HELLENIC REPUBLIC
National and Kapodistrian University of Athens
EST. 1837

OCEANOGRAPHY & EARTH OBSERVATION GROUP

Marine Heatwave Heat Budget during Coral Bleaching Events in the Red Sea

Sofia Darmaraki, George Krokos, Dionysios Raitsos, Ibrahim Hoteit , Lily Genevier

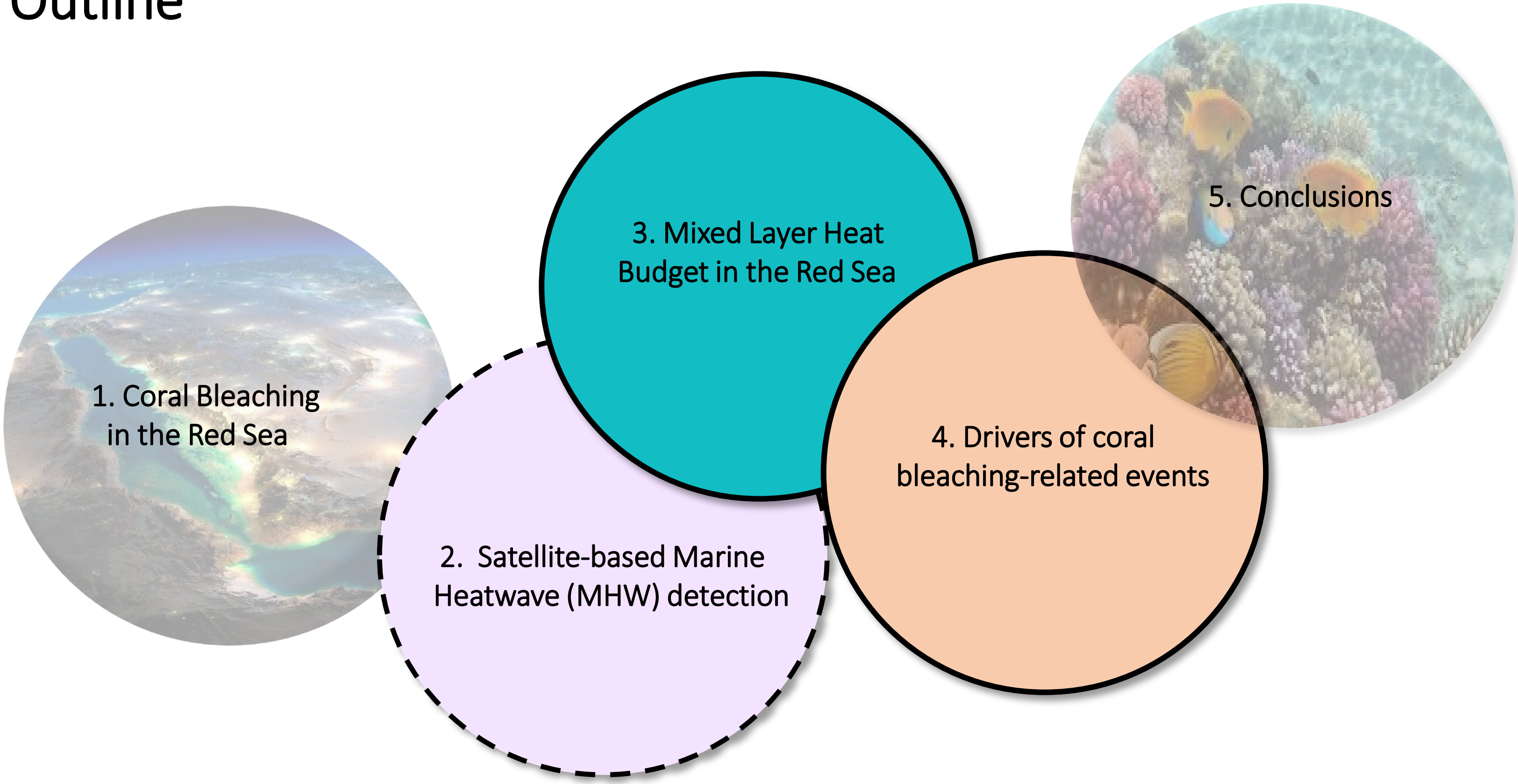
sofia.darmaraki@dal.ca
sofia.darm@gmail.com

@Sofia_Darmaraki

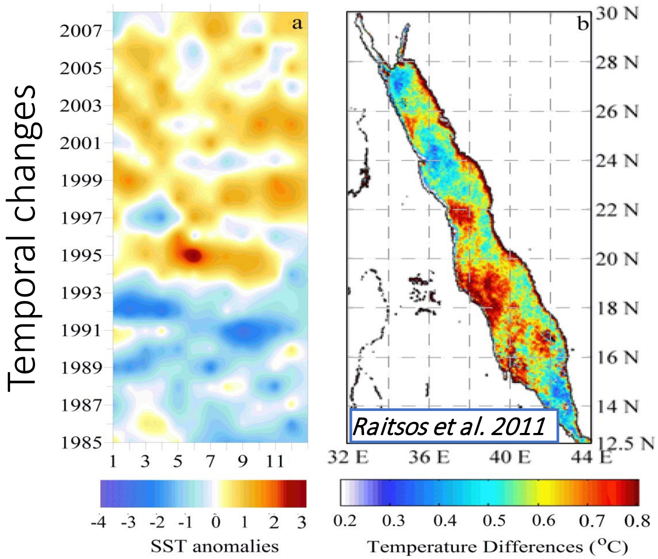
KAUST

living planet symposium
BONN 23–27 May 2022
TAKING THE PULSE OF OUR PLANET FROM SPACE
#LPS22
esa

