Marine Heatwaves in the Peru-Chile Upwelling System: from year long El Niños to 5-day localized warming.

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OS1.1 - 'Improved Understanding of Ocean Variability and Climate'

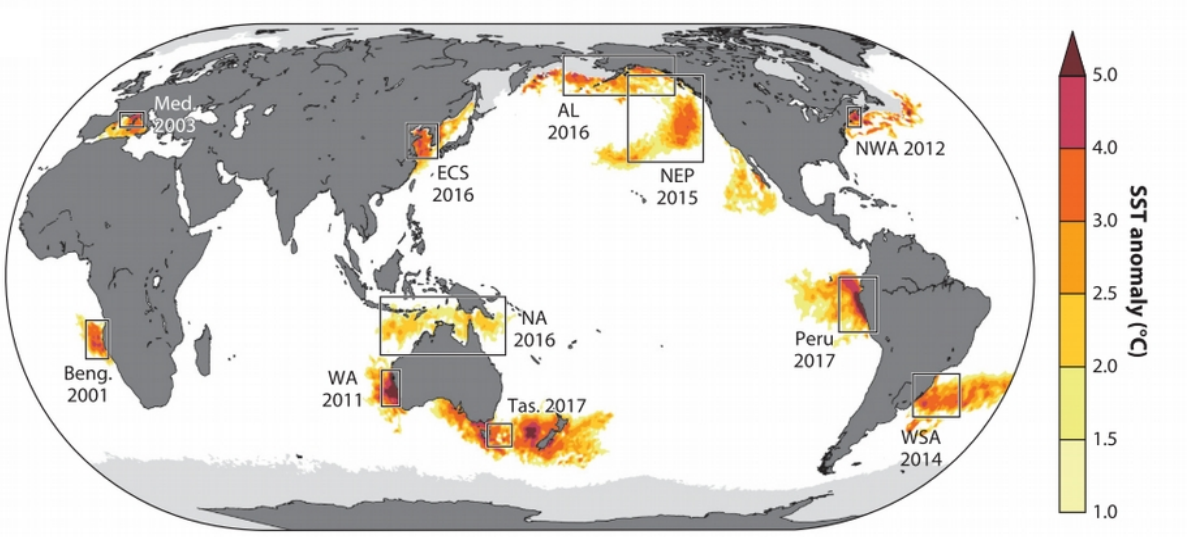
Alice Pietri, F. Colas, R. Mogollon, J. Tam, D. Gutiérrez

EXTREME EVENTS: MARINE HEATWAVES

Marine heatwaves (MHWs) are punctual events of anomalous extreme marine temperatures that can last for periods of a few days to a few months.

MHWs can result from ocean processes and/ or atmospheric forcing and the most prominent ones are generally associated with favorable (warm) phase of climate modes of variability (ENSO, PDO, NAO, etc.)

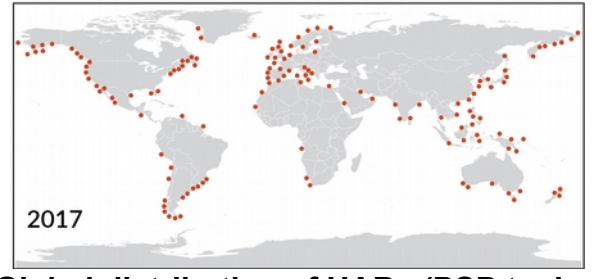
Marine Heatwaves often go along with and/or trigger other extreme oceanic events such as extreme hypoxy/anoxia, harmful algae blooms, etc.



Oliver et al. (2021) Annu. Rev. Mar. Sci

Dead zones (hypoxic water) in the coastal zones

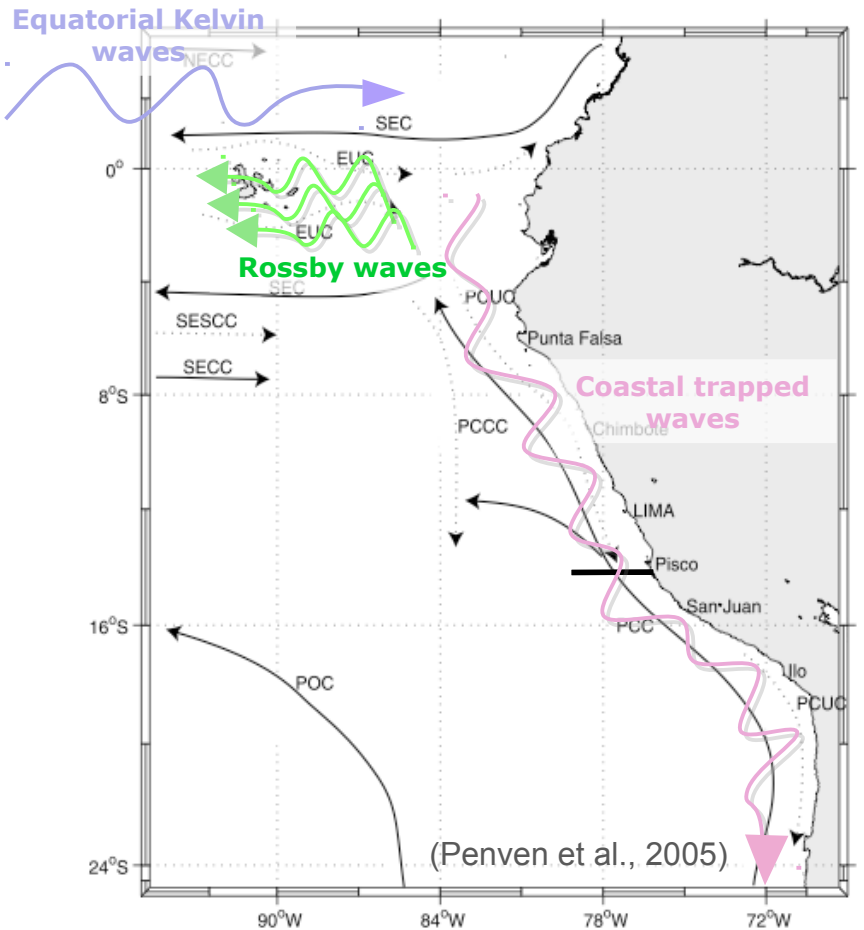
Hugo Ahlenius, UNEP/GRID-Arendal (2008)



