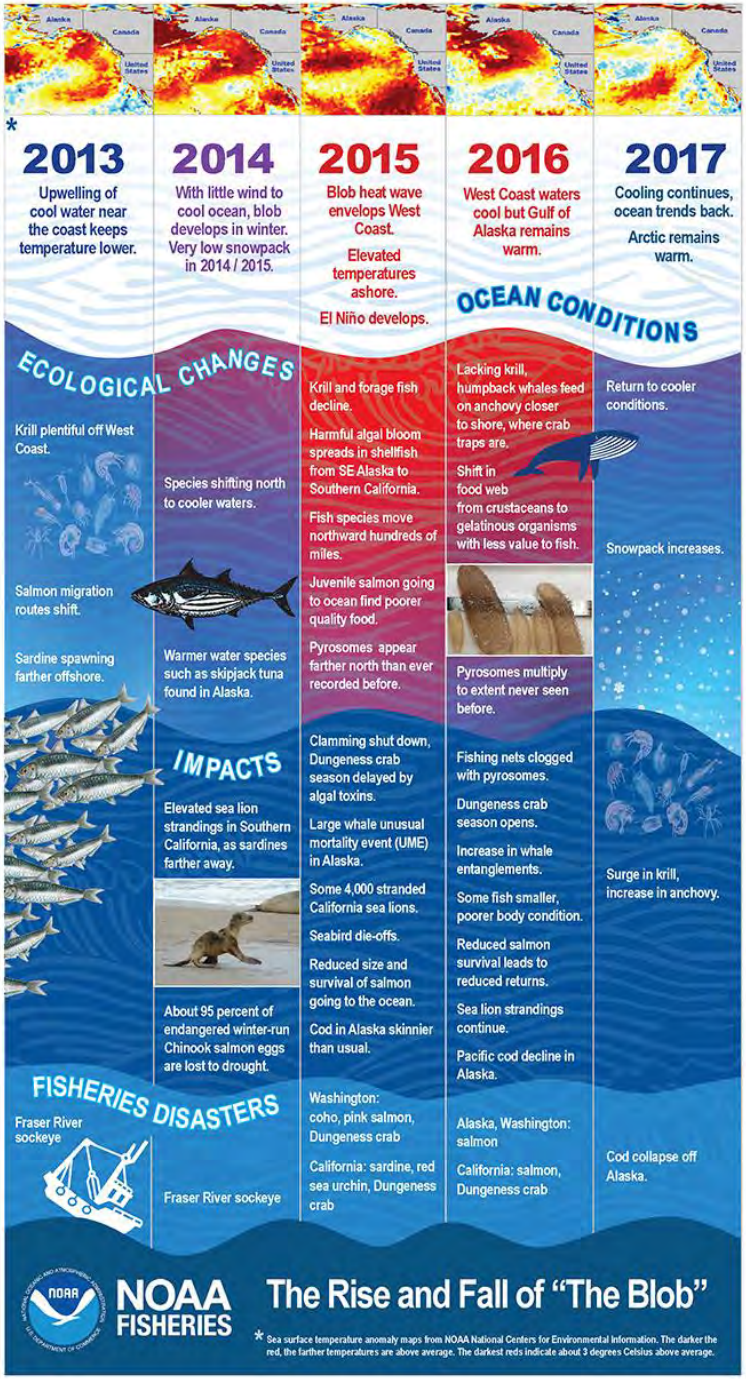
Slide from Stephanie Moore, NOAA NWFSC



Major Impacts

- Largest harmful algal bloom recorded on west coast, shut down crabbing and clamming
- Marine mammal impacts, including 1000's young California sea lion beach stranding
- Mass sea bird die-offs
- Multiple declared fishery disasters

McCabe et al. 2016; Jones et al. 2018; Piatt et al. 2019



Other Changes

- Many species shift to areas not typically found
- Pyrosomes increase to numbers not seen before; clog fishing nets
- Large whale unusual mortality event
- Gelatinous zooplankton favored
- Skinnier fish of several species

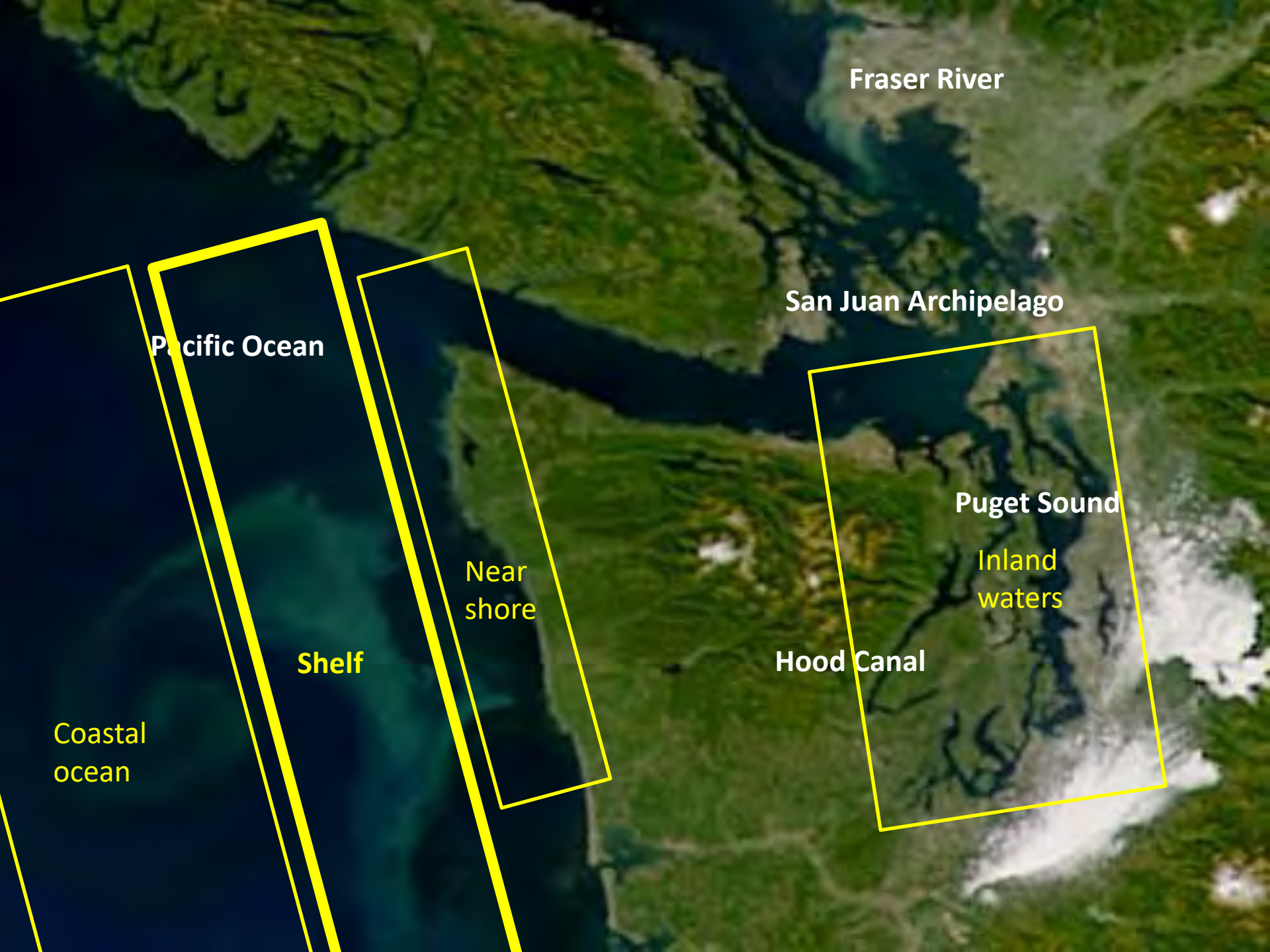
Bond et al. 2015; Siedlecki et al. 2016; Brodeur et al. 2018; Morgan et al. 2019


Fraser River
San Juan Archipelago
Pacific Ocean
Puget Sound
Hood Canal


Fraser River
San Juan Archipelago
Pacific Ocean
Puget Sound
Inland waters
Near shore
Shelf
Hood Canal
Coastal ocean

