

# Drivers of marine heatwaves and their decadal suppression in the southwest Indian Ocean in recent decades

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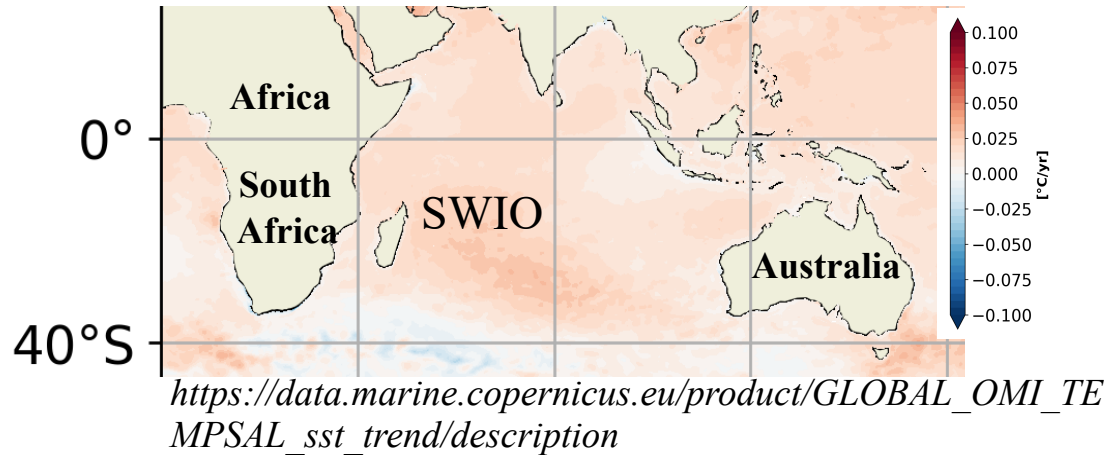
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*Kamp W. and Han W, 2026:*

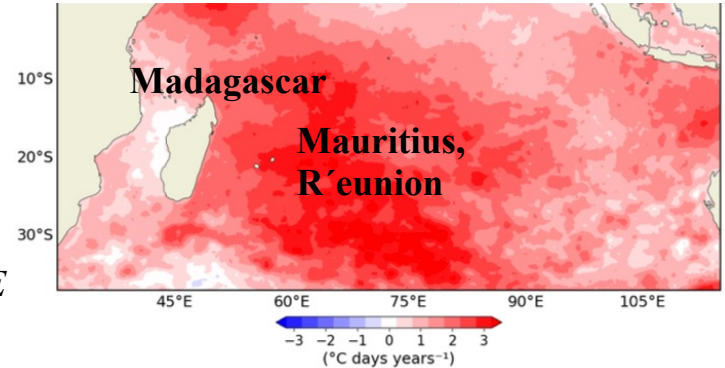
*Drivers of marine heatwaves and decadal suppression in the southwest Indian Ocean in recent decades, Communications Earth & Environment, in revision.*

# 1. Introduction

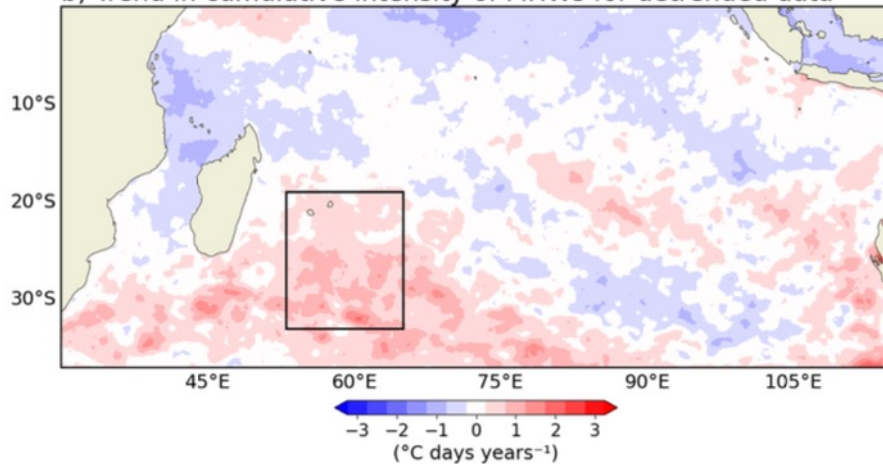
a) Sea surface temperature (SST) trends (1982-2024)



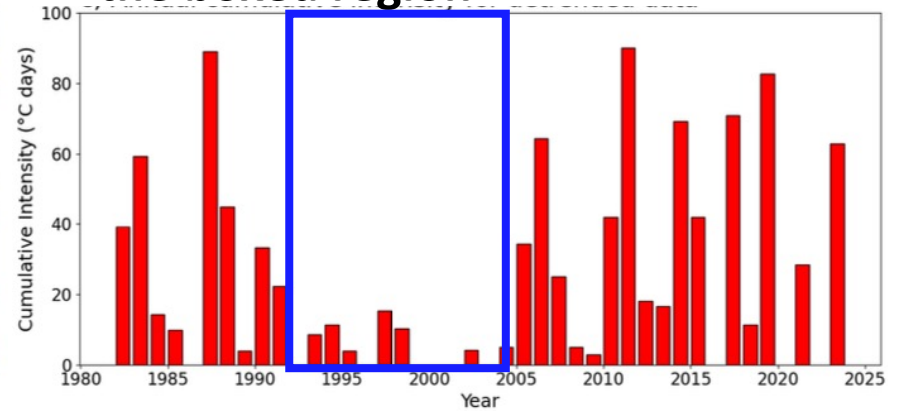
b) Linear trend: Marine HeatWave (MHW) annual cumulative intensity (MHW CI) (°C days/yr), 1982-2023 (fixed baseline)



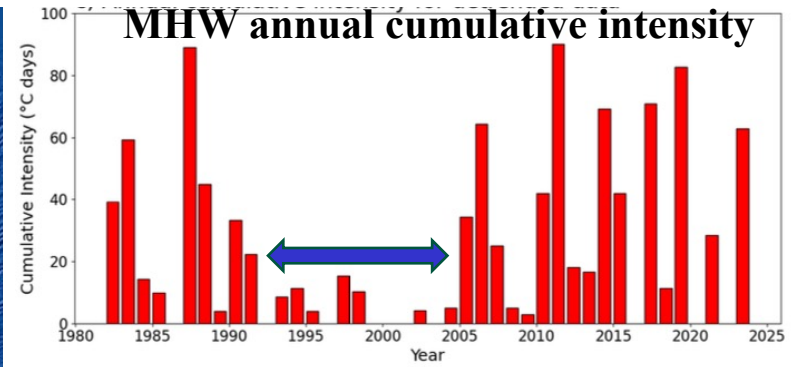
c) Linear trend: MHW annual cumulative intensity (CI) for detrended SST, 1982-2023



d) Time evolution of MHW CI averaged in the boxed region



Causes for MHWs & their decadal suppression in the Southwest Indian Ocean (SWIO) remain unclear