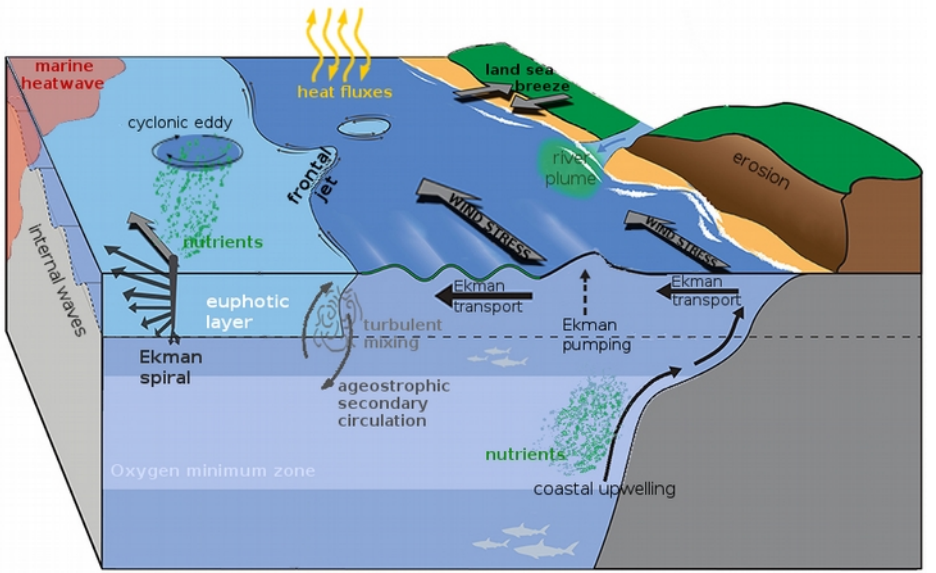
Global distribution of HABs (PSP toxins)

U.S. National Office for Harmful Algal Blooms, 2017

PERU-CHILE EASTERN BOUNDARY UPWELLING SYSTEM (PCUS)



- Year long upwelling favorable winds (Trade winds)
- Cold coastal water resulting from Ekman dynamics
- High productivity
- Shallow and pronounced oxygen minimum zone
- Subjected to equatorial variability: equatorial Kelvin waves reach the shoreline and partially propagate southward as coastal trapped waves.



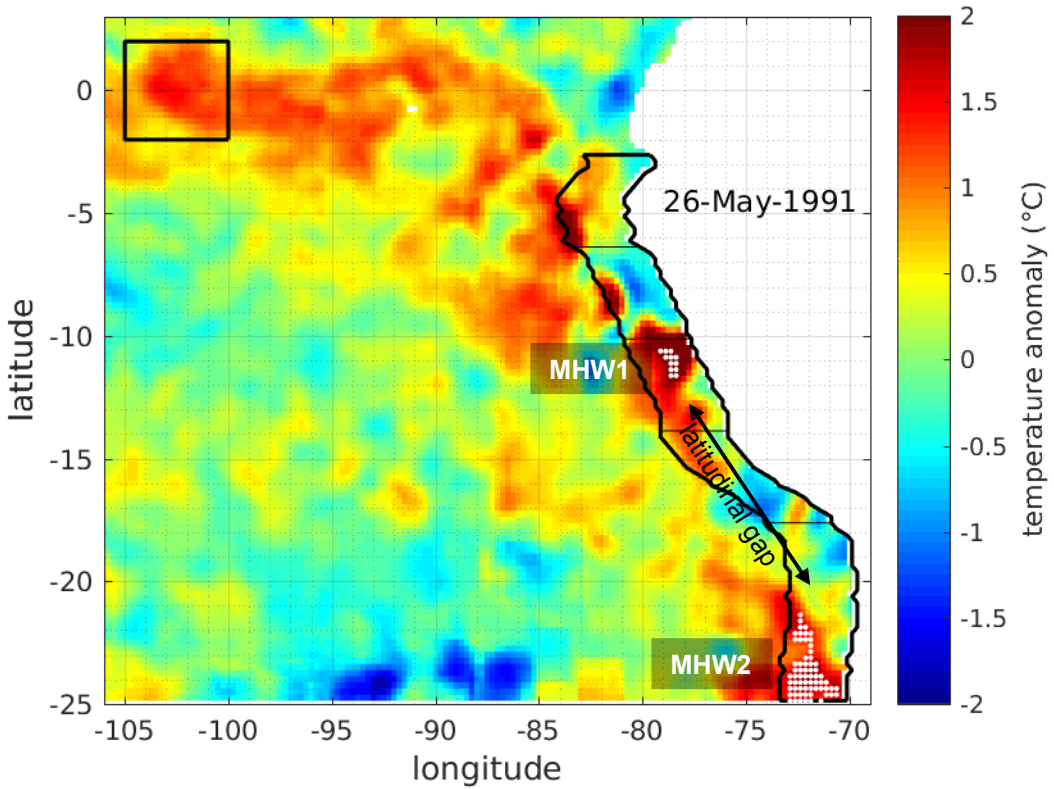
DEFINITION AND IDENTIFICATION OF MHW EVENTS IN THE PCUS

A MHW is identified on a time series when the SST rises above a threshold for more than 5 days.

The threshold is determined on each point of the domain and for each day of the year by the **90th percentile of the SST distribution** from 1982 to 2019 (Hobday et al. 2016).

The spatial coverage of the MHW is then determined by aggregating grid points that are above the threshold but are not necessarily contiguous.
To avoid clustering distant but concomitant events, “latitudinal gaps” (black arrow) are checked for (an unaffected latitudinal band surrounded by two affected regions).

The Category of the event is then derived by summing the SST anomaly for the whole duration of the MHW resulting in a cumulated warming which is then organized in 4 classes in function of the intensity of the MHW.



CHARACTERIZATION OF MHW EVENTS IN THE PCUS

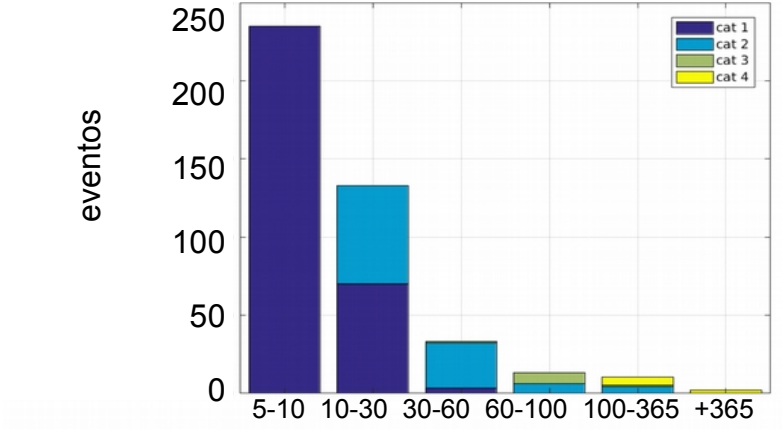
Over the 38 years SST time series **426 MHWs** were identified on the coastal band.