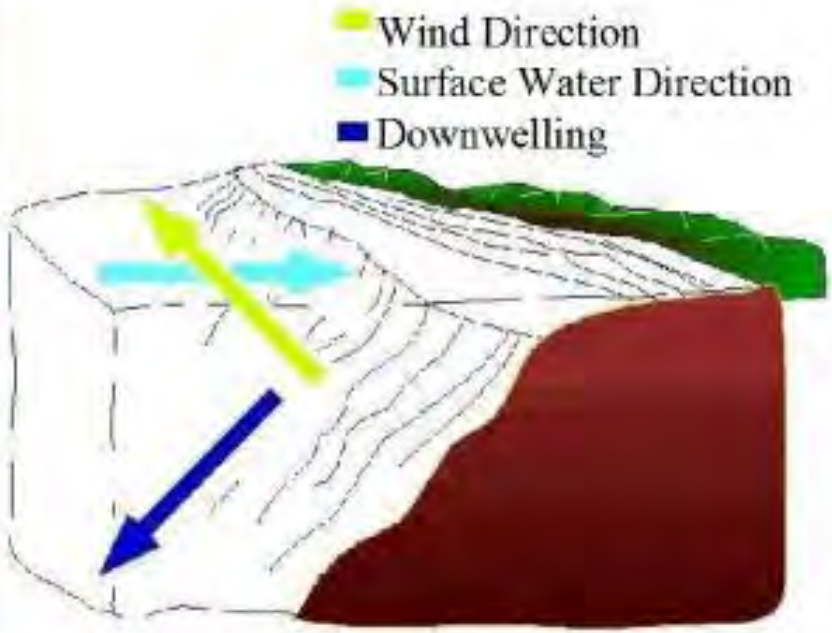
How do MHWs affect the coasts and nearshore ?

- Coastal shelf and nearshore dynamics
  - Influence of wind amplified; upwelling
- Inland sea dynamics
  - Influence of bathymetric features, e.g., sills, that can retain heat signal


Fraser River
San Juan Archipelago
Pacific Ocean
Puget Sound
Inland waters
Near shore
Shelf
Hood Canal
Coastal ocean

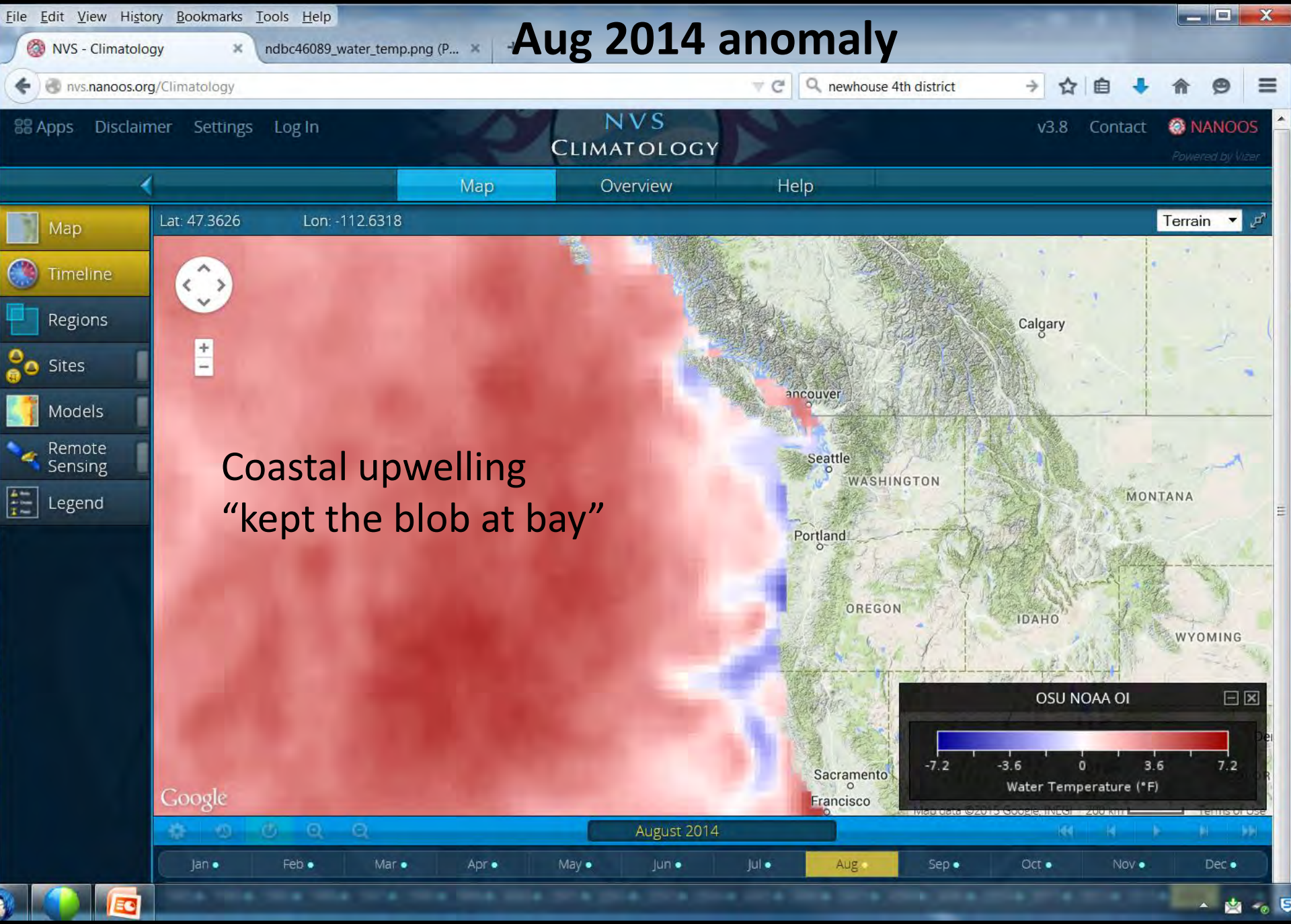
Coastal Upwelling

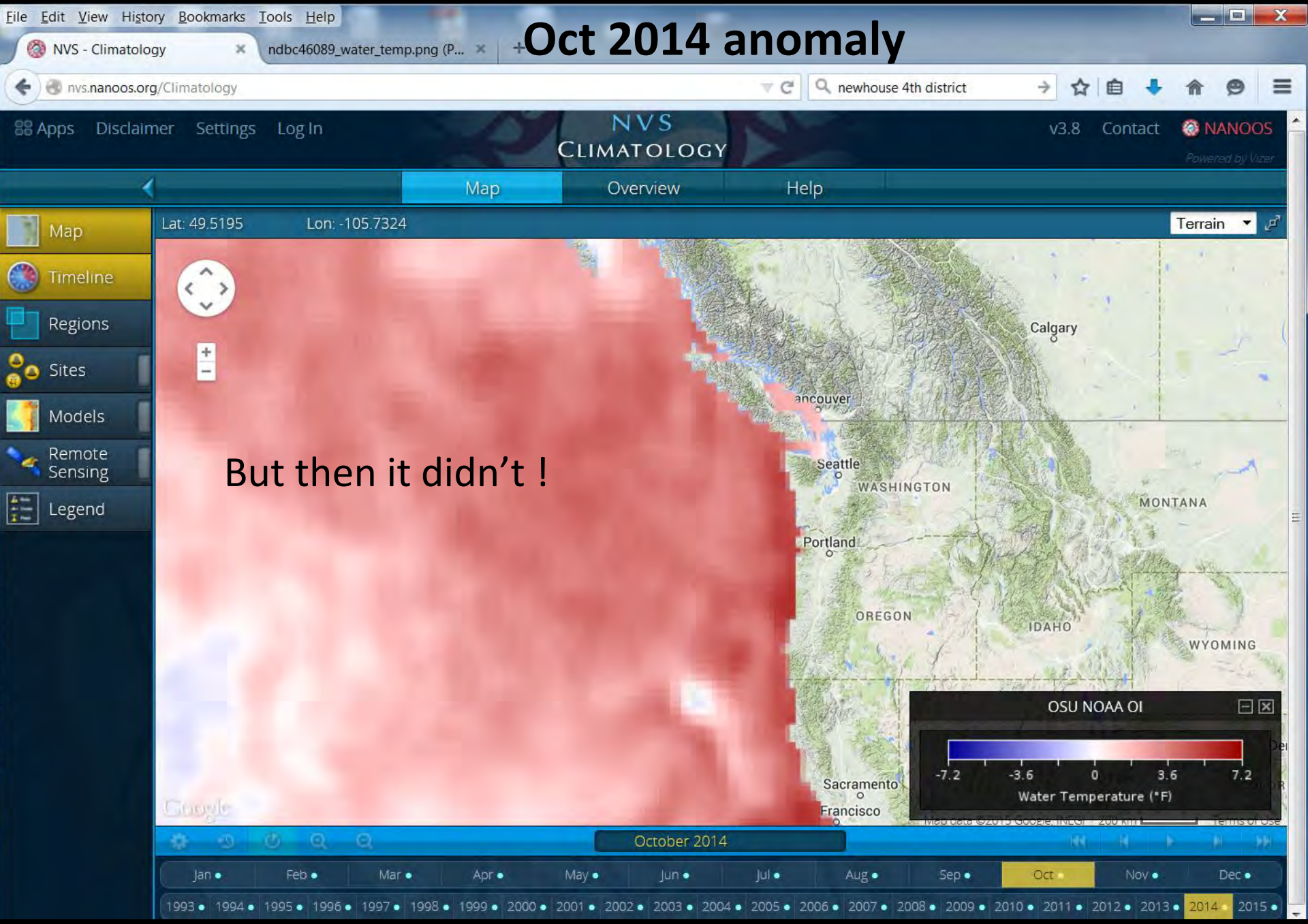
Fall Transition occurs when coastal upwelling conditions change to dominantly downwelling conditions.