## Goal:

- ❖ Investigate **MHW activities & drivers** in the Southwest (SWIO) in recent decades (1982-2023), and examine the causes for their **decadal suppression**

## Importance:

- ❖ MHWs in SWIO can have significant impacts on marine ecosystems (*e.g., coral reef-based tourism and fisheries*), and the warm SSTs affect regional weather and climate over the island nations and across south Africa

## 2. Approach

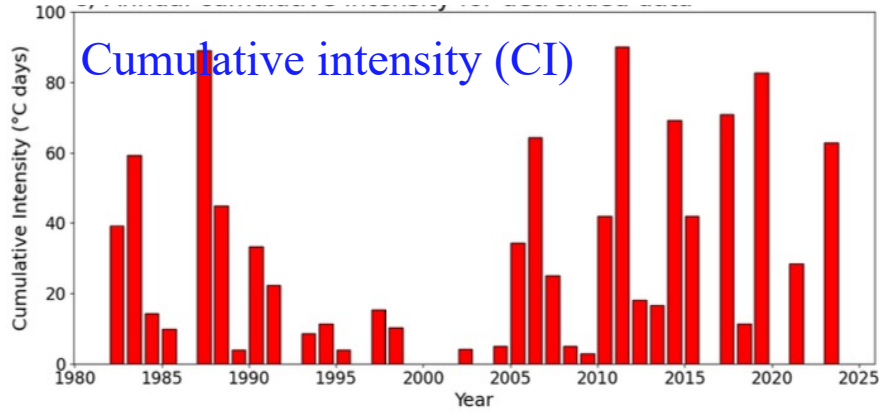
We analyze satellite & in situ observations, ocean/atmosphere reanalysis datasets, and CMIP6 climate model simulations

- **OISSTv2** (1982-2023),
- **ECCO** (Estimating the Circulation and Climate of the Ocean) reanalysis dataset (1992-2017),
- **CCMP Ocean Surface Winds** (1987-2023),
- **ERA5 reanalysis dataset** (1982-2023),
- **CMIP6** models' historical simulations (1920-2014)

# 3. Results

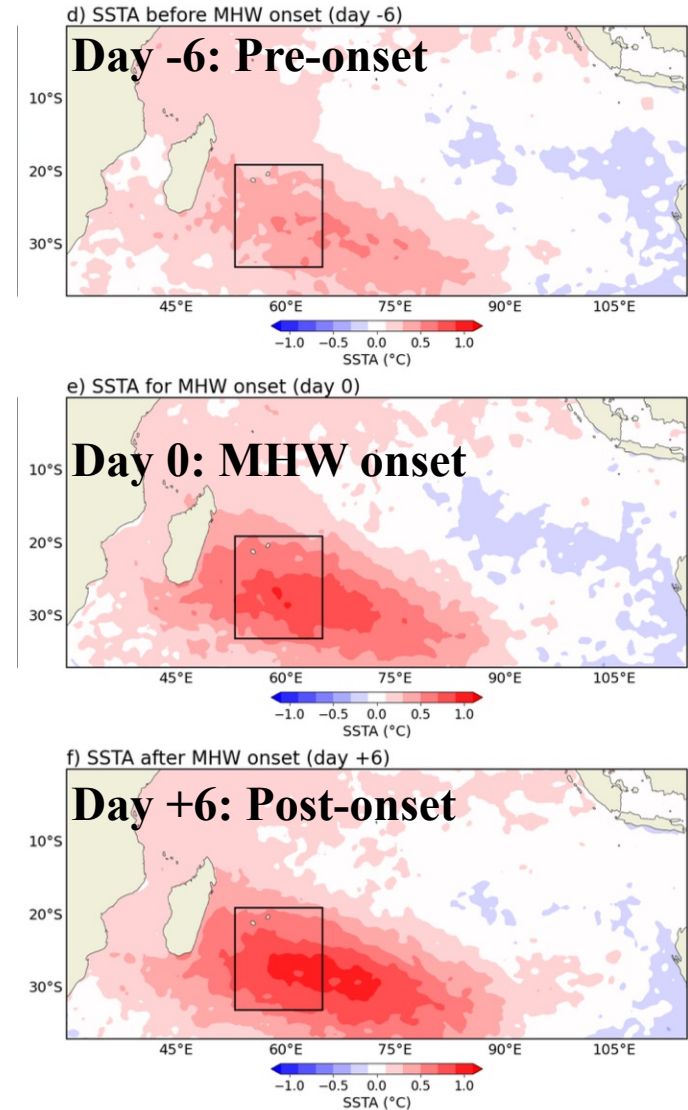
## (a) Characterization of MHWs

### Time evolution: MHW annual CI in SWIO box



- (i) MHWs are active after 2005 & before 1992, with decadal suppression in between;
- (ii) MHWs exhibit large-spatial scale, extending across the SWIO

### Spatial structure: composite SST anomalies (SSTA) for 91 MHWs (1982-2023)

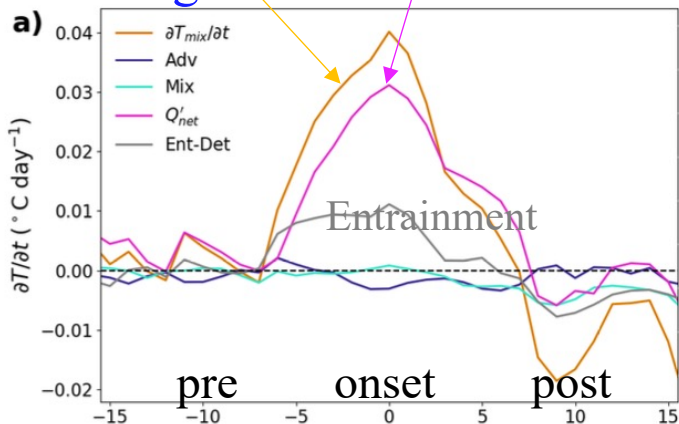


# (b) Processes that cause MHWs

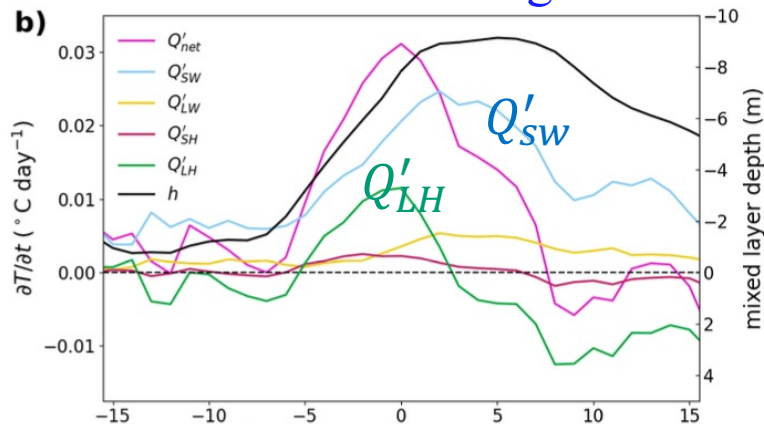
Mixed layer heat budget analysis using ECCO reanalysis dataset:

$$\frac{1}{h} \iint_{-h}^0 \frac{\partial T}{\partial t} dz = \frac{1}{h} \iint_{-h}^0 \frac{Q_{net}}{\rho C_p} dz - \frac{1}{h} \iint_{-h}^0 \mathbf{V} \cdot \nabla dz + \text{Mixing} + \text{Entrainment}$$