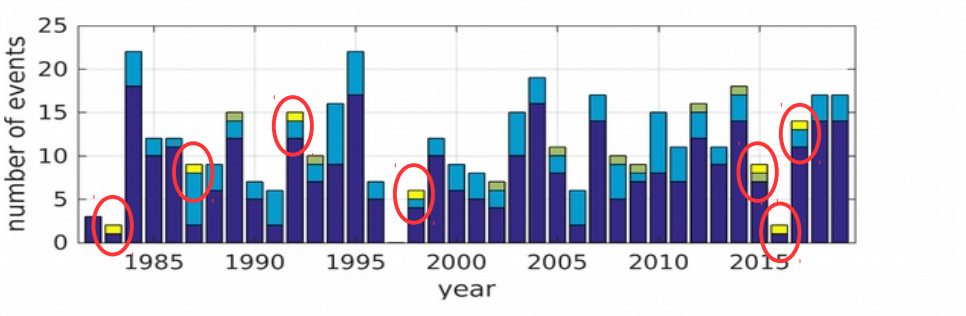
On average the coastal domain is subjected to **11 events a year** with a maximum of 22 events observed in 1984 and 1995.

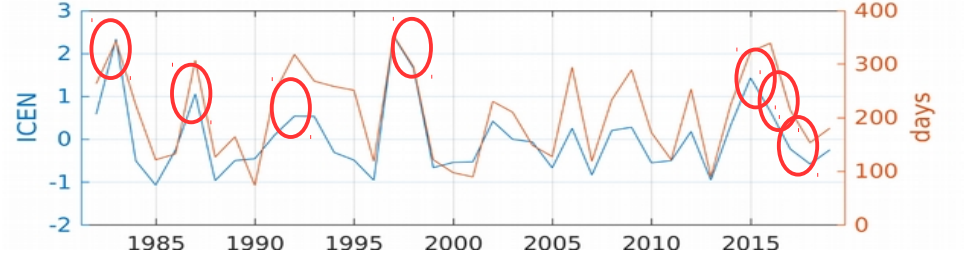
They range from **5 to 610 days** in duration and spatially cover from 1 data point (~625 km2) to the whole coastal domain (~ 562500 km2).

The number of days annually affected by a MHW on the domain ranges **from 73 days to the whole year** when long duration MHWs are observed.

Category 4 events all last more than 100 days and happen during years with high ICEN index





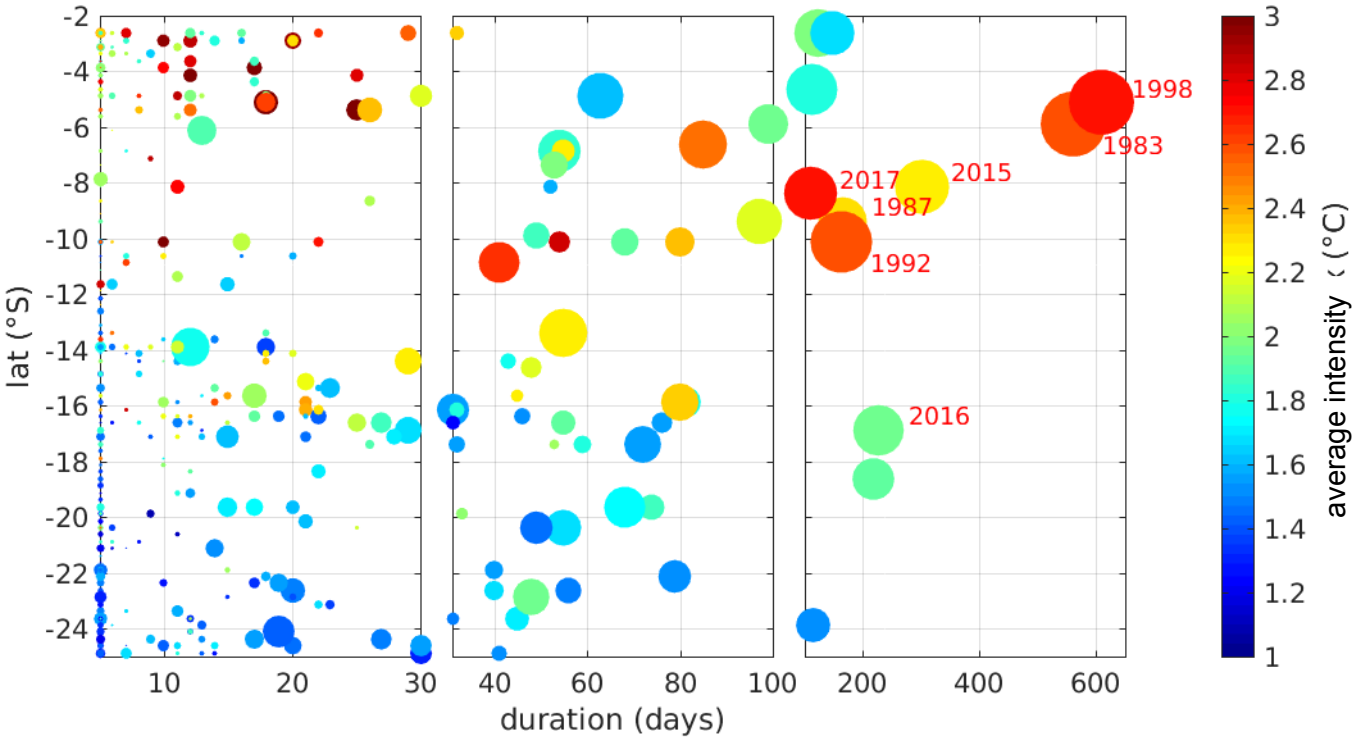


CHARACTERIZATION OF MHW EVENTS IN THE PCUS

The spatial distribution of MHWs characteristics is contrasted from North to South:

- **longer and warmer MHWs** develop preferentially in the Northern part of the domain
- the Southern part of the domain is more prone to be affected by **short and small size events**
- category 4 MHWs (highlighted with their year on the figure), generally related to ENSO variability, have the longest duration and their maximum anomaly falls in the Northern part of the domain.

All MHW events from 1982 to 2019 represented by latitude and duration.