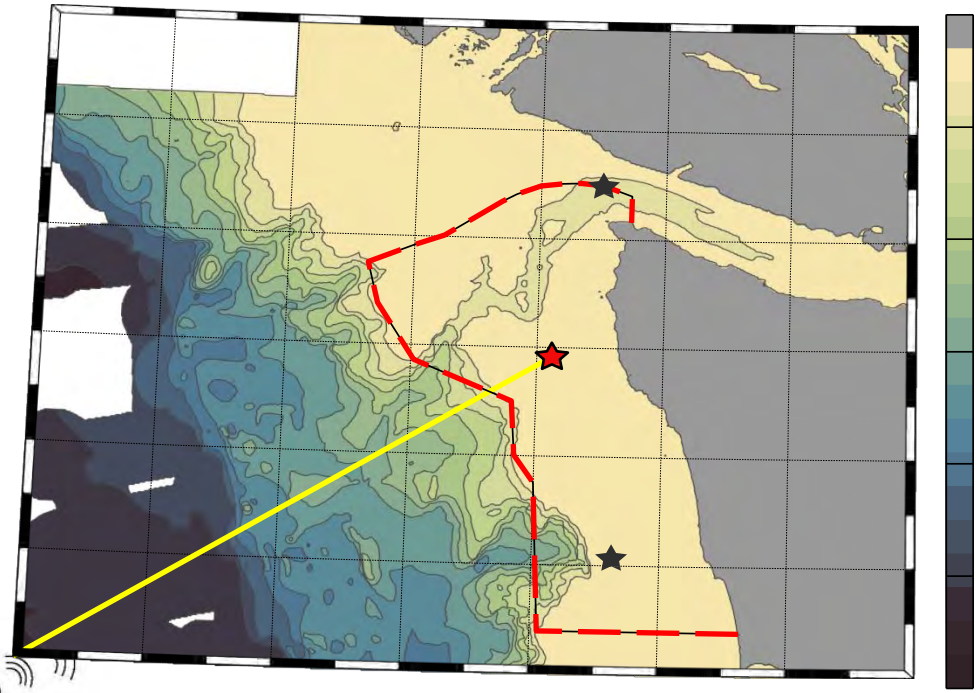
Source: NOAA

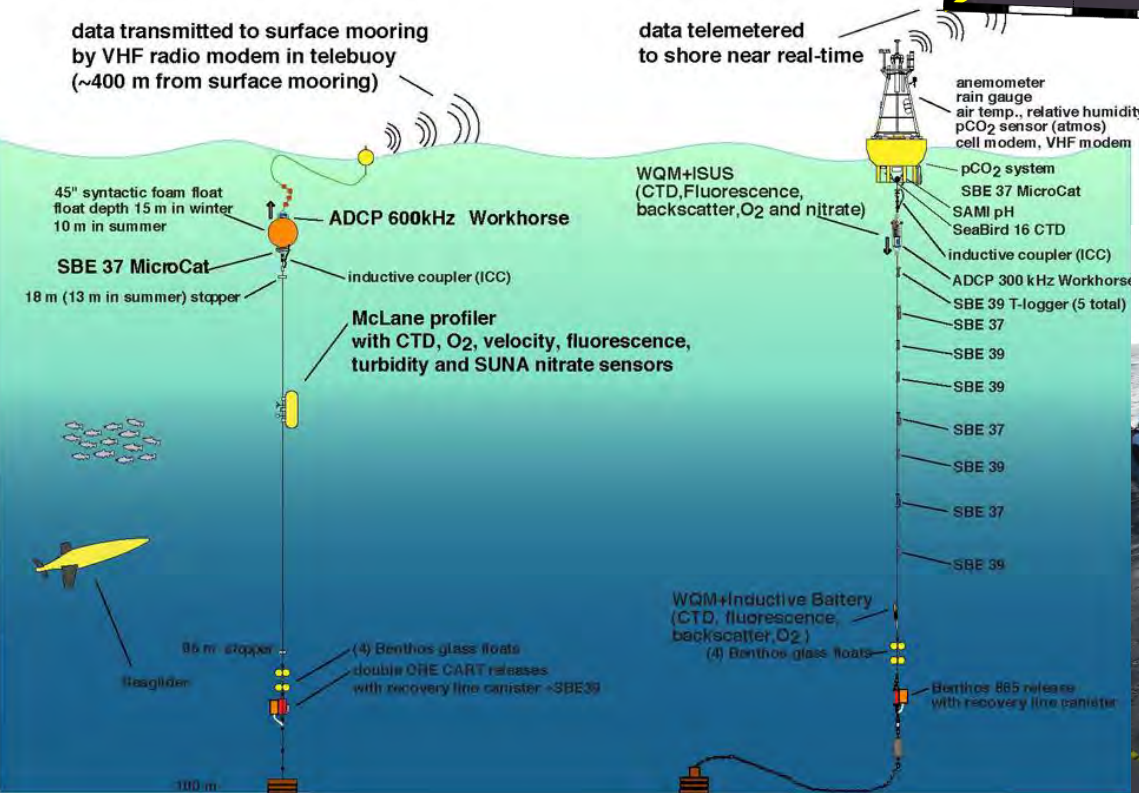
Aug 2014 anomaly

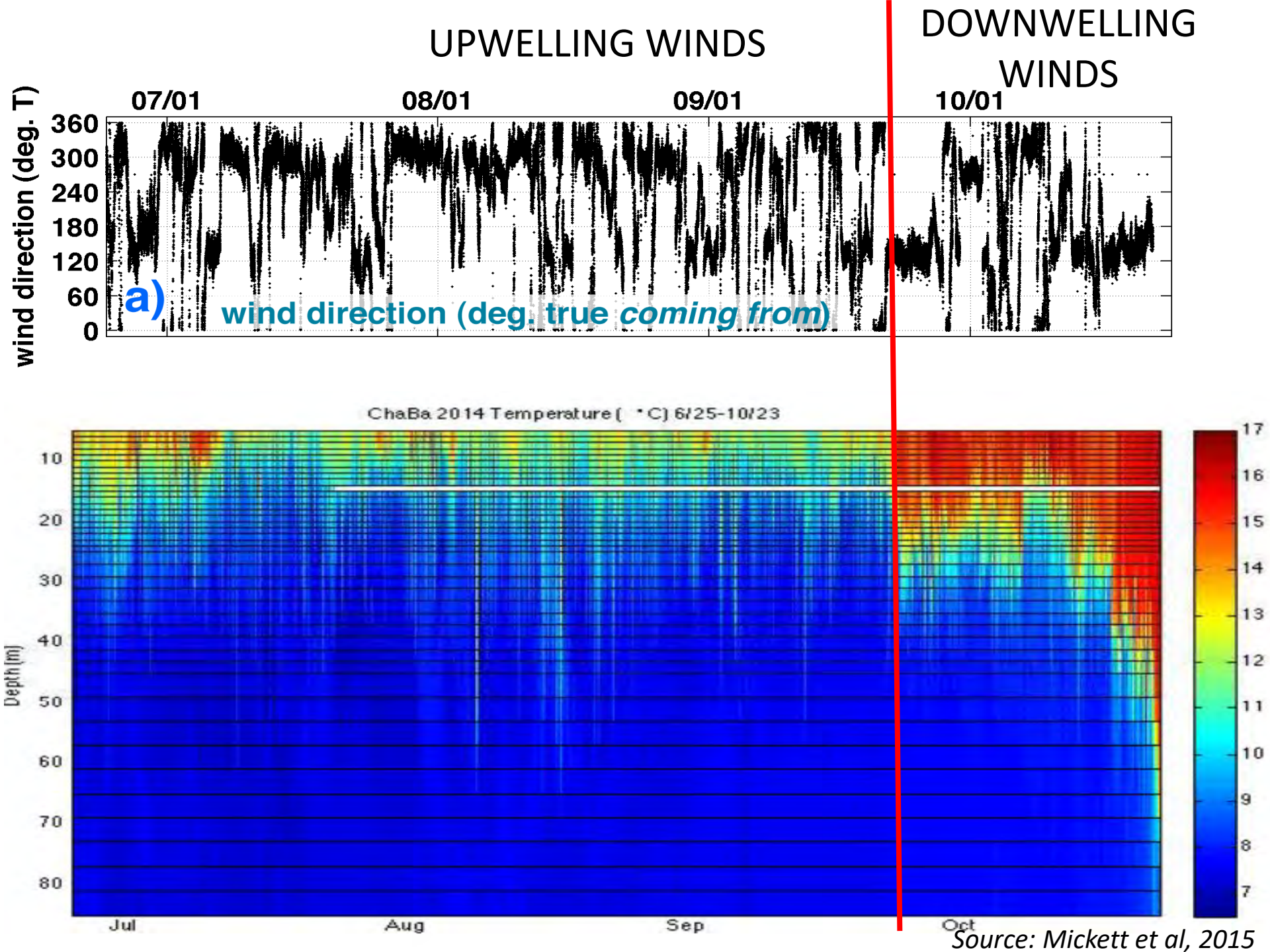



Oct 2014 anomaly
File Edit View History Bookmarks Tools Help
NVS - Climatology
ndbc46089_water_temp.png (P...
nvs.nanoos.org/Climatology
newhouse 4th district
Apps Disclaimer Settings Log In
NVS
CLIMATOLOGY
v3.8 Contact NANOOS
Powered by Vizer
Map Overview Help
Map
Timeline
Regions
Sites
Models
Remote Sensing
Legend
Lat: 49.5195 Lon: -105.7324
Terrain
But then it didn't !
Calgary
Seattle
WASHINGTON
MONTANA
Portland
OREGON
IDAHO
WYOMING
Sacramento
Francisco
OSU NOAA OI
-7.2 -3.6 0 3.6 7.2
Water Temperature (°F)
October 2014
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015

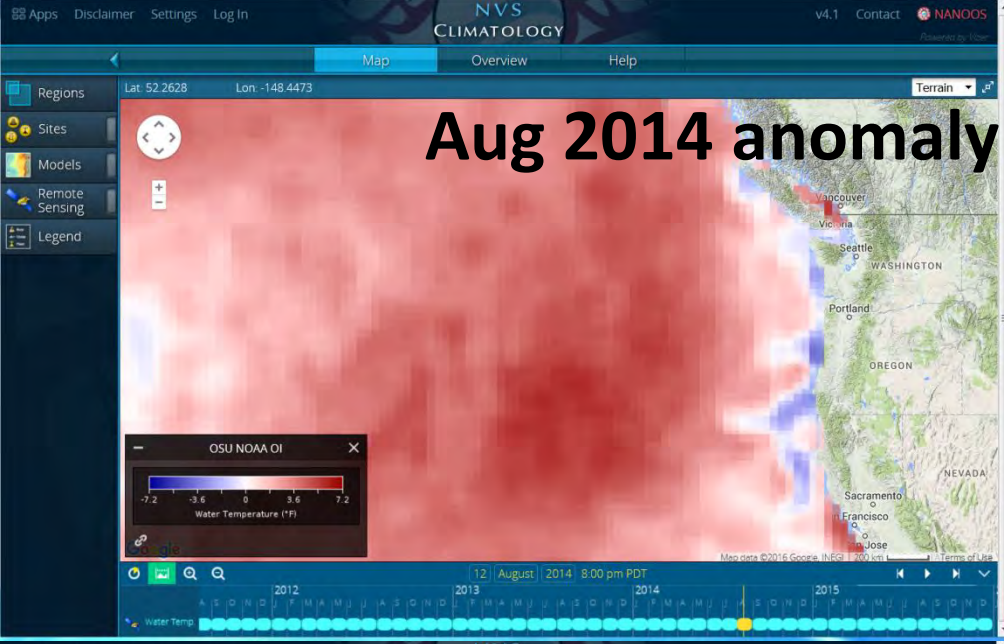
Cha'ba Buoy and NEMO profiler, La Push, WA