Outline


1. Coral Bleaching in the Red Sea
2. Satellite-based Marine Heatwave (MHW) detection
3. Mixed Layer Heat Budget in the Red Sea
4. Drivers of coral bleaching-related events
5. Conclusions

Temperature anomalies in the Red Sea

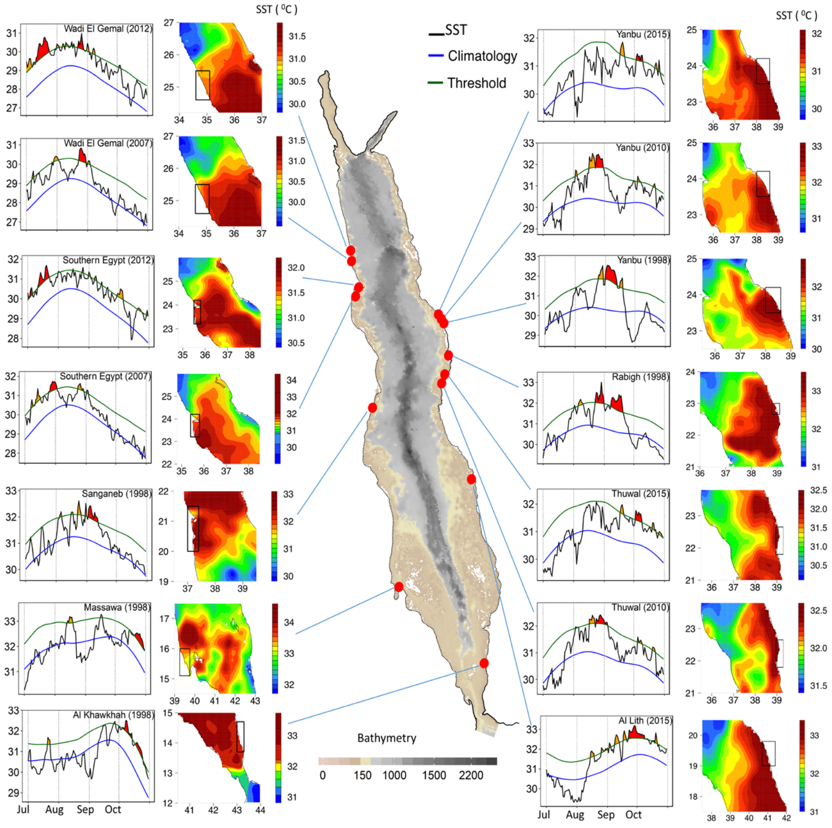


- Semi-enclosed basin
- Influenced by Mediterranean Climate & Indian monsoons
- Large marine biodiversity
- Vigorous Thermohaline Circulation

YA, D. (2021). Egyptian Journal of Aquatic Biology and Fisheries, 25(5), 17-37.

- Fringing corals around Red Sea coastline:
  - can withstand exceptionally high temperatures
  - Yet, several coral bleaching events have occurred; e.g. 2007,2010,2012,2015

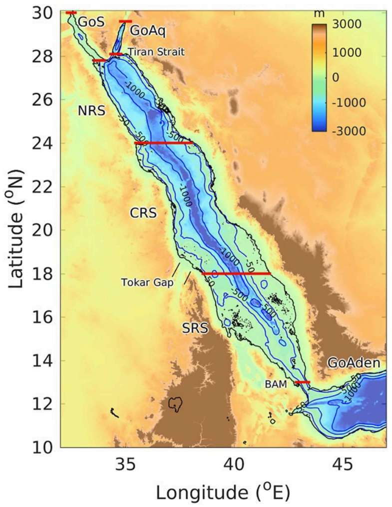
MHW "hotspots" over Red Sea coral reefs



Genevier, L. G. C., Jamil, T., Raitsos, D. E., Krokos, G., & Hoteit, I. (2019). *Global Change Biology*, **25**, 2338– 2351.

- **Based on:**
  - Daily, satellite SST **(OSTIA,0.05°)** 1985-2015 *(e.g. Donlon et al., 2012)*
  - MHW definition (*Hobday et al., 2016*)
  - Coral bleaching reports (*in situ*, ***see Genevier et al., 2019***)
- **Tuned** (summer) MHW detection to capture **reported** coral bleaching between July – October : SST > 95th percentile for 7 days or more
- Environmental conditions extended farther than reported coral-bleaching area
- **Project goal**: Physical processes inside the mixed layer, which caused coral bleaching – related (summer) MHWs

The Red Sea Regional hydrodynamic Model



Ocean Component: MIT general circulation model (MITgcm; Marshall et al., 1997)

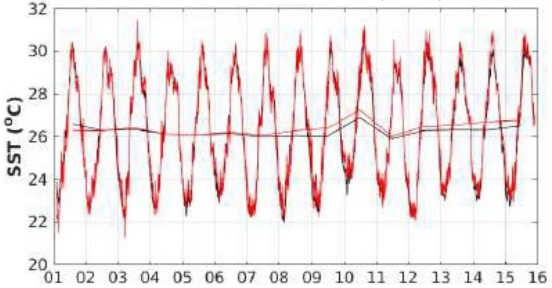
- 50 Vertical Layers
- Horizontal resolution: 0.01° (~1 km)
- Atmosphere forcing: ERA-Interim reanalysis (~ 5km)
- Dataset: 3D daily-averaged fields, January 2001 – December 2015