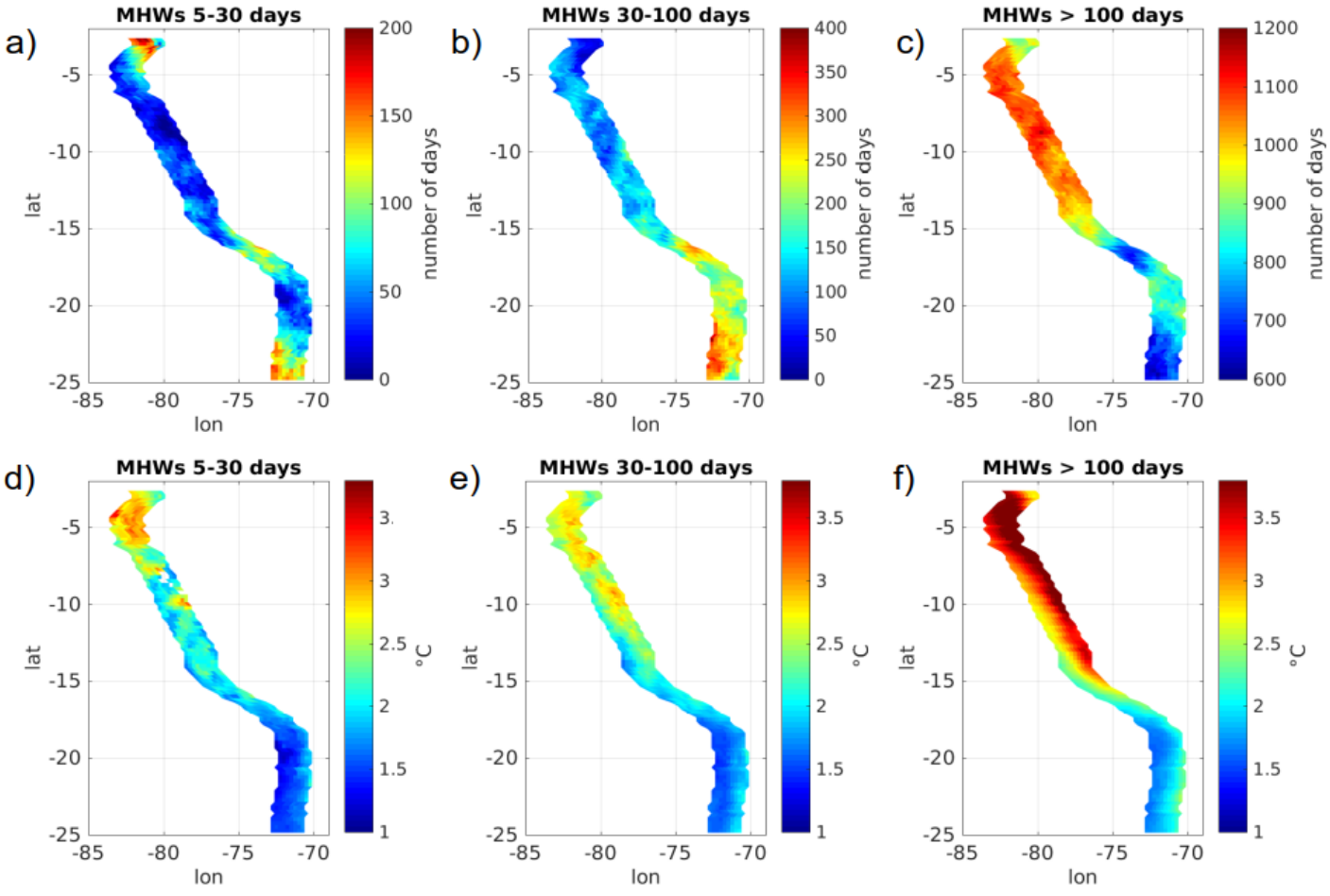
CHARACTERIZATION OF MHW EVENTS IN THE PCUS

MHWs 5-100 days are more frequent south of 14°S with preferred locations around 16-17°S and 22-25°S.

MHWs > 100 days are more common in the Northern part and the exposure decreases significantly south of 14°S.

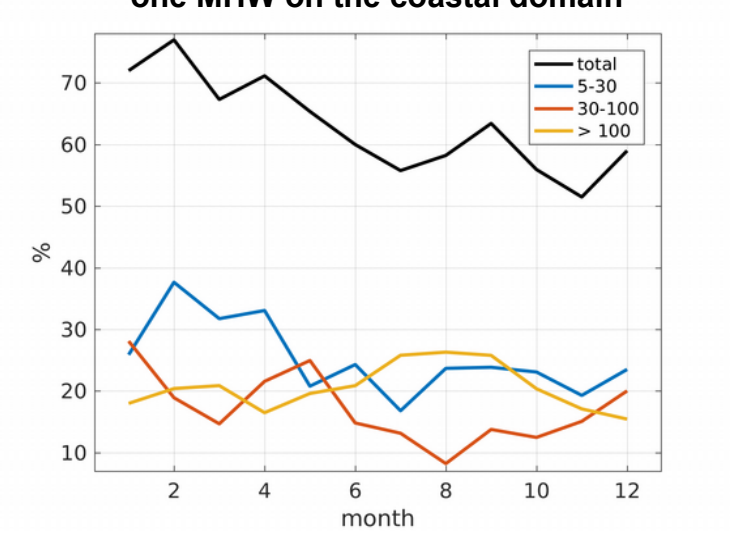
Overall, in the Northern part of the domain the exposure to the longest MHWs is about 7 times higher than the exposure to the shorter ones while in the Southern part it is only twice as high.

MHWs temperature anomaly is higher north of 14°S with an averaged 2°C anomaly. South of 14°S the averaged anomaly only reaches 1.6°C.



SEASONALITY OF MHW EVENTS IN THE PCUS

Percentage of days affected by at least one MHW on the coastal domain

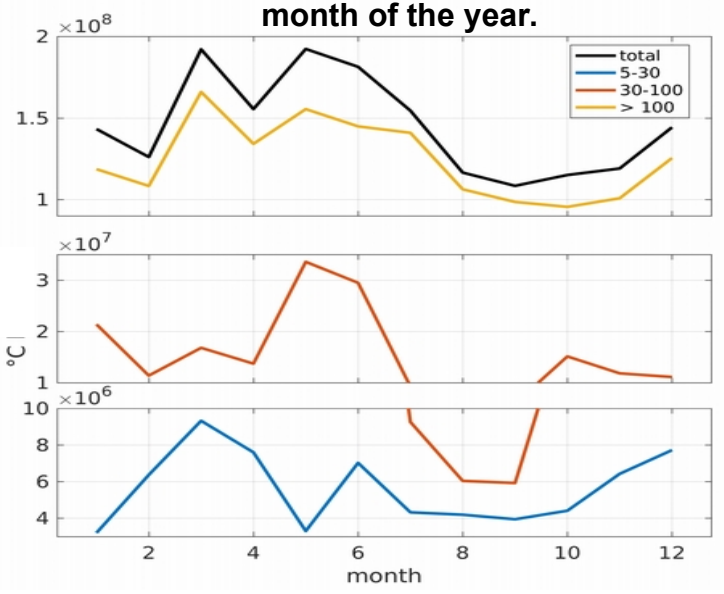


- MHWs tend to affect the coastal domain preferably from January to April
- The maximum occurrence at the beginning of the year is mainly driven by shorter events with a probability of occurrence of more than 30%.
- On the contrary, long events tend to occur preferably in austral winter, from July to September.

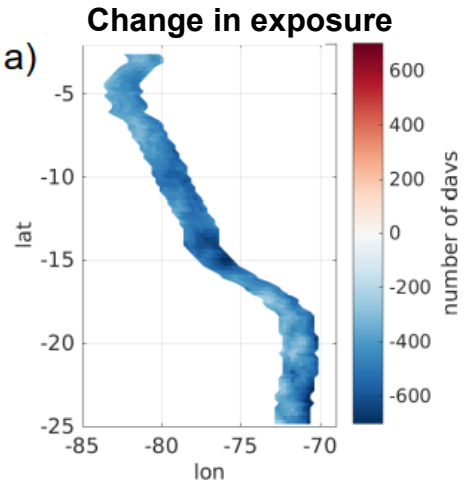
The cumulated heating is an indicator for the impact of a MHW, the highest values are associated with a large spatial extension, a long duration and/or an intense SST anomaly.