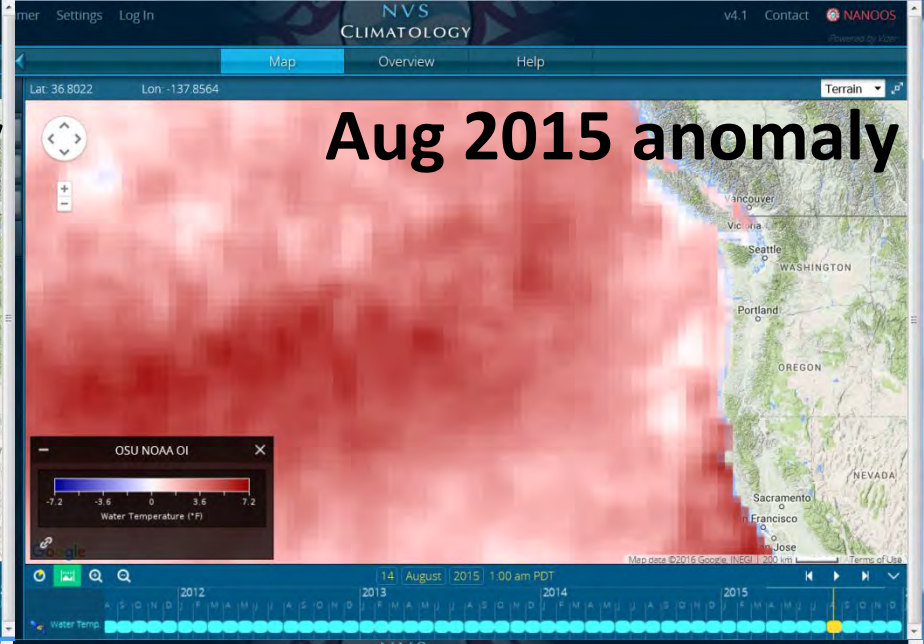


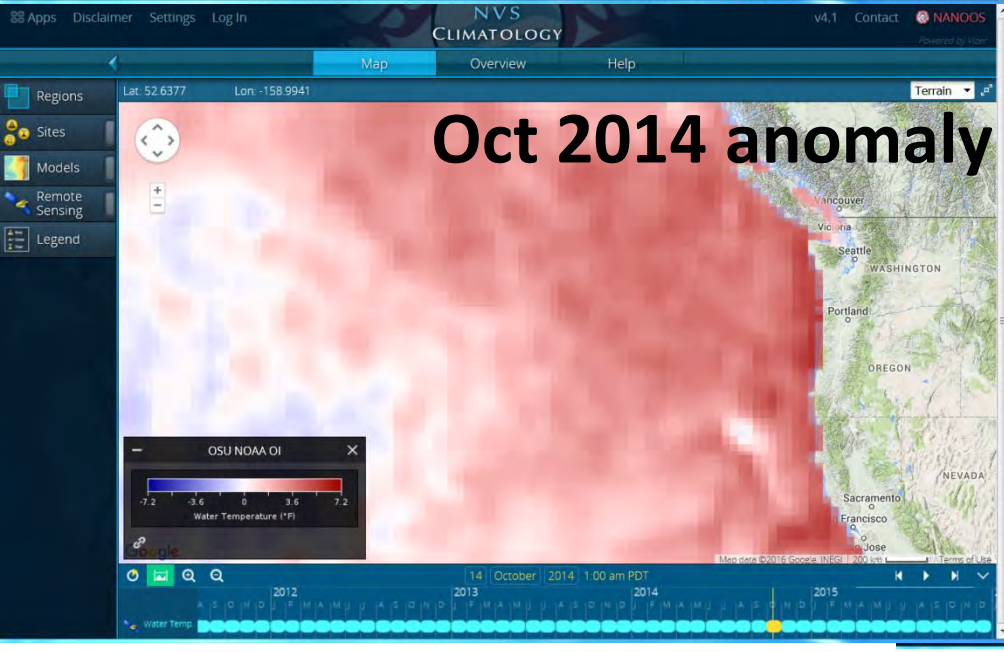


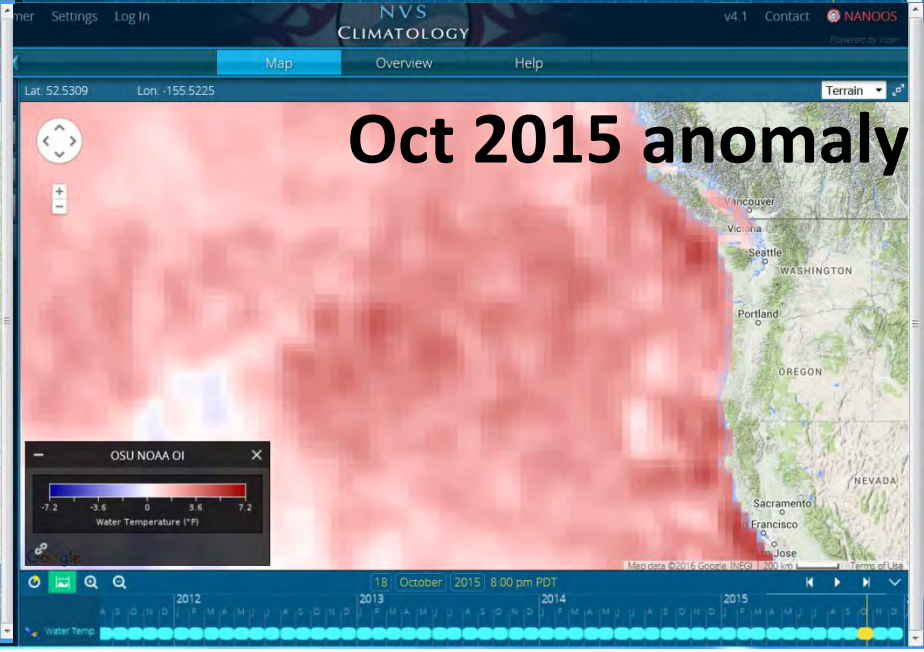


Source: Mickett et al, 2015









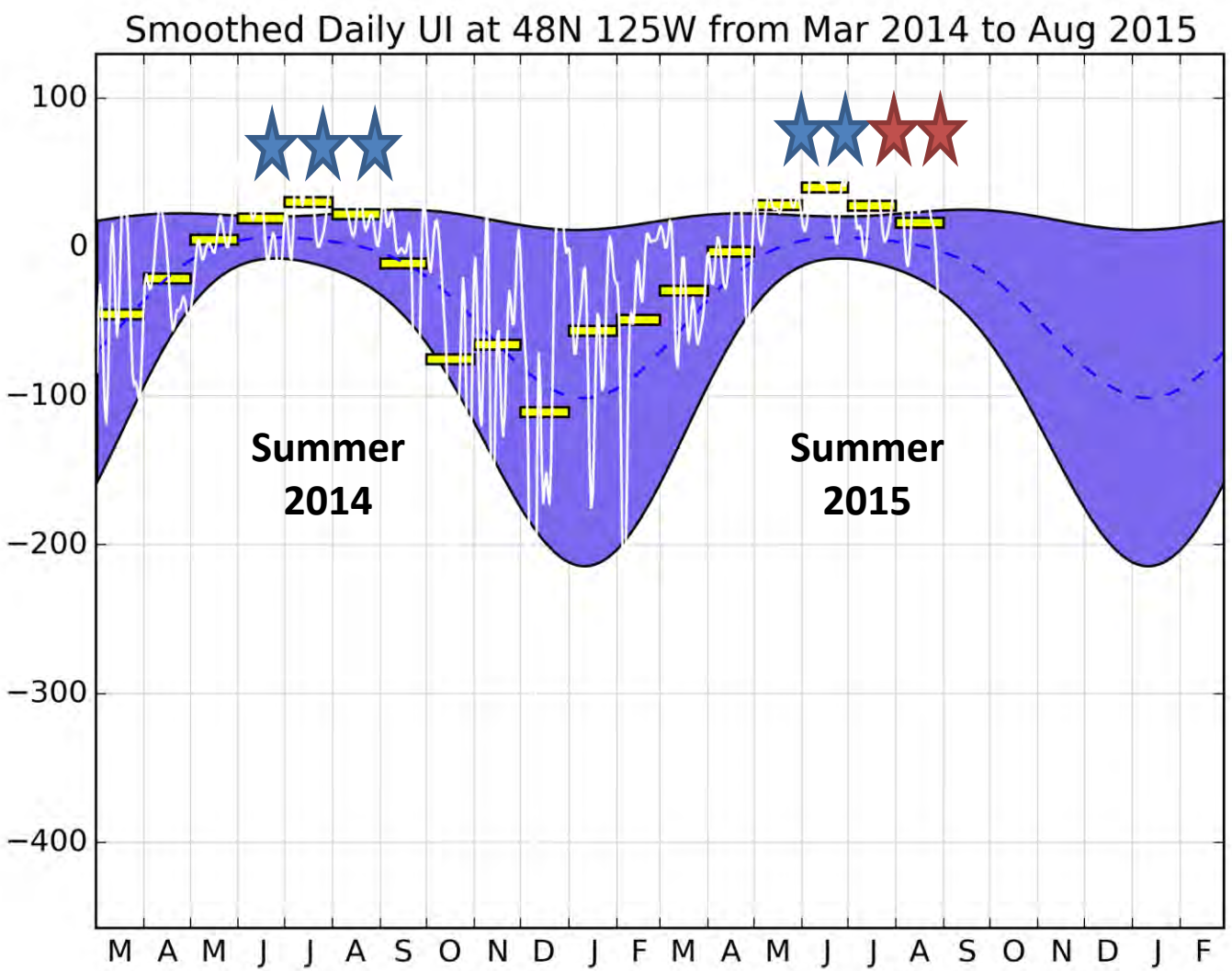
Aug 2015 had already warmer than avg waters at coast