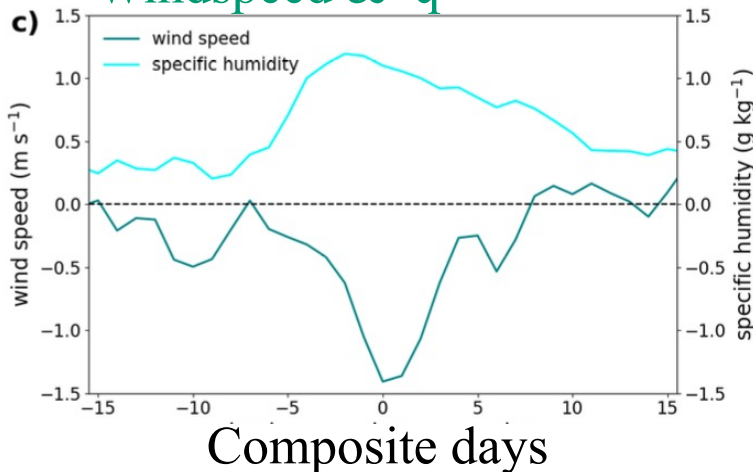
Budget terms



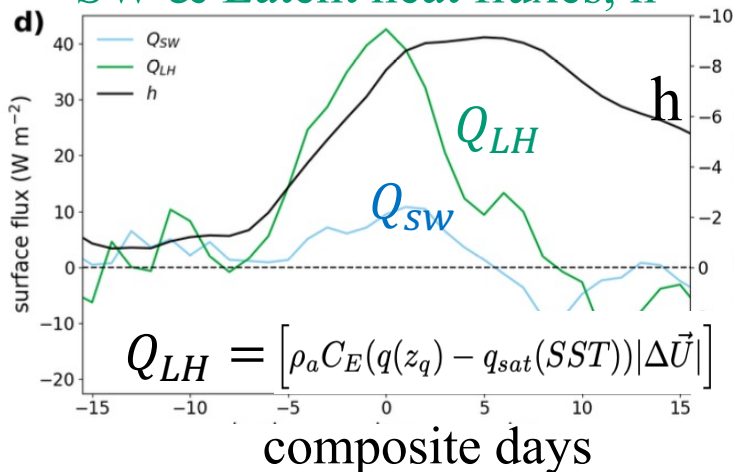
Individual heat flux budget terms



Windspeed & q



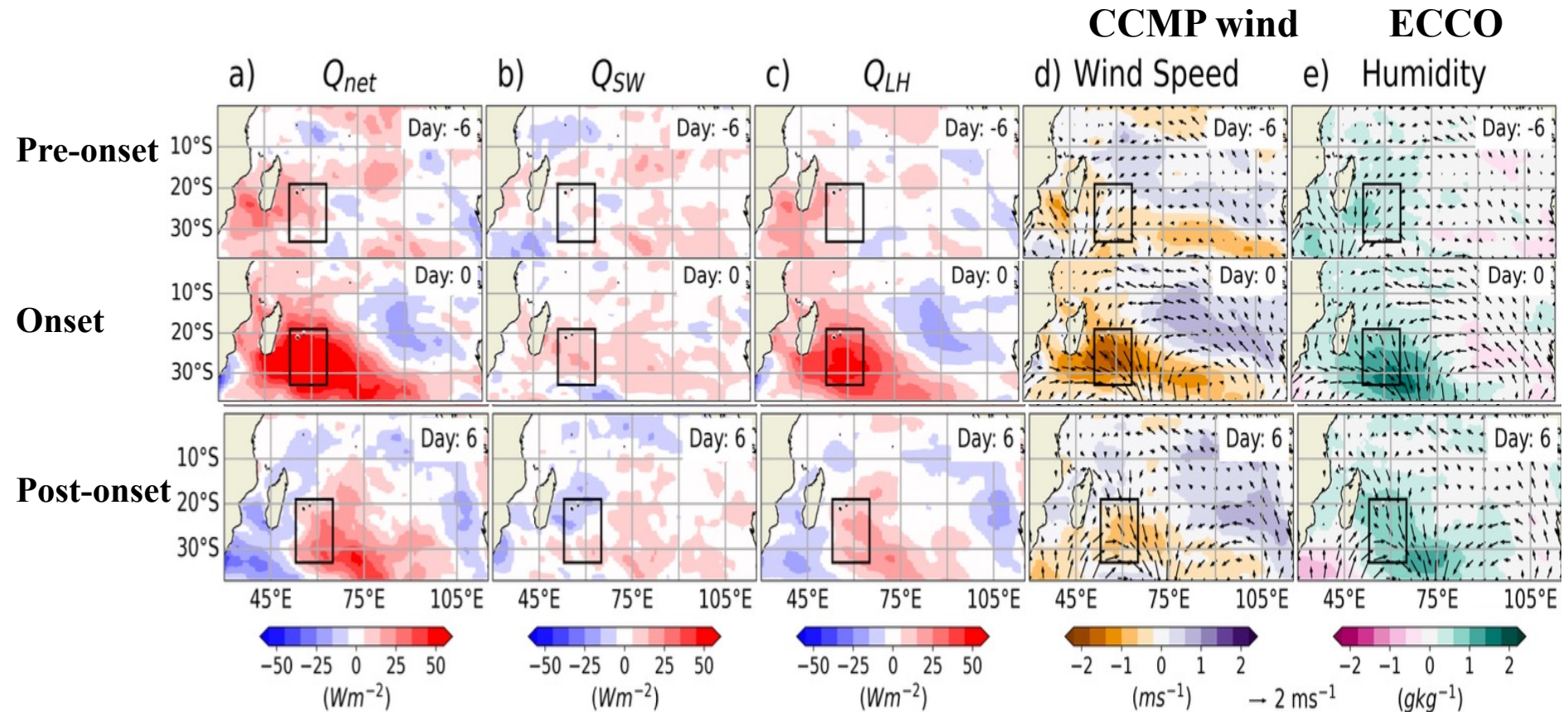
SW & Latent heat fluxes, h



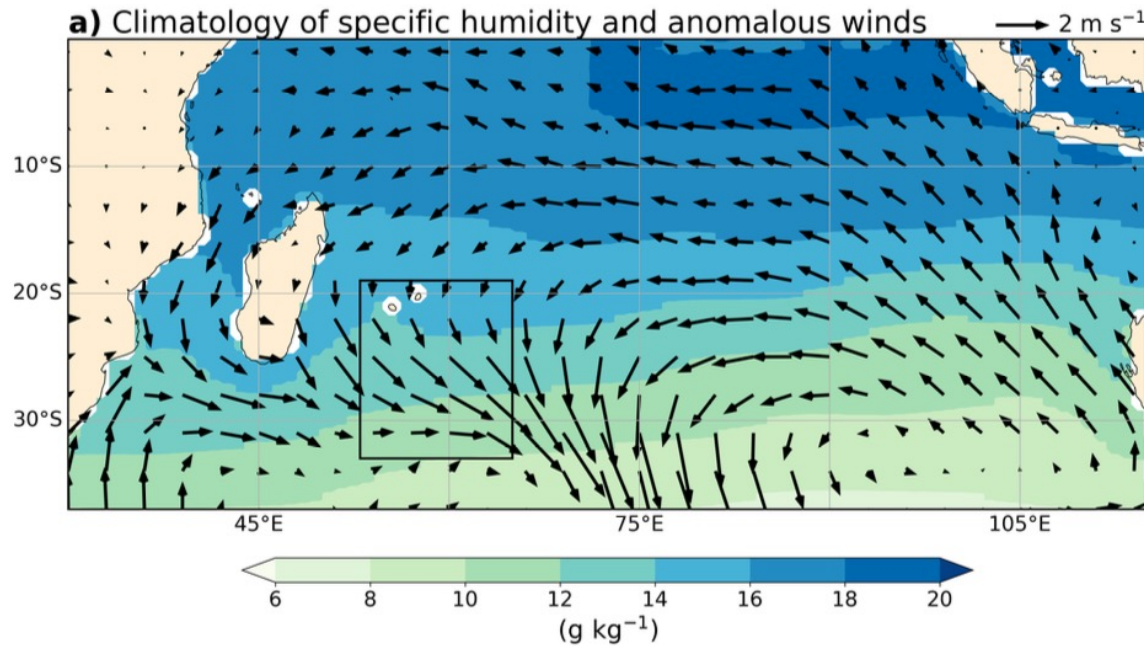
Weak wind  
& +Qnet

-> thin h

# MHW composites: $Q$ ( $\text{w/m}^2$ ), wind & specific humidity

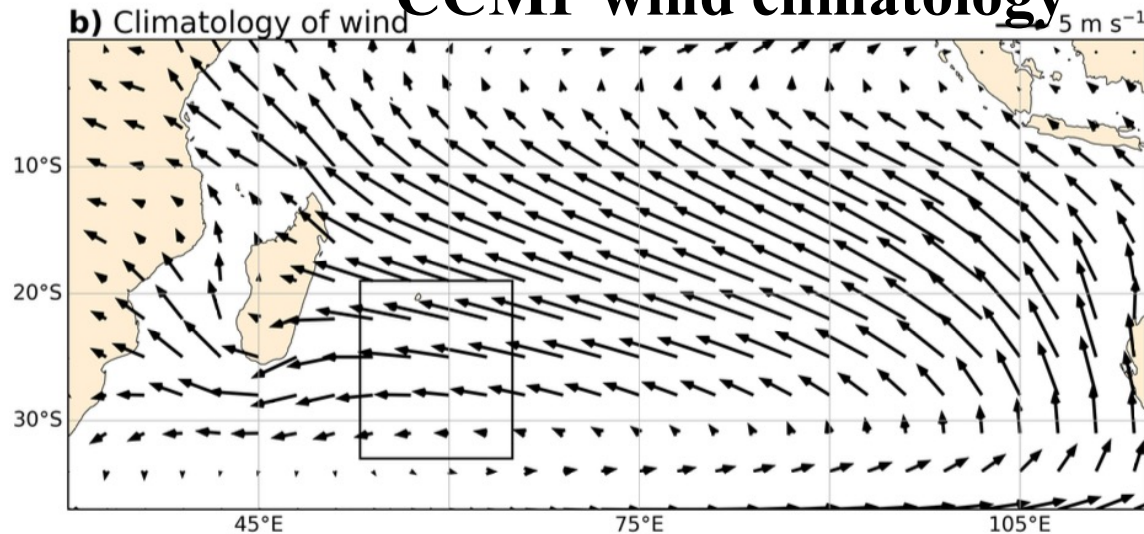