Seasonality of cumulated heating is largely driven by long duration events with a pronounced impact of MHW heating in austral Autumn and Winter (March-July).

Cumulated heating due to MHWs for each month of the year.

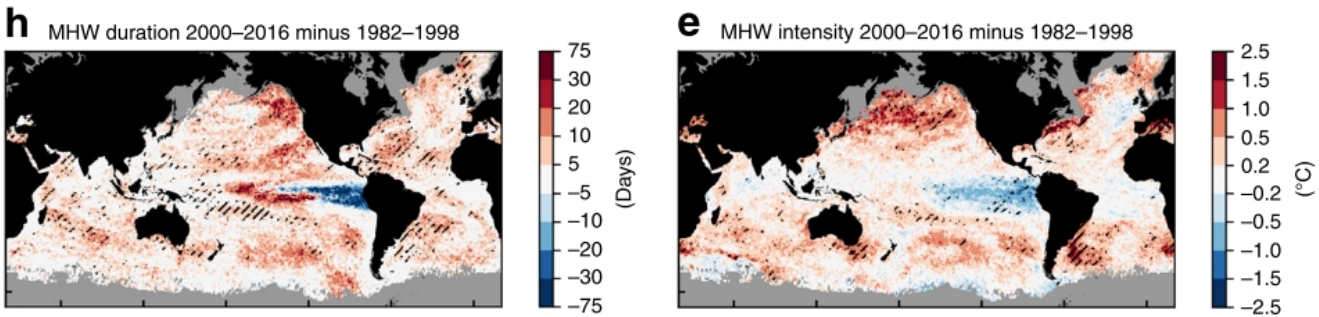


TRENDS AND EVOLUTION OF MHW EVENTS IN THE PCUS



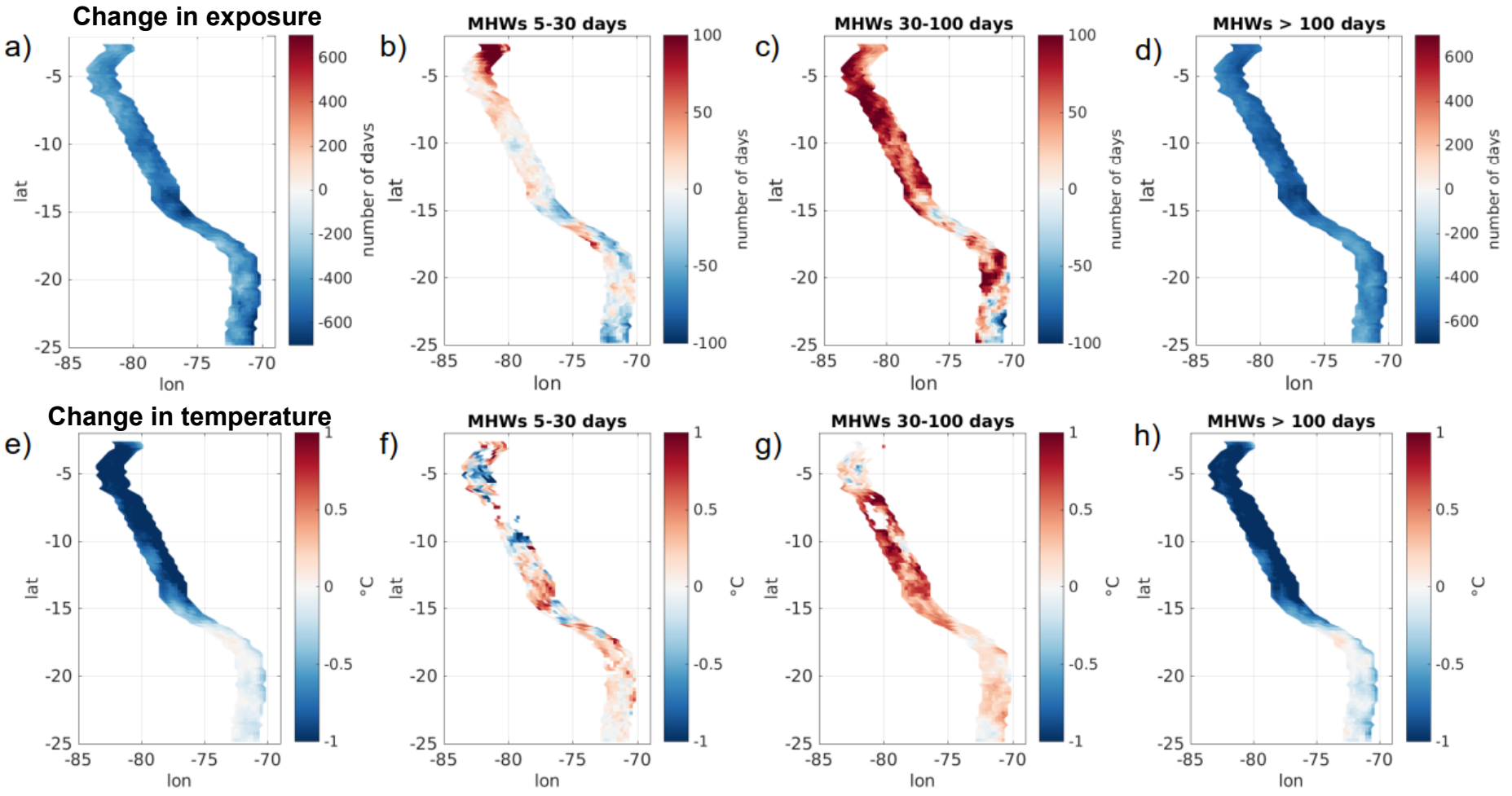
The evolution of MHWs in the PCUS is approached by comparing averaged exposure and intensity during the time periods 1982-2000 and 2001-2019:

- In general MHW exposure shows a decrease in the recent period compared to the earlier one, which is consistent with the findings of Oliver et al. (2018).
- The average 465 days difference between the two periods can be explained by the presence of two majors El Niño events in 82-83 and 97-98 (MHWs of respectively 560 and 610 days in the coastal domain).
- The temperature anomaly associated with MHWs tends to be cooler in the recent period North of 15°S while in the Southern part of the domain the trend is less clear.



Oliver et al. (2018) Nature com.