Newton et al, OSM, 2016

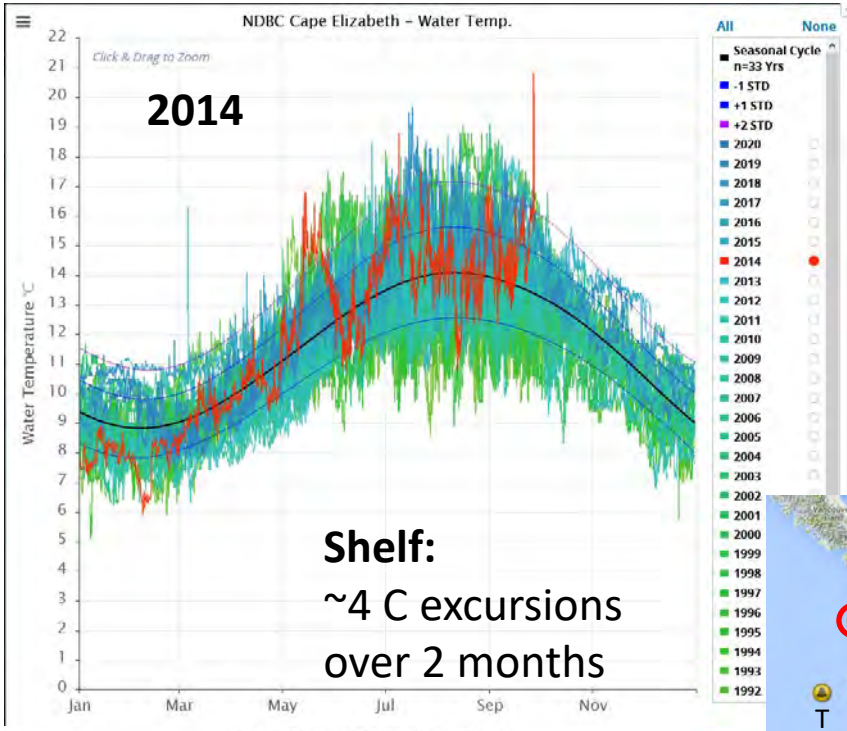
48 N: Upwelling indicated by star

= upwelling; **cooler** than normal water T at coast

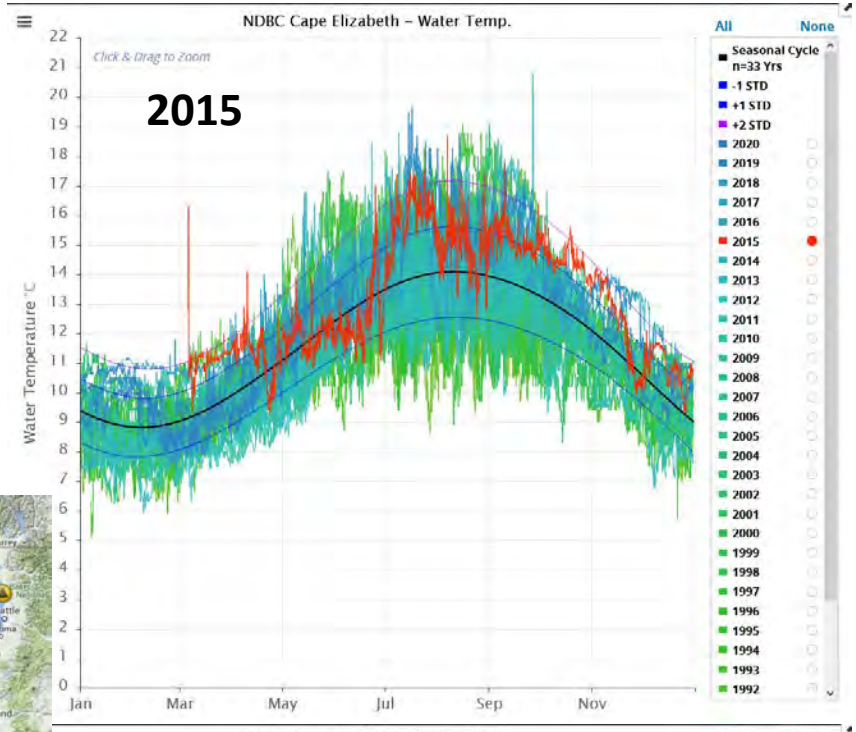
= upwelling; **warmer** than normal water T at coast