Krokos, G., Cerovečki, I., Papadopoulos, V. P., Hendershott, M. C., & Hoteit, I. (2021), *Journal of Geophysical Research: Oceans*, e2021JC017369

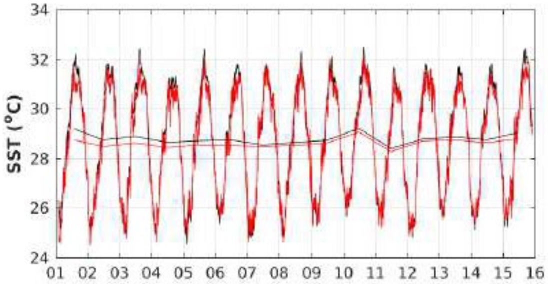
Validation of model SST over different regions of the Red Sea:

- Model SST agrees better with satellite-derived (OSTIA) SST during winter, differences are larger during summer.

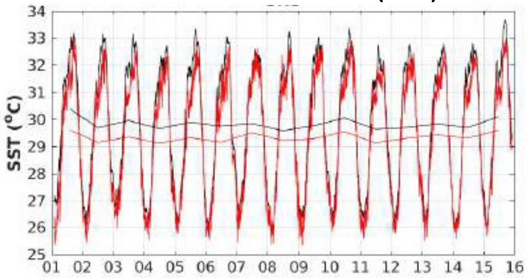
North Red Sea (NRS)



Central Red Sea (CRS)



South Red Sea (SRS)



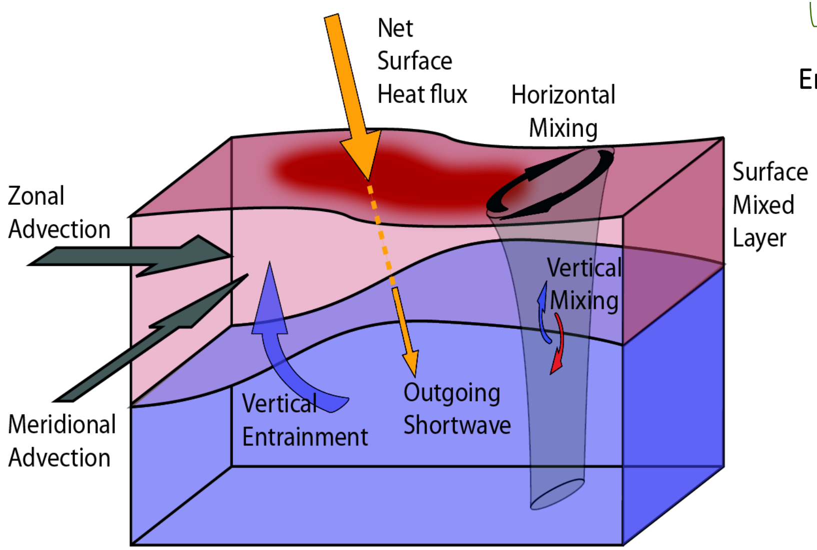
Heat exchanges in the Mixed Layer can tell us more about MHW dynamics

Mixed Layer Heat Budget (**MLHB**) terms :

$$\frac{\partial \overline{T}}{\partial t} = \overline{\frac{1}{\rho C_p}\frac{\partial q}{\partial z}} - \overline{\nabla_H(\mathbf{U}\cdot T)} - \overline{\frac{\partial w}{\partial z}} + \left\langle \left(\overline{T} - T_{-h}\right)\frac{\partial h}{\partial t}\right\rangle + \overline{\frac{\partial\left(K_z\frac{\partial T}{\partial z}\right)}{\partial z}} + \overline{\nabla_H\left(K_H\left(\nabla_H \cdot T\right)\right)}$$

Temperature tendency | Air-Sea Heat Flux | Horizontal Advection | Vertical Advection | Mixed-layer Tendency | Vertical Diffusion | Horizontal Diffusion

Entrainment Processes (Vertical Advection, Mixed-layer Tendency) | Mixing Processes (Vertical Diffusion, Horizontal Diffusion)