# ECCO q climatology + CCMP wind anomalies for MHWs (day 0)



Northerly wind anomalies during MHWs advect humid air from tropics to the SWIO

## CCMP wind climatology



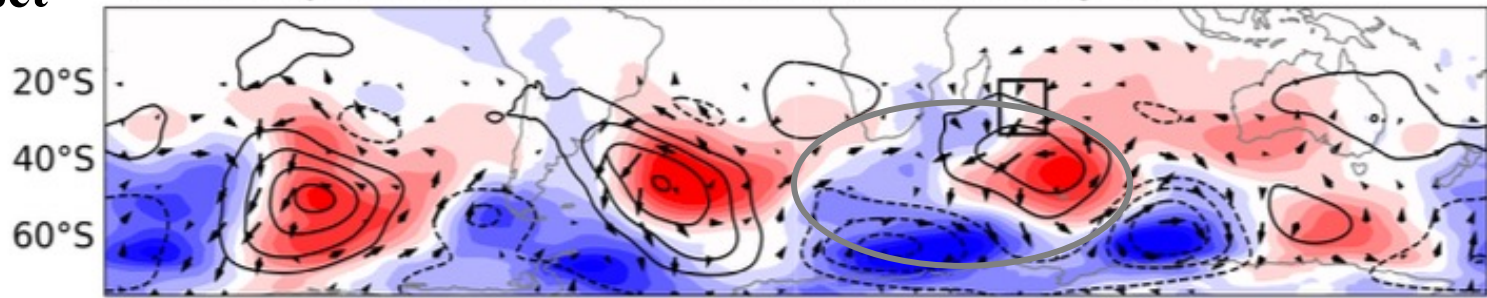
Wind anomalies act against mean winds & thus weaken the wind speed

**Wind anomalies!**

# MHW composites: Sea Level Pressure (color), 200hPa z (line) & CCMP surface wind vectors

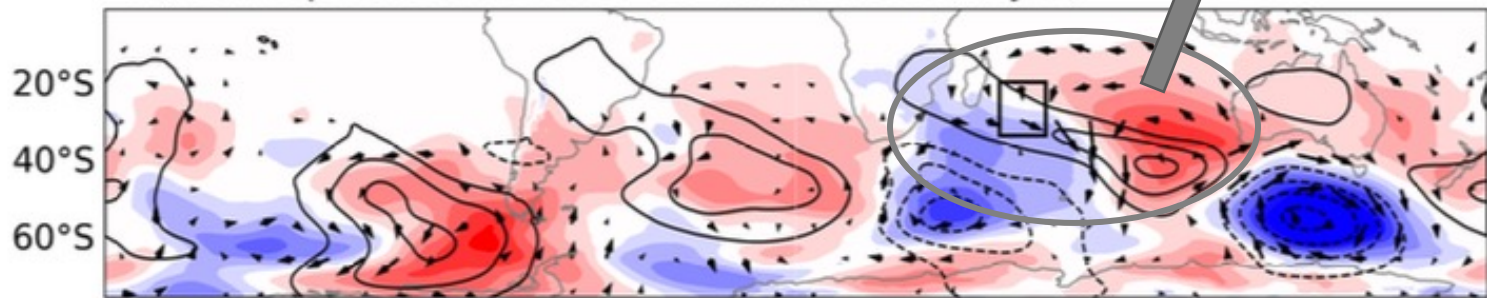
Pre-onset

a) Atmospheric anomalies before MHW onset (day -6)