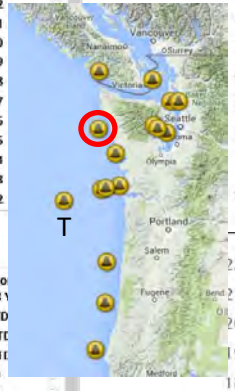


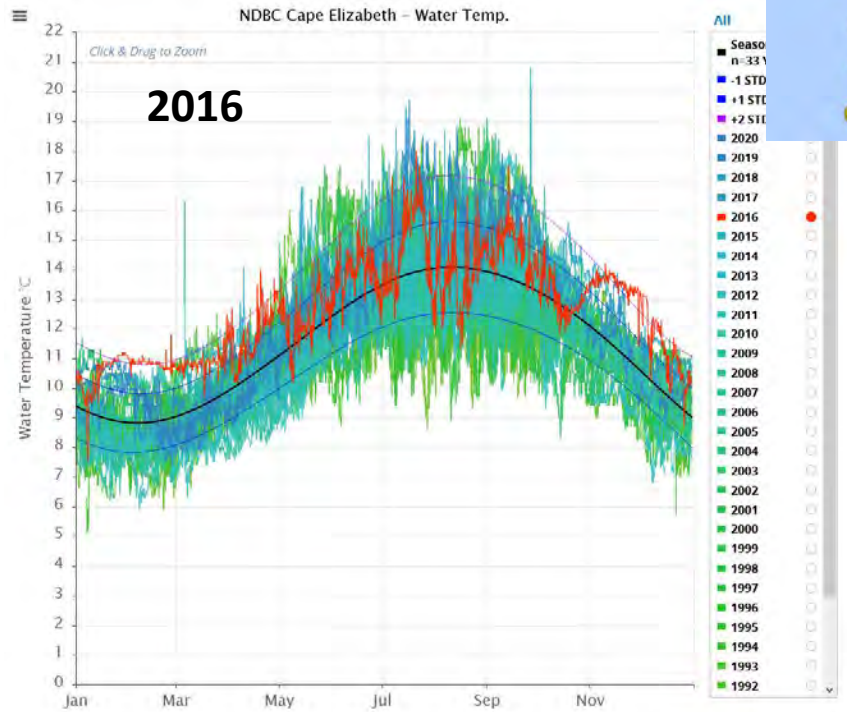
Newton et al, OSM, 2016

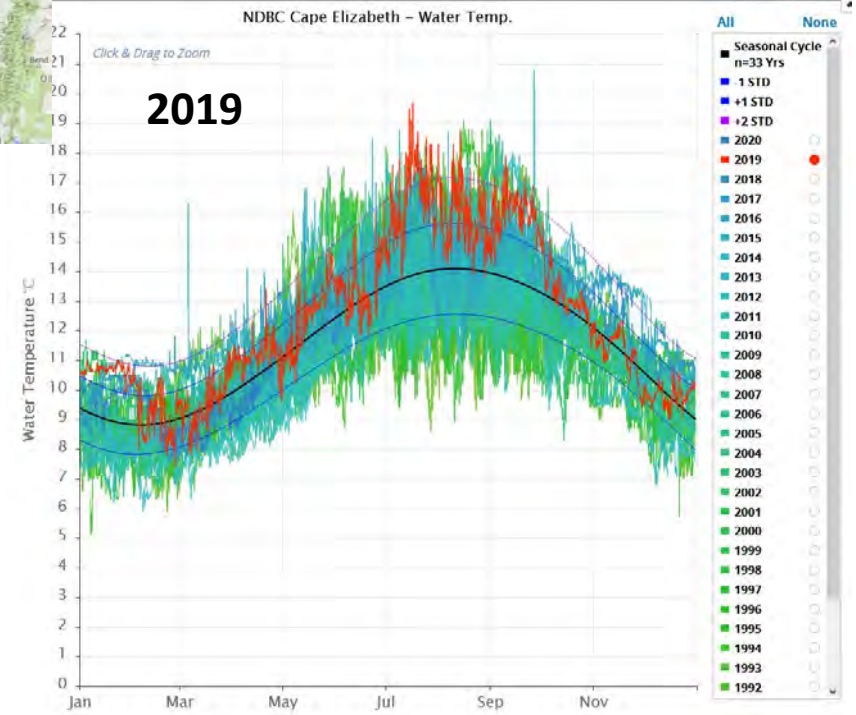


Shelf:
~4 C excursions
over 2 months



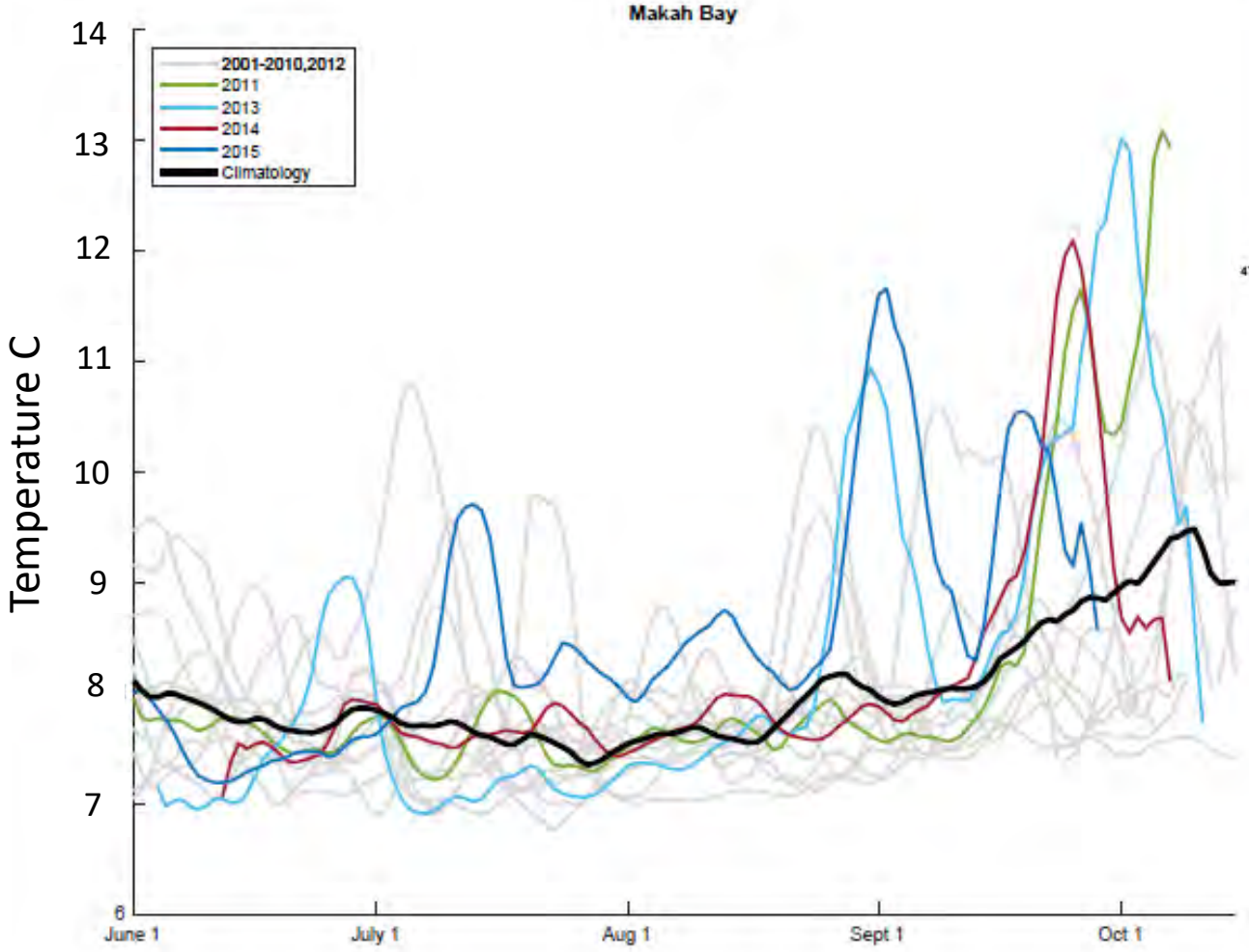







Fraser River
San Juan Archipelago
Pacific Ocean
Puget Sound
Inland waters
Near shore
Shelf
Hood Canal
Coastal ocean

Olympic Coast National Marine Sanctuary mooring positive temperature anomalies