TRENDS AND EVOLUTION OF MHW EVENTS IN THE PCUS



TRENDS AND EVOLUTION OF MHW EVENTS IN THE PCUS

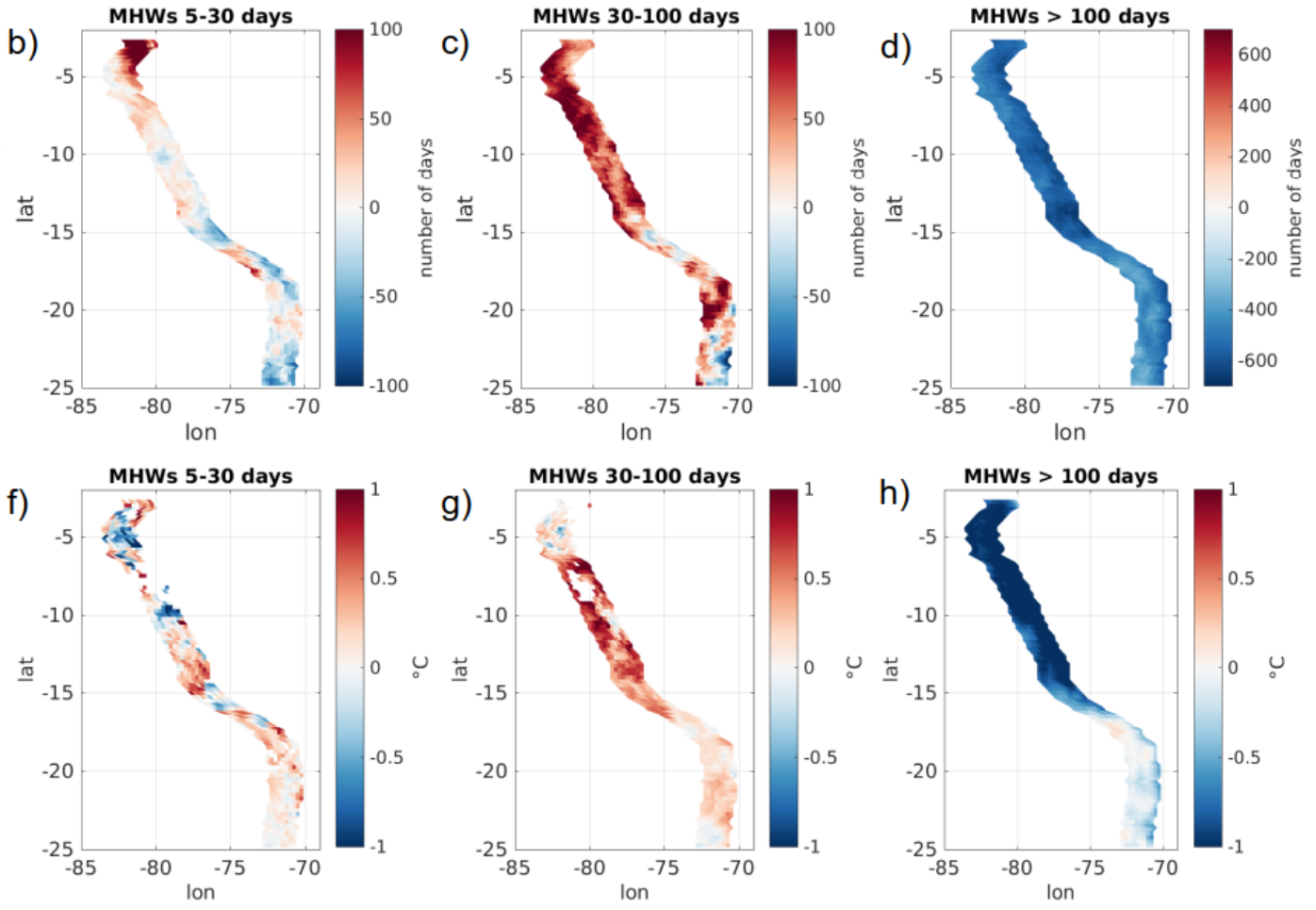
The tendency to a reduction in exposure and intensity is mainly driven by long duration events:

→ <u>Events shorter than 100 days</u> follows an opposite trend: **46 more days** during the period 2001-2019 compared to the period 1982-2000 and **an intensity 0.3°C higher.**

→ <u>MHWs shorter than 30 days</u> exhibit different trends from North to South:

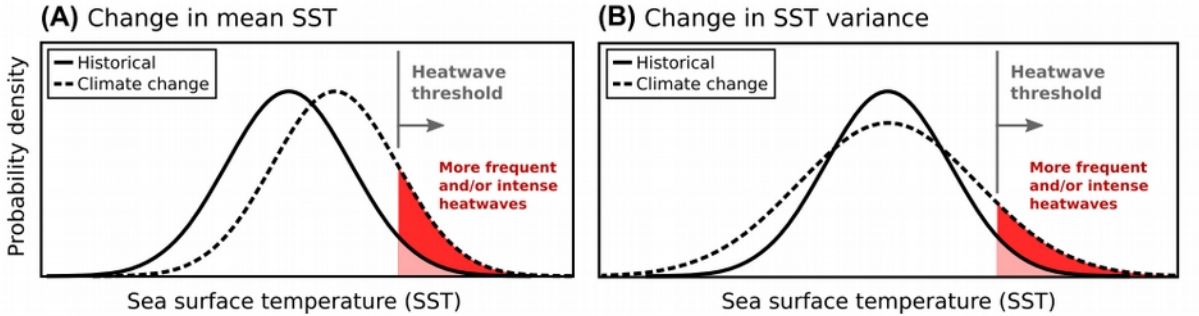
- North of 14°S has seen **23 more days**

- South of 14°S there were **14 days less**



TRENDS AND EVOLUTION OF MHW EVENTS IN THE PCUS

Changes in the frequency and intensity of MHWs may arise from increases in the mean SST or changes in its variability.

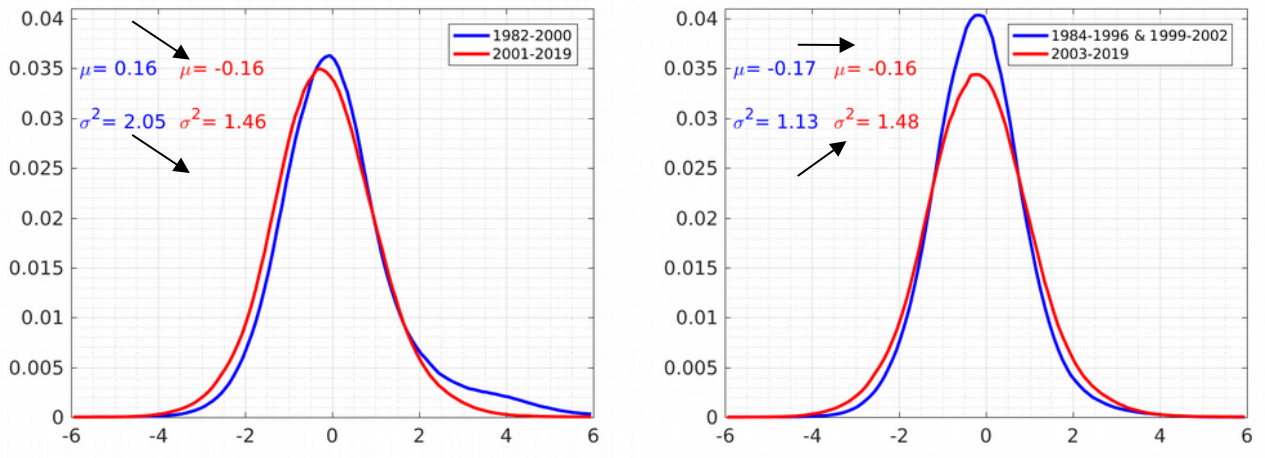


Oliver et al. (2019) Climate Dynamics

Between <u>1982-2000 and 2001-2019</u> there is **a decrease of the averaged temperature** of 0.32°C and a **decrease in the variance** of the distribution

→ the decrease in MHW occurrences and intensity is likely due to changes in the mean and the variability of the SST.