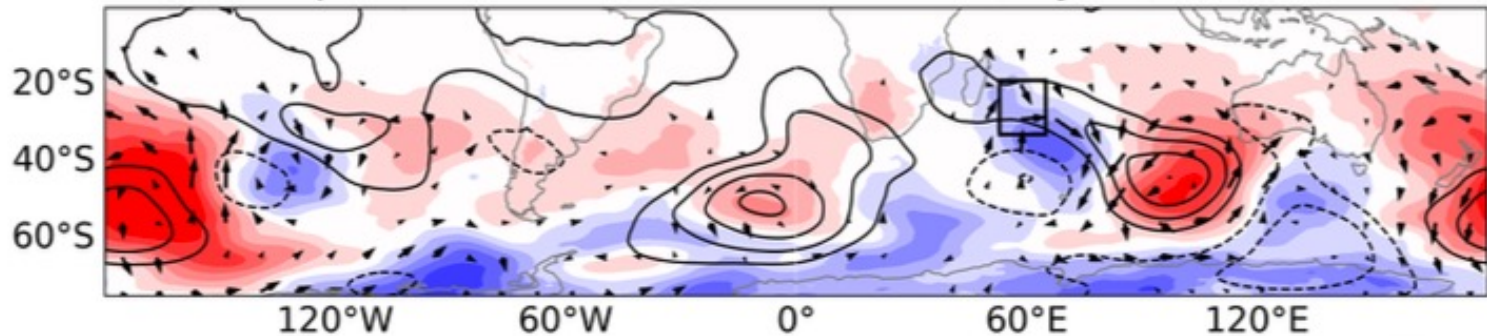
Onset

b) Atmospheric anomalies for MHW onset (day 0)

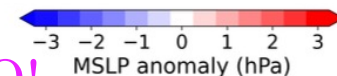


Post-onset

c) Atmospheric anomalies after MHW onset (day +6)



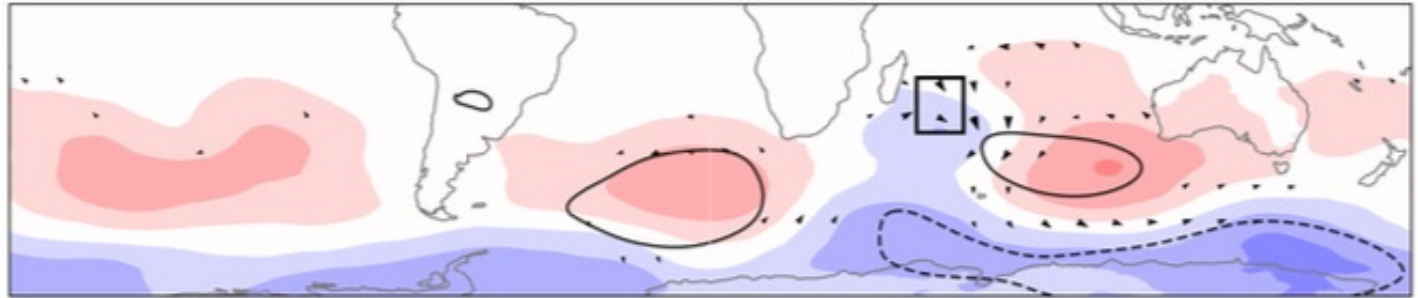
Surface winds & SLP associated with midlatitude  
Atmospheric Rossby waves: extending to subtropical SIO!



# MHW composites (day 0): Sea Level Pressure (color), 200hPa z (line) & CCMP surface wind vectors

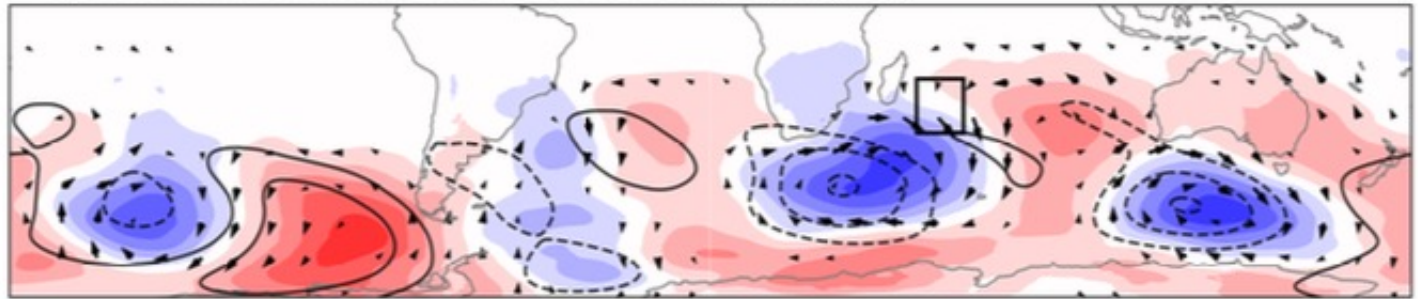
d) Low-frequency: period > 100 days (day 0)

P>100days  
(clim seasonal  
cycle removed)



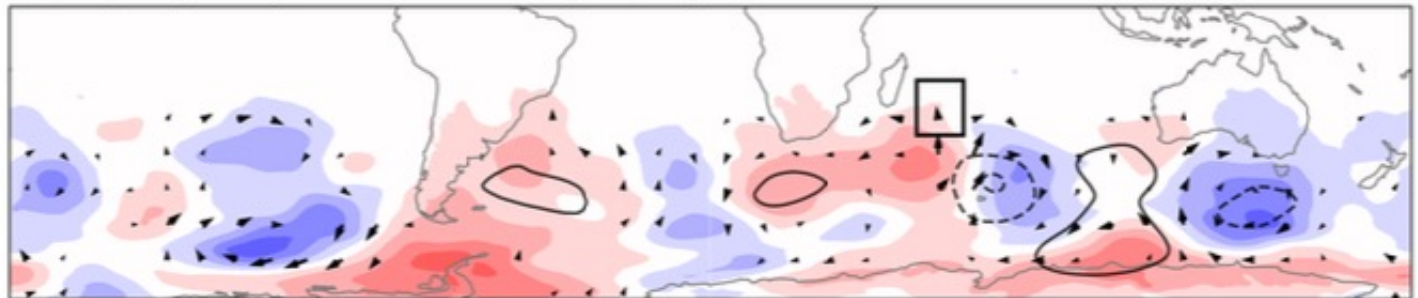
e) Intraseasonal: period 10-100 days (day 0)

P=10-100days



f) Synoptic: period < 10 days (day 0)