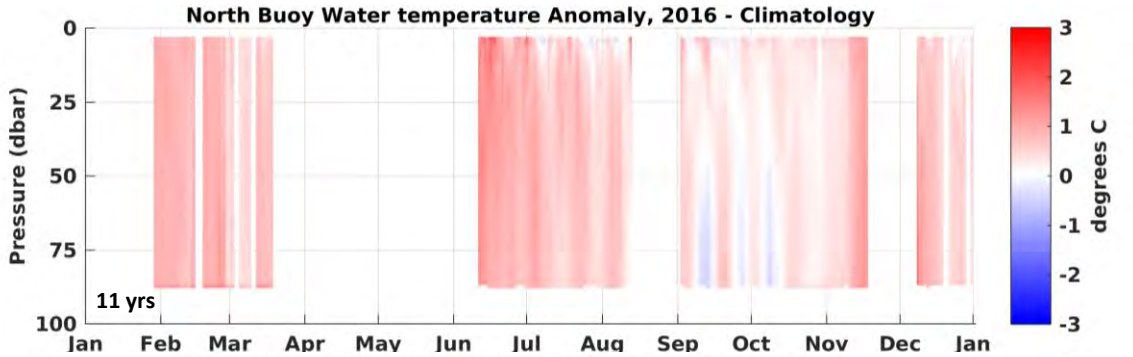


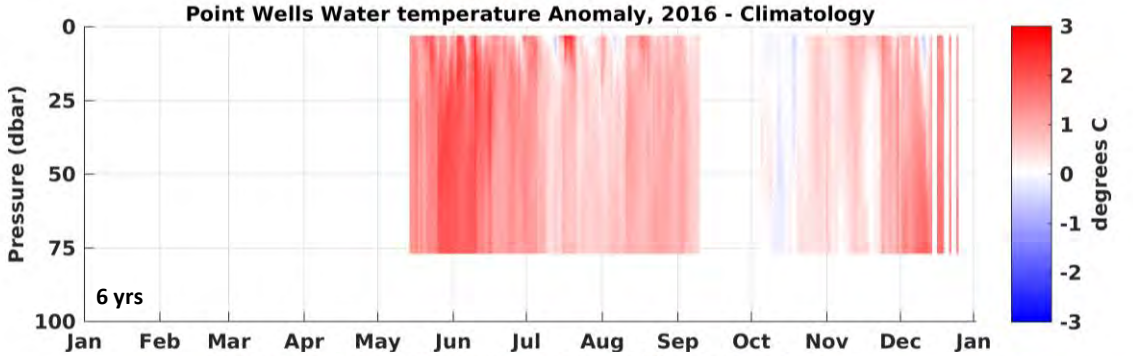
Nearshore:
~4 C excursions over 2 weeks, not 3 months!

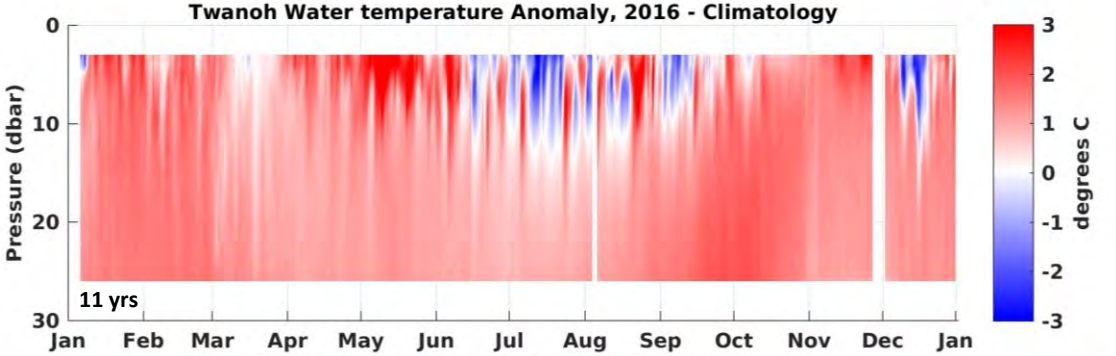
Koehlinger et al., submitted

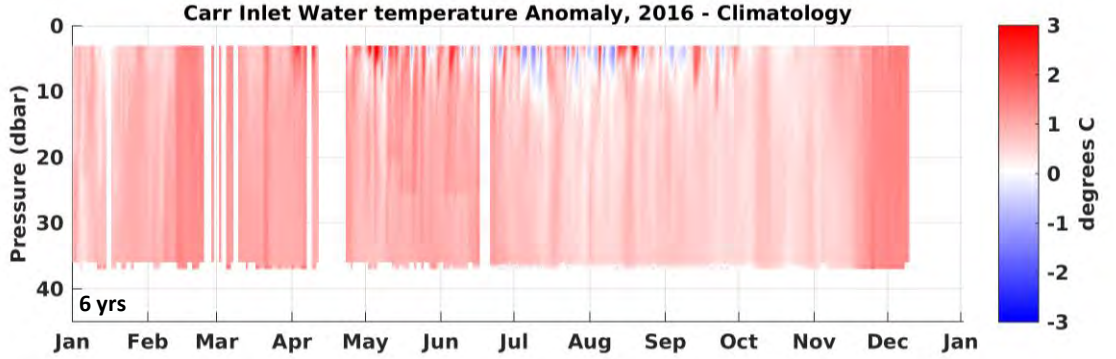

Fraser River
San Juan Archipelago
Pacific Ocean
Puget Sound
Inland waters
Near shore
Shelf
Hood Canal
Coastal ocean