Holbrook et al., 2019

where,

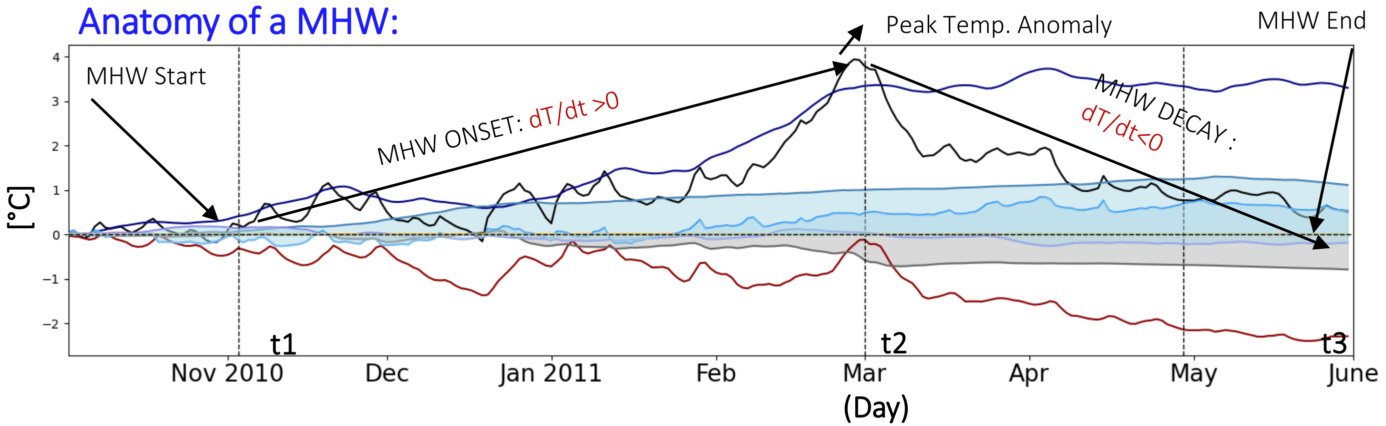
Volume average: $\overline{x} = \frac{1}{V}\int_{x1}^{x2}\int_{y1}^{y2}\int_{-h}^{0} x\, dxdydz$

Area average : $\langle x\rangle = -\frac{1}{V}\int_{x1}^{x2}\int_{y1}^{y2} xdydx$

- **3-D, daily** Online MLHB.
- **Years:** 2001-2015
- **Investigate** the 4 RHS terms relative to the LHS of equation

Mixed Layer Heat Budget Analysis of MHWs: Methods

Anatomy of a MHW:



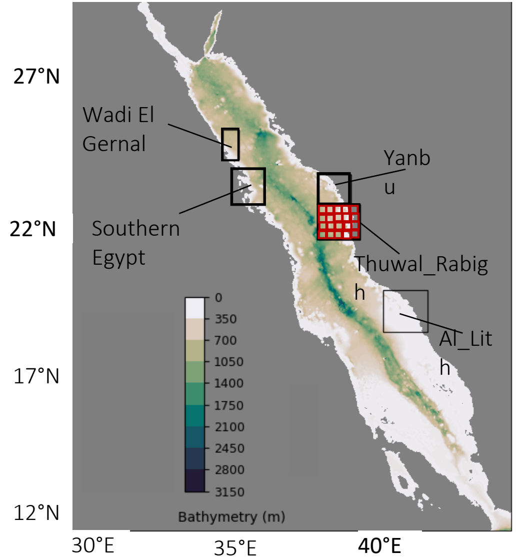
1. We study the ONSET & DECLINE of the most severe MHWs of 2001-2015 based on satellite/model

2. For each MHW phase: Calculate time-integrated heat contribution to the total temperature change of MLHB term (**x**) at each grid point

e.g: *Contribution* x_{ONSET} =.

$$\int_{t1}^{t2} x_{ONSET} dt \ / \int_{t1}^{t2} \left(\frac{dT}{dt}\right)_{ONSET} dt$$

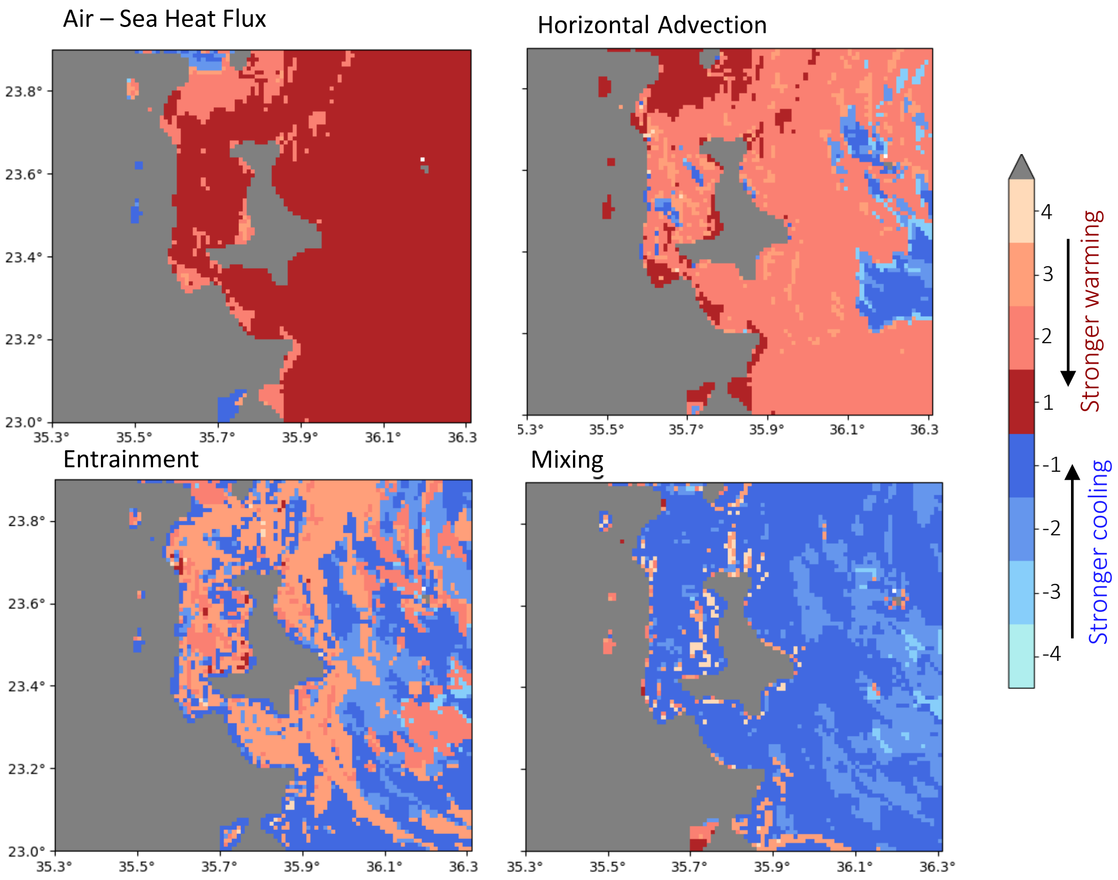
3. Decide on dominant, local-scale driver based on: *Highest positive (negative) heat contribution to MHW Onset (Decay)*