Distributions of the SST anomalies



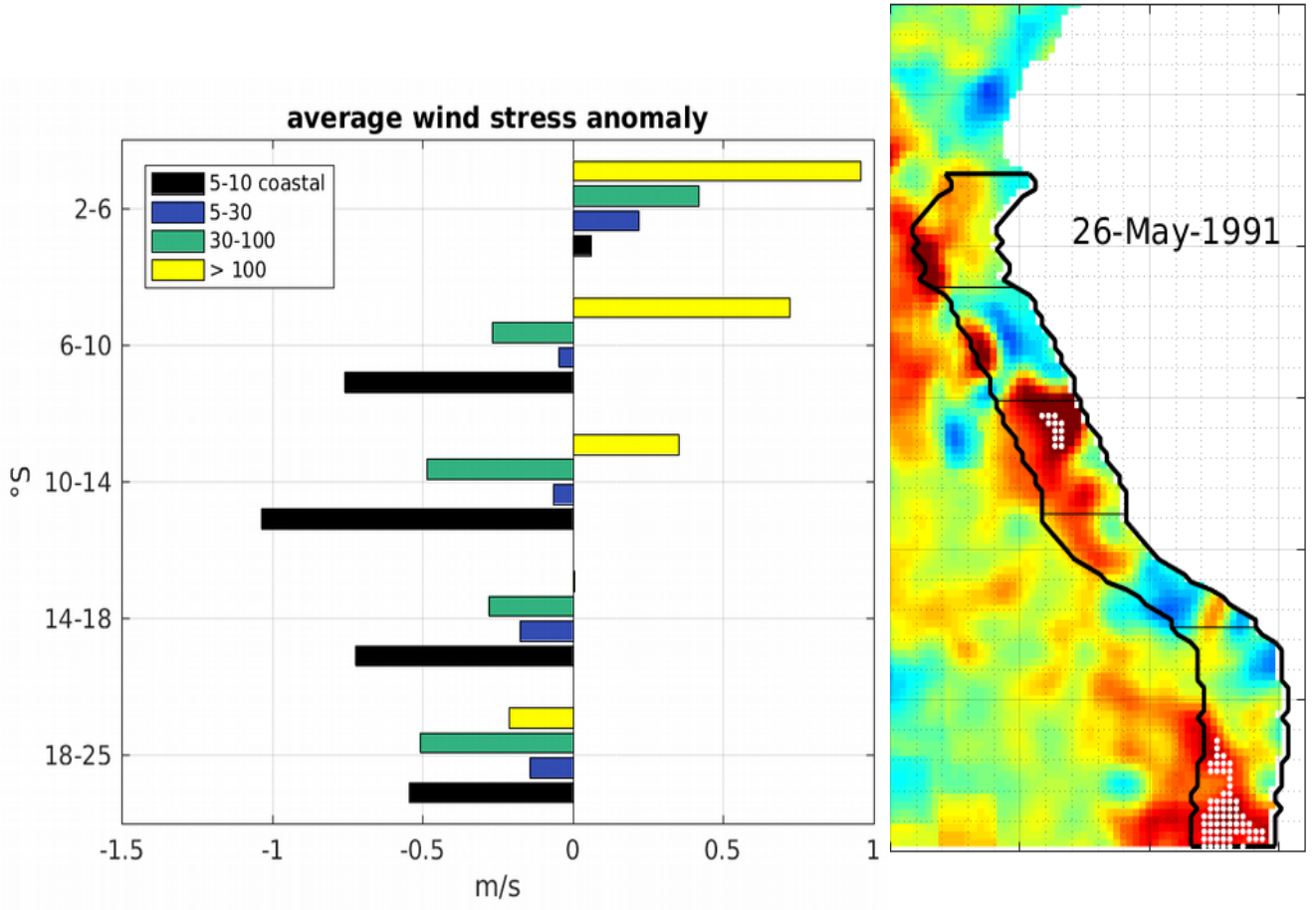
<u>Removing the ENSO events of 82/83 and 97/98</u> the averaged SST anomaly stays the same but **the variance of the distribution increases**

→ increased occurrences of short duration MHWs is likely due to an increase in the variability of the SST.