Fraser River
San Juan Archipelago
Pacific Ocean
sills
Puget Sound
Hood Canal



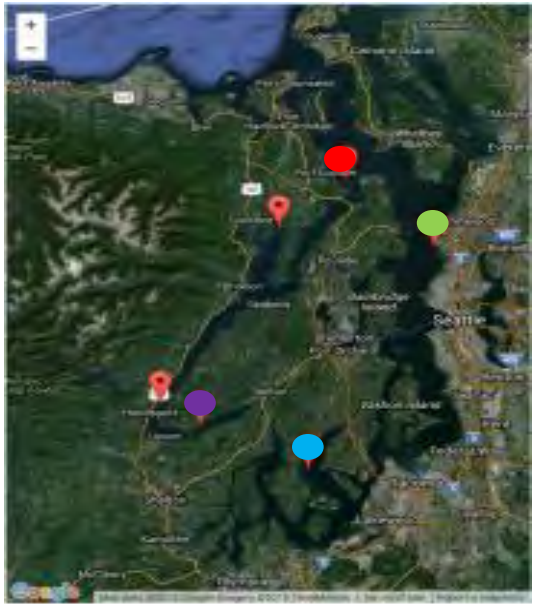




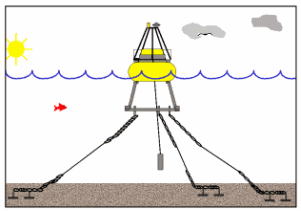


Warm anomalies persisted in 2016

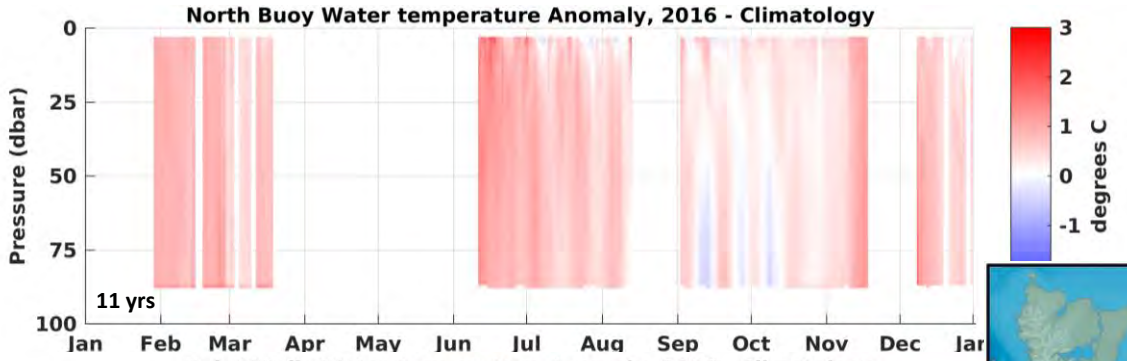
2016 Puget Sound Temperature Anomalies

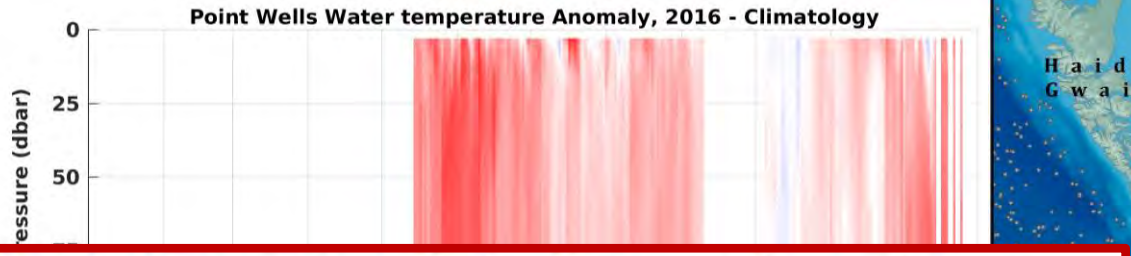


ORCA Profiling Buoys



Warm anomalies persisted in 2016-7

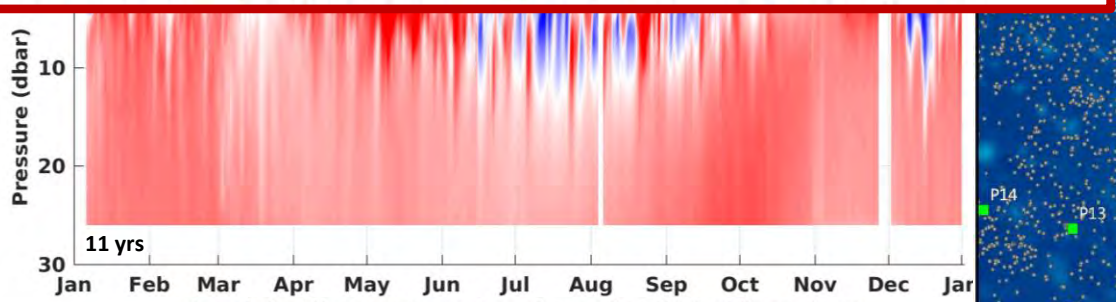


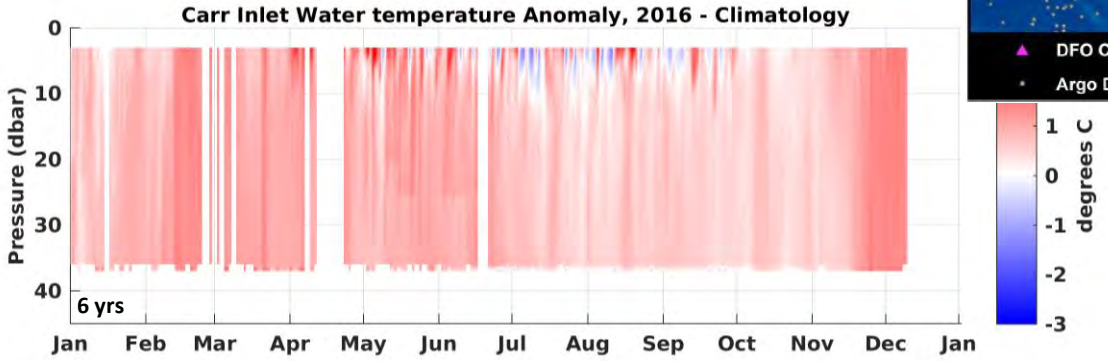


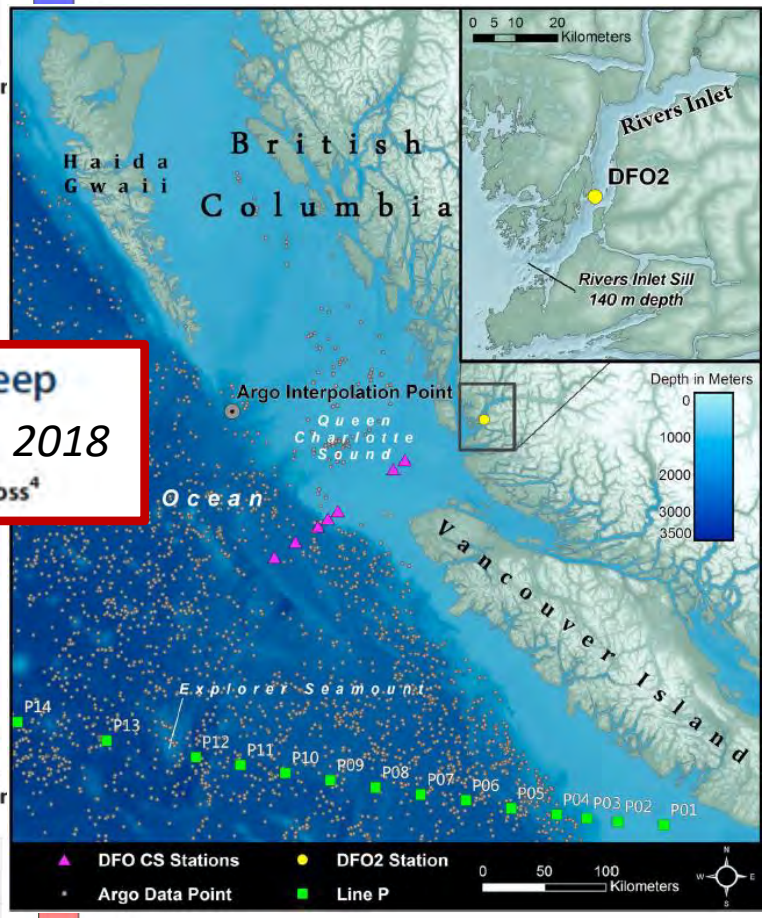
Warming From Recent Marine Heatwave Lingers in Deep British Columbia Fjord

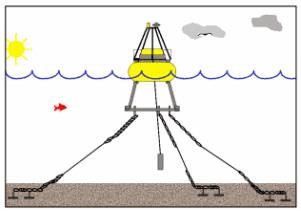
GRL, 2018

Jennifer M. Jackson[1], Gregory C. Johnson[2], Hayley V. Dosser[1,3], and Tetjana Ross[4]









MHW dynamics different in coastal/inland waters:

- There were differences in the ***extreme temperature anomalies*** in terms of the magnitude of the excursion and its duration.
- Coastal shelf and nearshore had shorter episodic excursions, due to influence of upwelling; whereas anomalies in the ocean and inland seas lasted longer, and especially so in the inland seas (fjords) because of water mass retention due to sills.

Location	anomaly (C)*	~duration*
Coastal ocean	2	3 months
Shelf	4	2 months
Nearshore	4	2 weeks
Inland waters	2-7	3-4 years

*Draft "eyeball" summary, not based on peer-reviewed analysis; intended for comparative purposes only. Please do not share

Summary

- MHWs are complex, are and will be increasing
- Effects on ecosystems and humans can be profound
- Localized areas can experience different effects
- Some useful resources:
  - **www.nanoos.org**
  - **www.marineheatwaves.org**

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THANK YOU!

IOOS Integrated Ocean Observing System

NANOOS

UNIVERSITY of WASHINGTON