Atmosphere-driven MHW onset: Southern Egypt 14/7/12 – 19/7/12

➢ Example

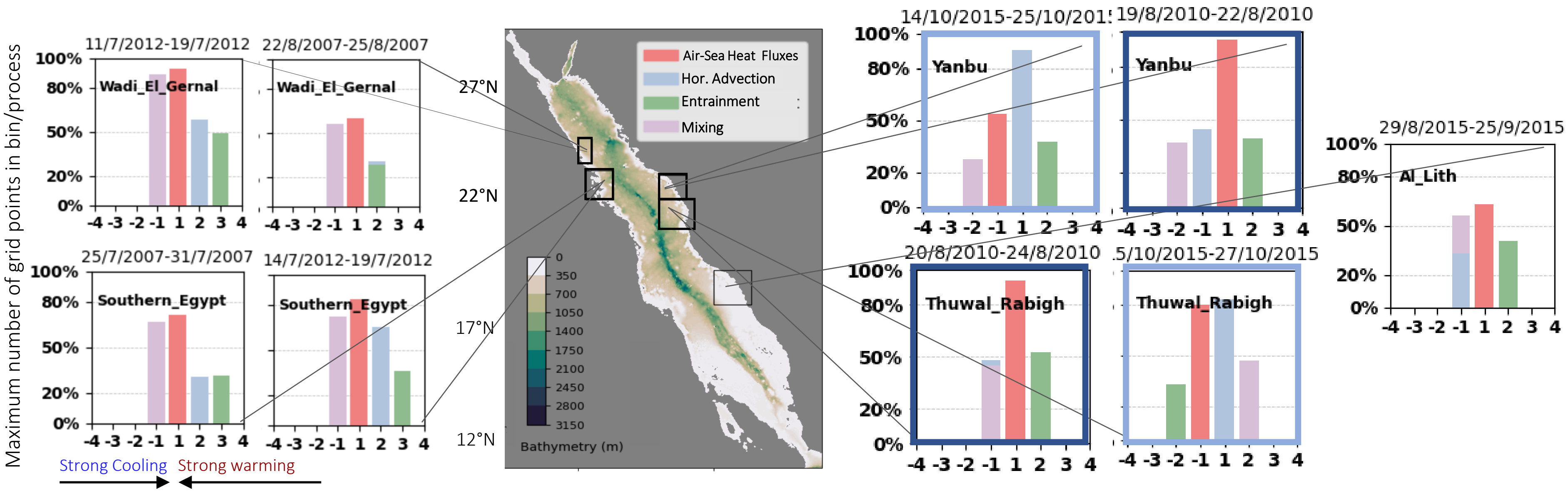
Ranking of MLHB Heat Contribution



For each process:

- **Count** the number of grid points in each (heat contribution) bin
- **Find** the bin sampled the most
- **Report** this as the most “dominant” behavior of the physical process during the event