P<10days



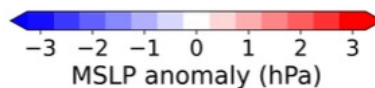
120°W

60°W

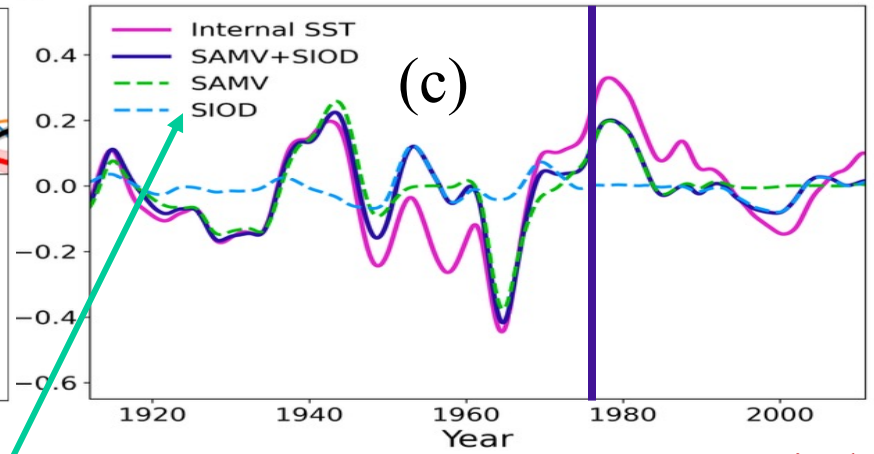
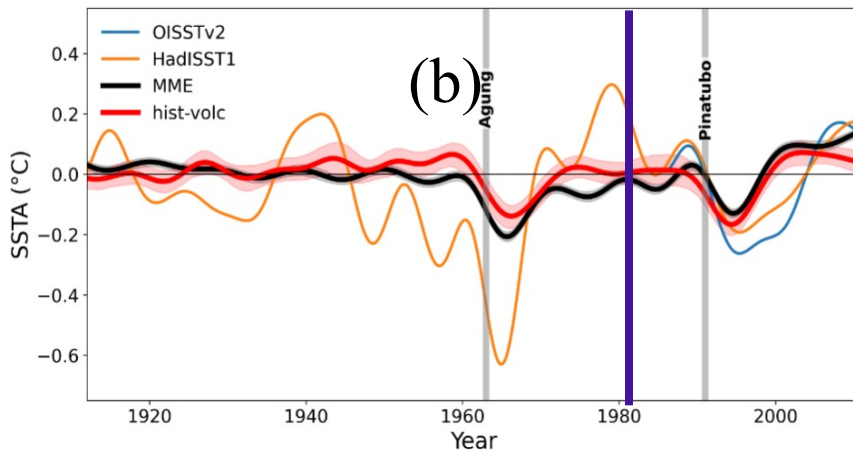
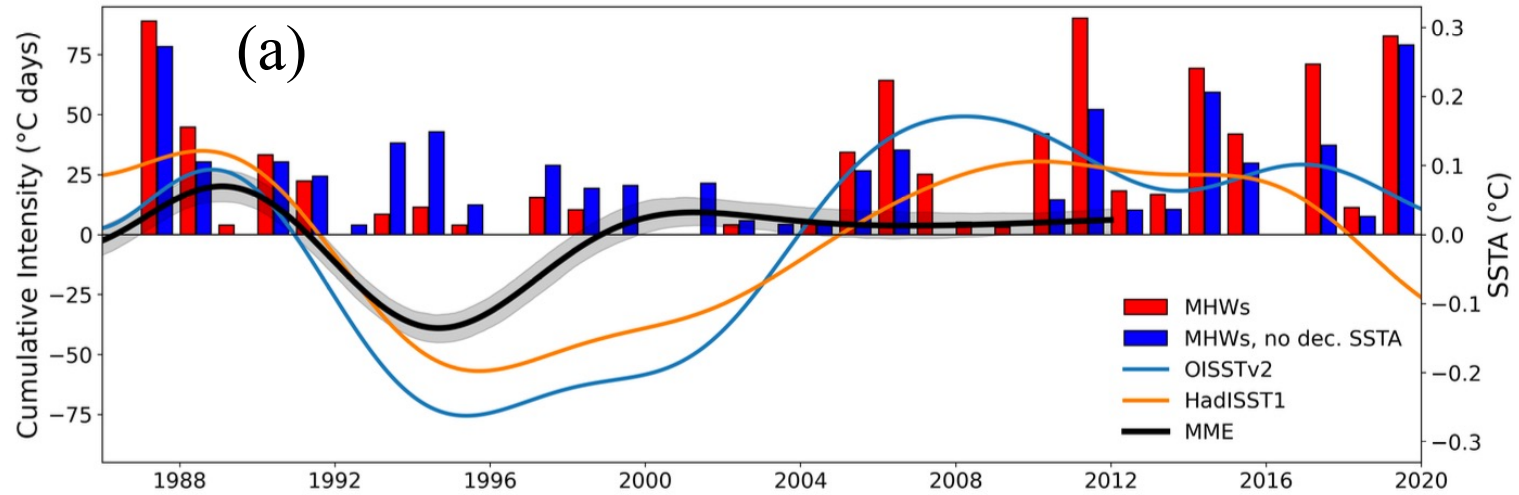
0°

60°E

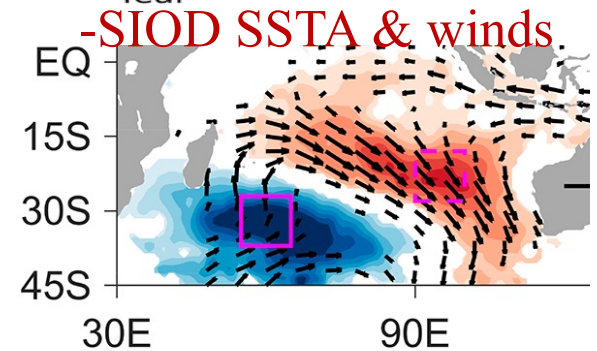
120°E



# (c) MHW decadal suppression



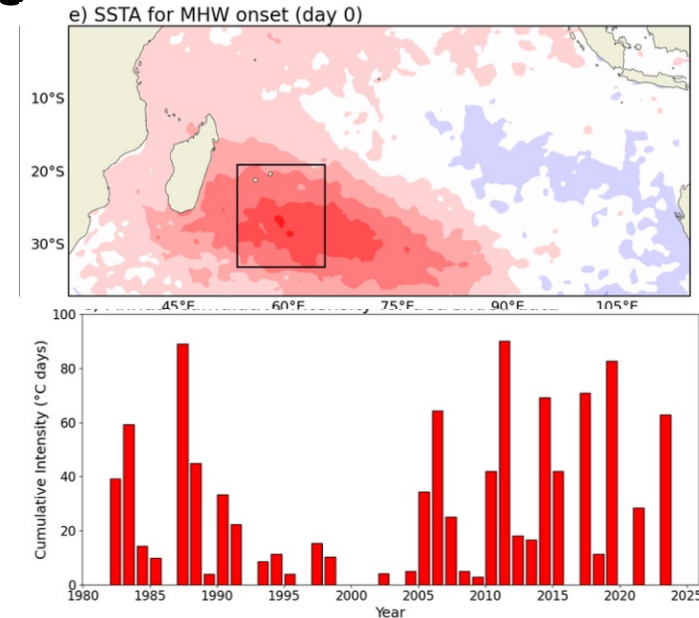
**Subtropical Indian Ocean Dipole (SIOD)**