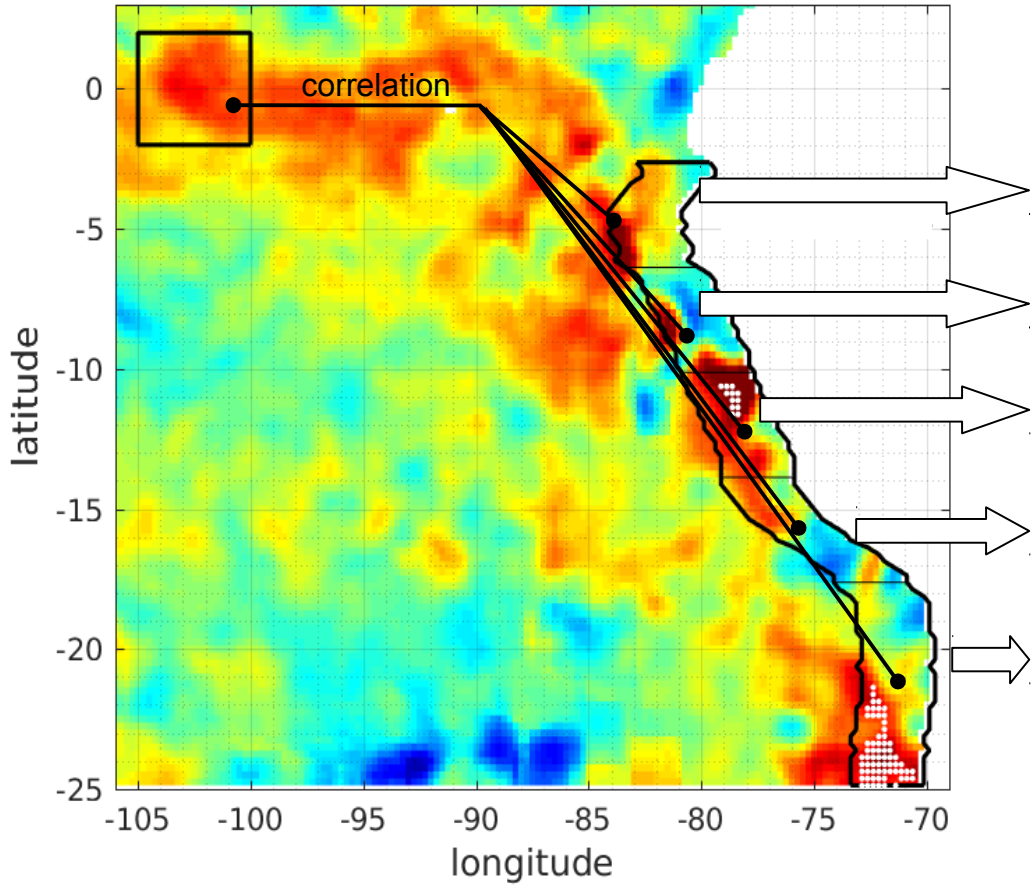
REMOTE AND LOCAL CONDITIONS

Averaged wind anomaly on the 1st day of a MHW event:

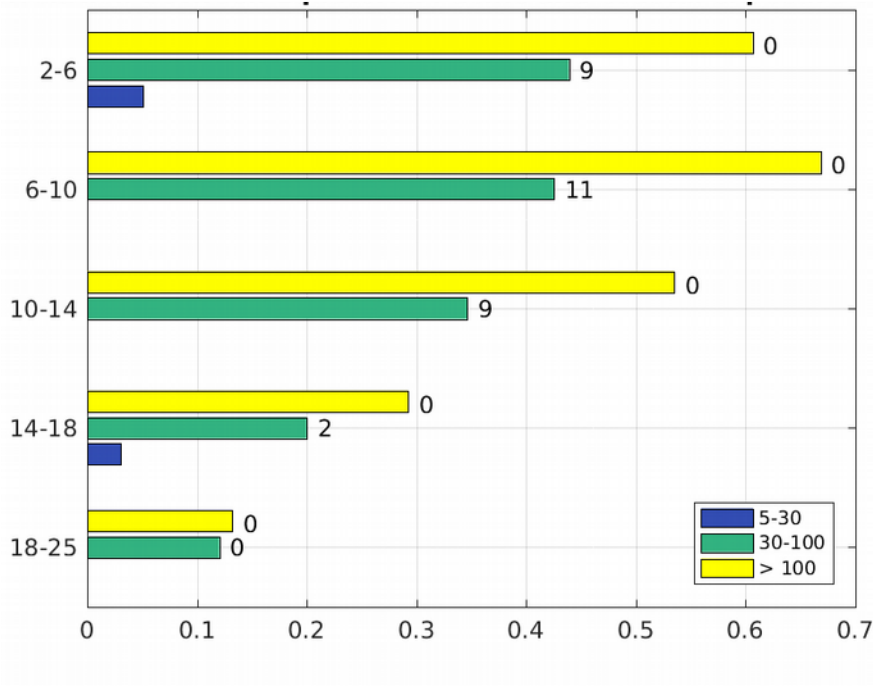
- MHWs longer than 100 days tend to exhibit **positive wind anomalies** north of 14°S. This could be related to the intensification of the North/South SST gradient (Chamorro et al. 2018).
- MHW shorter than 100 days are on average accompanied by **negative wind anomalies** South of 6°S.
- Short (5 to 10 days) and coastal (less than 100 km) events present the **highest negative anomalies.**



REMOTE AND LOCAL CONDITIONS



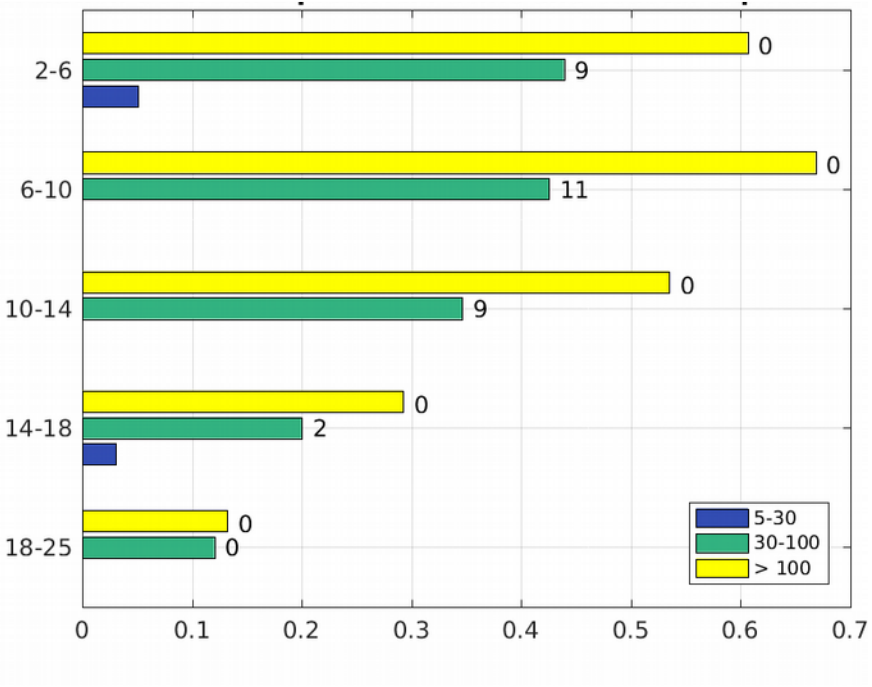
Correlation between MHW occurrences at the equator and at the coast by latitude bands



REMOTE AND LOCAL CONDITIONS

- The longer MHWs, of more than 100 days, show **significant correlation** (> 0.5) with equatorial MHWs events North of 14°S.
- MHWs with duration 30-100 days in the coastal domain also **show correlation** with equatorial MHWs of same duration North of 14°S.
- MHWs of less than 30 days **show very little to no significant correlation** to the corresponding events in the equatorial region.
- The 9-11 days lag (2.2-2.8 m s^{-1}) observed for the correlation of MHWs 30-100 days can be related to the propagation speed of Intraseasonal Equatorial Kelvin Waves ~ 2.3-2.6 m s^{-1}

Correlation between MHW occurrences at the equator and at the coast by latitude bands



CONCLUSION

- The PCUS is highly sensitive to changes in temperature. It is regularly subjected to warm marine events caused by El Niño but even more frequently to marine heatwaves more localized and of shorter duration.

- There are significant differences in MHWs characteristics and evolution North and South of 15°S:

  → the northern part of the domain is more prone to long and warm events which have decreased in frequency and intensity in the recent decades.

  → the southern part of the domain presents a higher number of shorter and localized events consistently during the last decades.

- There are significant differences between events depending on their duration:

  → longer events are generally associated with equatorial variability and exhibit a positive wind anomaly. They tend to be less numerous recently.

  → shorter events are on averaged associated with negative wind anomalies, they have been shown to increase in frequency and intensity.