Most extreme coral bleaching-related MHW onsets mainly atmosphere-driven

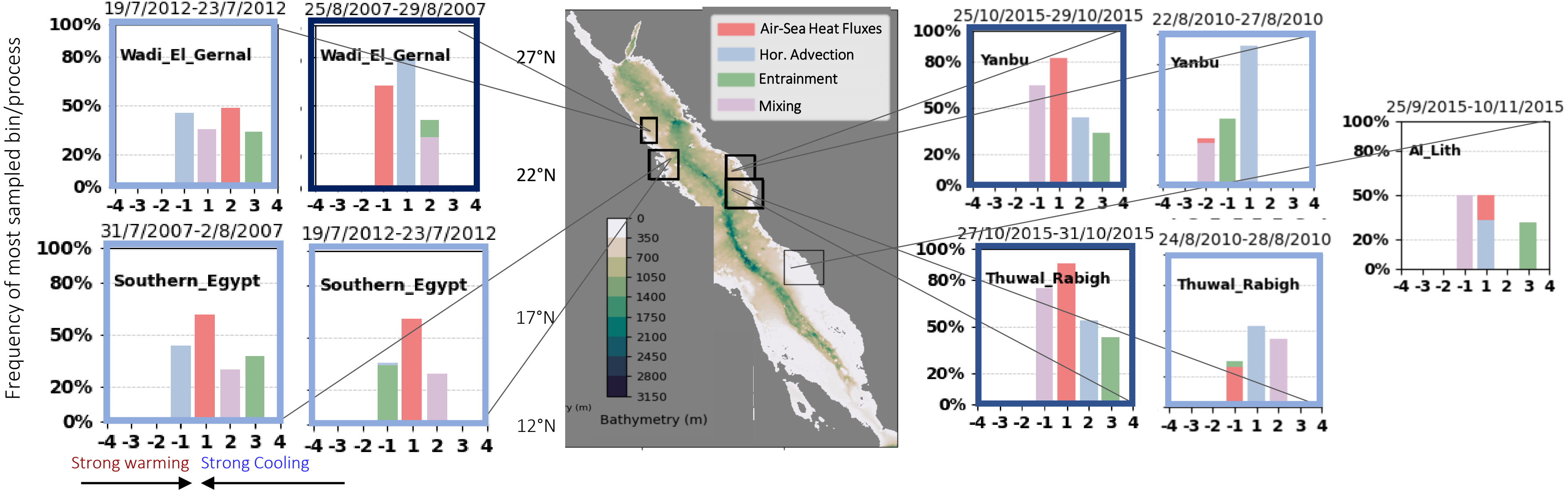


- NW Coast of Red Sea MHWs:
  - Dominant driver : **Air-Sea Heat fluxes**
  - Secondary warming mechanisms: **Hor.Advection** & **Entrainment**
  - Primary cooling mechanism: **Mixing**

- CE Red Sea MHWs:
  - **August** Warming: Air-Sea Heat fluxes & Entrainment
    Cooling: Hor. Advection & Mixing
  - **October**: Hor.Advection (warming), Air-Sea Heat Fluxes (cooling),
    Entrainment & Mixing: Both warming/cooling

- South Red Sea MHW:
  - Follows August warming/cooling patterns of CE Red Sea MHWs

MHW decay drivers change with season and region



- <u>NW Coast of Red Sea MHWs:</u>
  - July Cooling: Air-sea Heat Fluxes, Mixing, Entrainment
    Warming: Hor.Advection Entrainment
  - August Cooling: Hor.Advection, Mixing, Entrainment
    Warming: Air-sea Heat Fluxes

- <u>CE Red Sea MHW:</u>
  - August Cooling: Hor.Advection,Mixing
    Warming : Air-Sea Heat Fluxes, Entrainment, Mixing,
  - October Cooling: Air-Sea Heat fluxes, Hor.Advection, Entrainment, Warming: Mixing

- <u>South Red Sea MHW</u>:
  - Follows October warming/cooling patterns of CE Red Sea MHWs

Take-home message

Marine Heatwaves causing coral bleaching in the Red Sea

- Red Sea corals may not withstand extreme warm temperatures (observed)
- Summer MHW Definition: SST > 95^{th} percentile for 7 days
- Identification based on satellite and high-resolution, regional model
- Examine heat contributions to mixed layer temperature during events

Dominant MHW drivers causing coral bleaching

➢ **MHW Onset:**

NW, SE & CE Red Sea:
Air-Sea H.Flux

CE Red Sea (October)
Hor. Advection

➢ **MHW Decay:**

NW & CE Red Sea:
Air-Sea H.flux, Hor.Advection
Mixing

Southeast Red Sea (October)
Hor. Advection, Air-Sea H.flux

Perspective

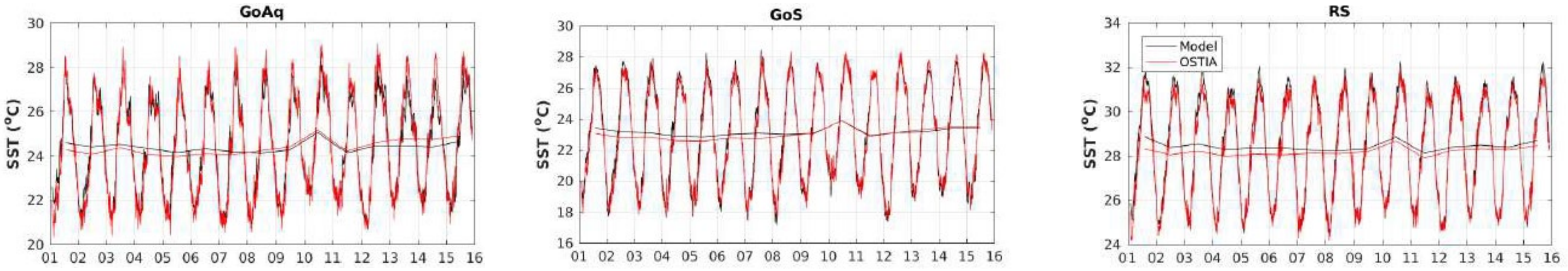
-Statistical study on several MHWs in selected regions of the Red Sea for more robust results

THANK YOU FOR YOUR ATTENTION !

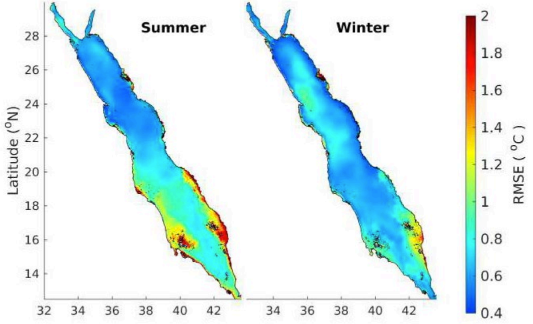
Questions?