# Summary & conclusions

❖ Large-scale MHWs are detected in the SWIO in recent decades (1982-2023); surface wind anomalies associated with **subtropical intruding, midlatitude atmospheric intraseasonal Rossby Waves** *weaken wind speed & increase humidity, reducing  $Q_{LH}$  loss, thinning  $h$ , amplifying  $Q_{SW}$  warming & triggering MHWs*

❖ Volcanic eruption combined with decadal variability of the Subtropical Indian Ocean Dipole (SIOD) reduce SST and cause the decade long (1992-2005) MHW suppression



# Acknowledgement

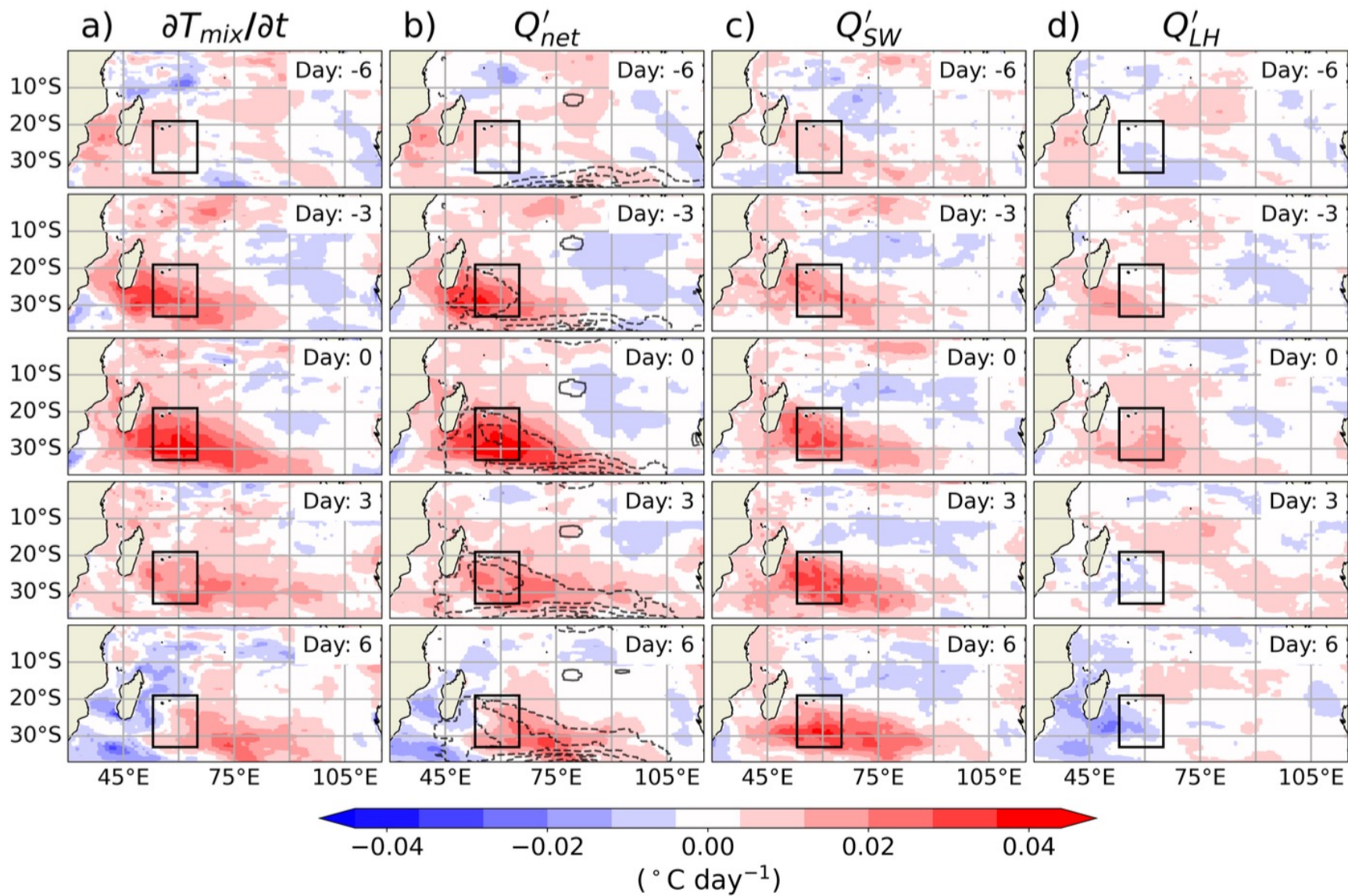
The authors thank the funding support from NASA OSTST 80NSSC26K0209 & IOVWST 80NSSC23K0982 (subaward M2304447)