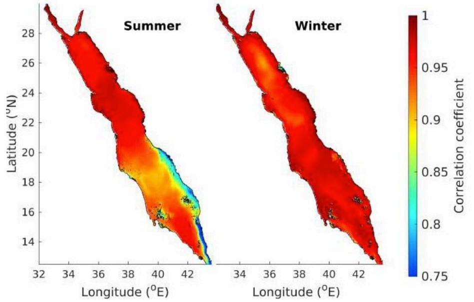
sofia.darmaraki@dal.ca,

Validation of the model:



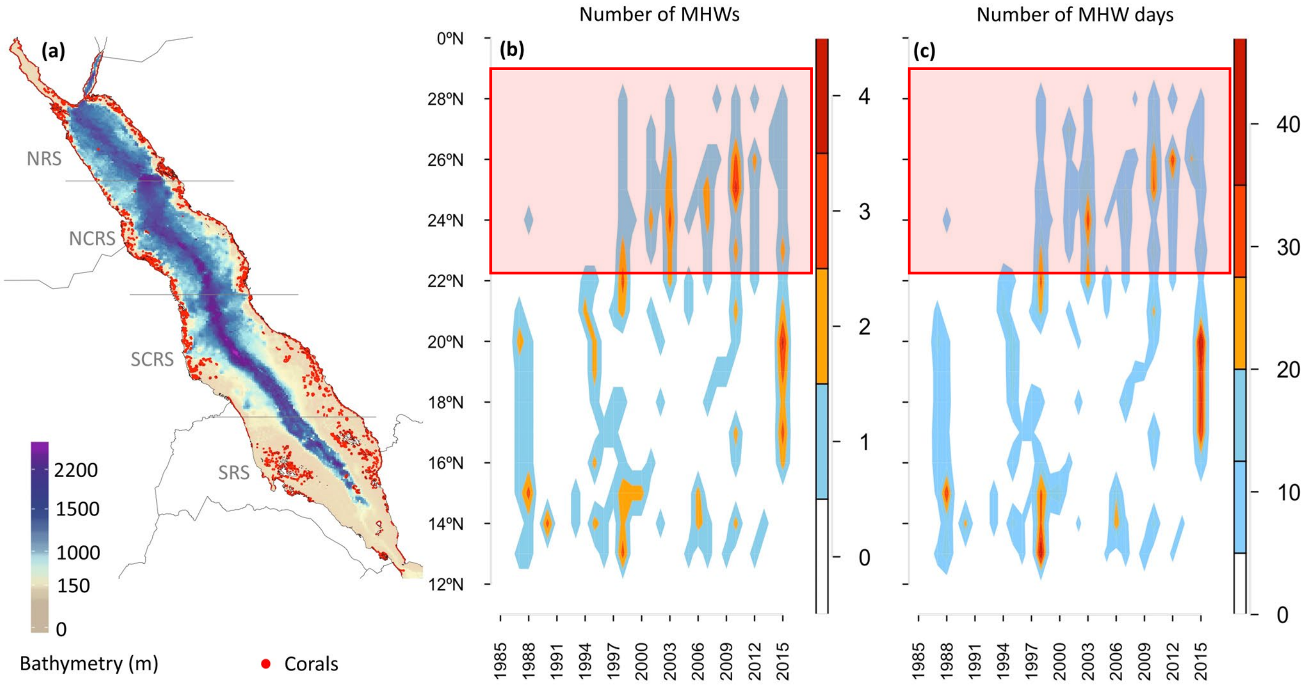
Modeled and satellite (OSTIA) derived daily SST over the model simulation period (2001-2015), averaged over different regions of the Red Sea.Figure taken from Krokos et al., 2021





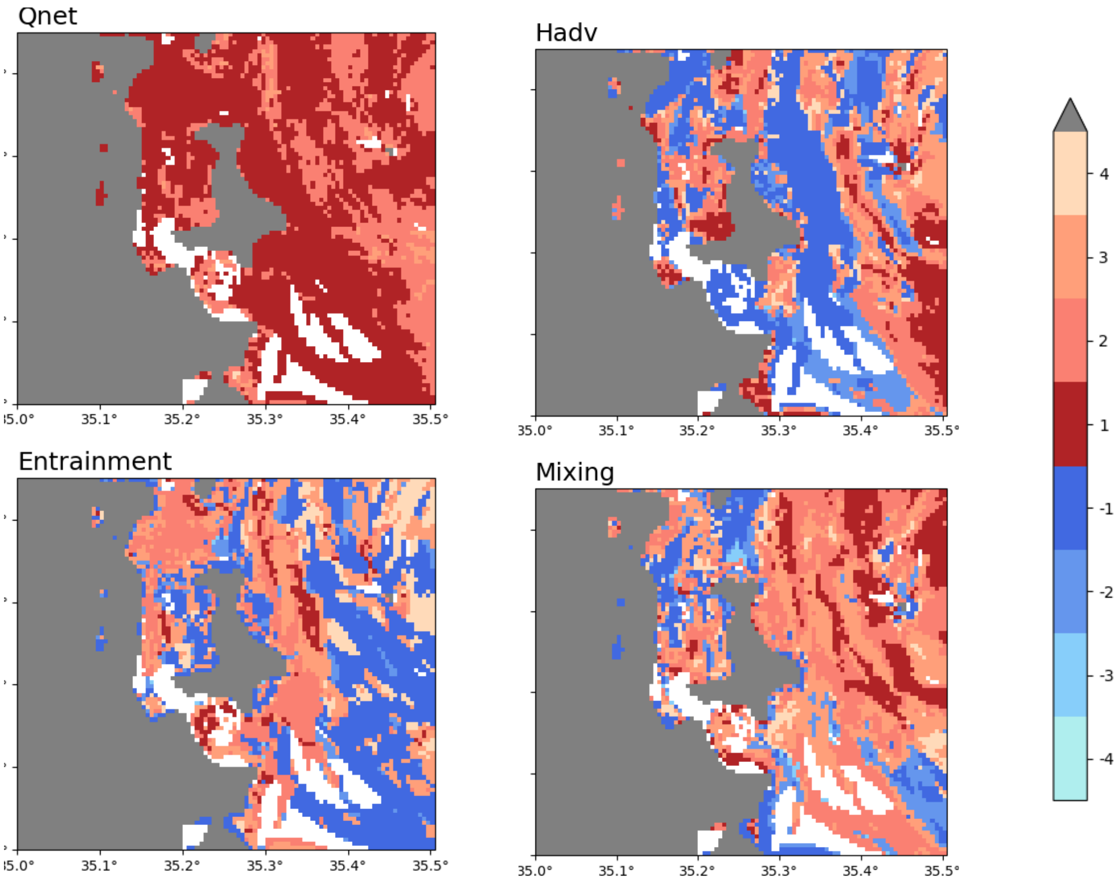
The Root Mean Square Difference (RMSD) between the daily modeled and satellite derived SST (OSTIA), time averaged over the model simulation period (2001-2015), separately for the winter (October-April) and summer (May-September) periods. Lower panel: The correlation coefficient between the two SST estimates. Figure taken from Krokos et al., 2021