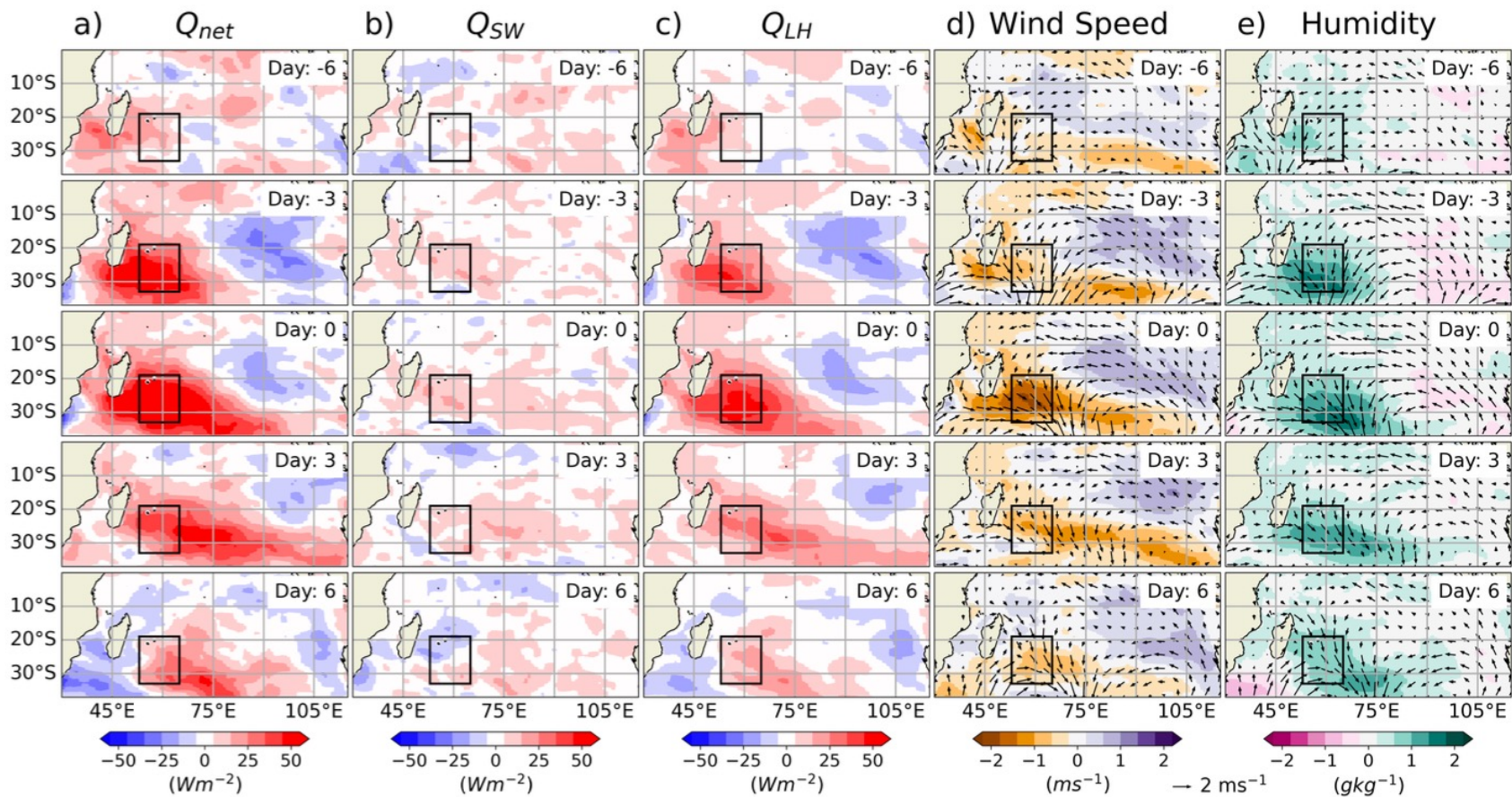
## Mixed layer heat budget analysis using ECCO dataset:

$$\frac{1}{h} \int_{-h}^0 \frac{\partial T}{\partial t} dz = \frac{1}{h} \int_{-h}^0 \frac{Q_{net}}{\rho C_p} dz - \frac{1}{h} \int_{-h}^0 \mathbf{u} \cdot \nabla T dz + \frac{1}{h} \int_{-h}^0 \kappa_H \cdot \nabla^2 T dz + \text{subsurface} \quad (1)$$

$$\text{subsurface} = -\frac{1}{h} \Delta T \frac{\partial h}{\partial t} - \left[ w \frac{\partial T}{\partial z} \right] - \frac{1}{h} \kappa_z \frac{\partial T}{\partial z} \Big|_{-h} \quad \text{and} \quad \Delta T = \begin{cases} [T] - T_{det} & \left( \frac{\partial h}{\partial t} < 0 \right) \\ 0 & \left( \frac{\partial h}{\partial t} = 0 \right) \\ [T] - T_{ent} & \left( \frac{\partial h}{\partial t} > 0 \right) \end{cases} \quad (2)$$

$$Q_{LH} = \Lambda_v \left[ \rho_a C_E (q(z_q) - q_{sat}(SST)) |\Delta \vec{U}| \right] \quad (3)$$

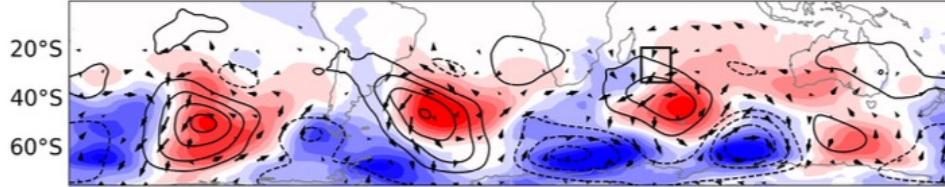




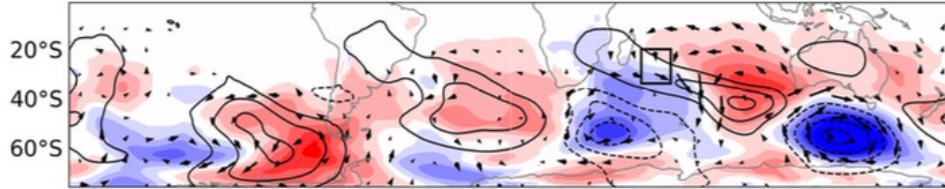
# MHW composites: MSLP (color), 200hPa z (line contours) & CCMp surface wind (vectors)

Periods > 100 days (remove seasonal cycle)

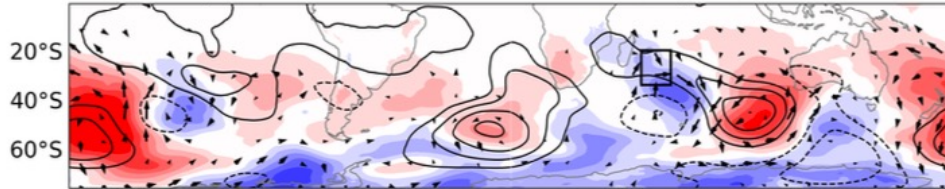
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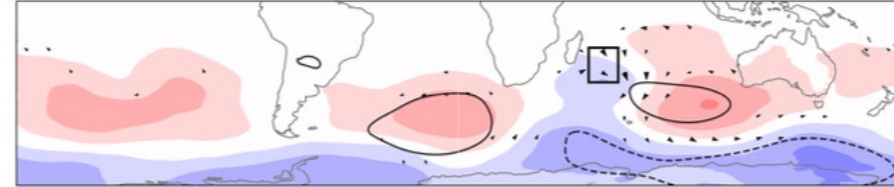
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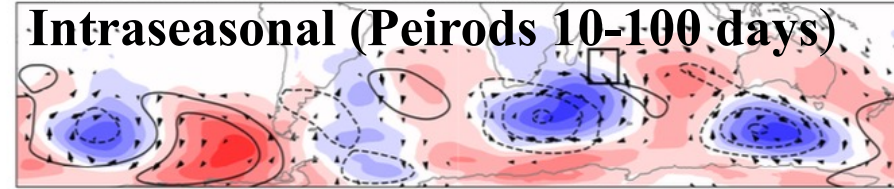
c) Atmospheric anomalies after MHW onset (day +6)



d) Low-frequency: period > 100 days (day 0)



e) Intraseasonal: period 10-100 days (day 0)

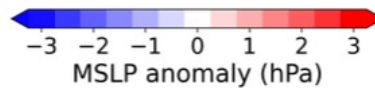


f) Synoptic: period < 10 days (day 0)



**Intraseasonal (Periods 10-100 days)**

**Synoptic (Periods <10 days)**



→ 2 ms<sup>-1</sup>