Results: MHWs over time



- An emergent bleaching regime in the northern Red Sea?

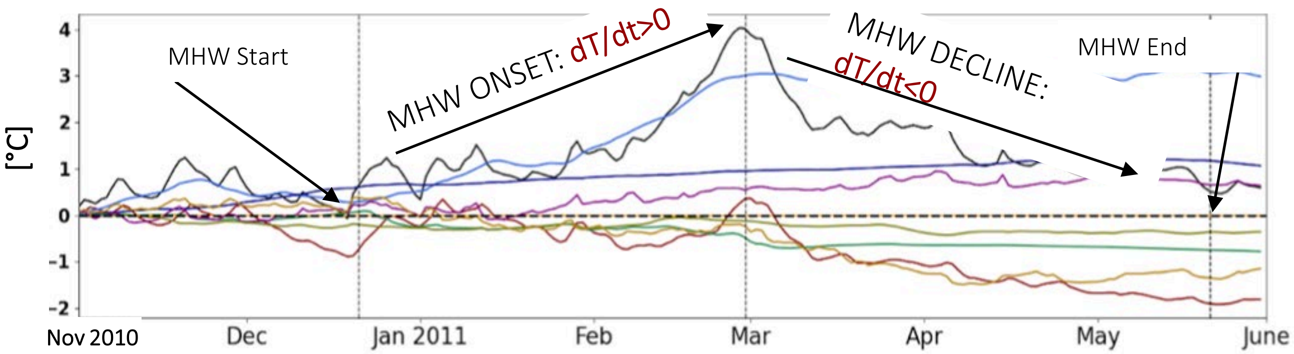
Genevier, L. G. C., Jamil, T., Raitsos, D. E., Krokos, G., & Hoteit, I. (2019). *Global Change Biology*, **25**, 2338– 2351.



Qnet
Hadv
Entrainment
Mixing
35.0°
35.1°
35.2°
35.3°
35.4°
35.5°
4
3
2
1
-1
-2
-3
-4

Changes in contributions due to the choice of spatial scale:

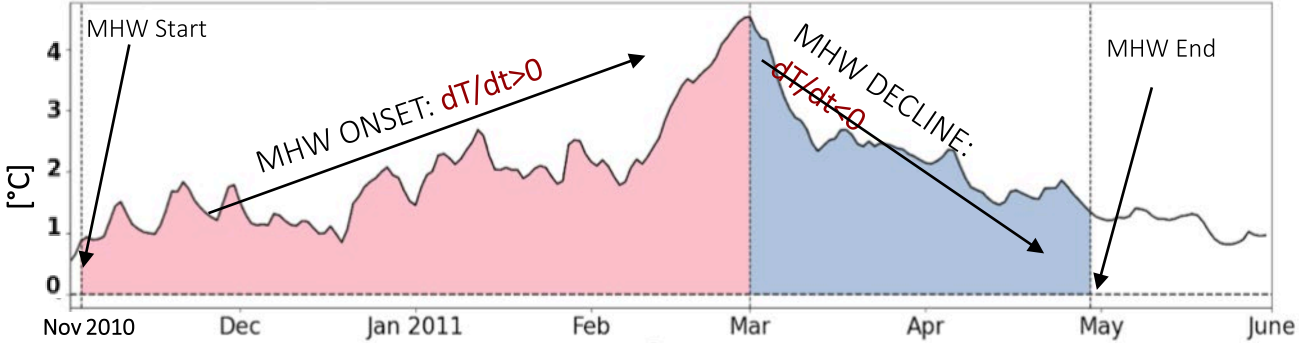
Cumulative Heat Anomaly of each MLHB term before, during and after W.Australia MHW 2011



Grid Box: Lat (-30, -26) Lon (112-116)

Duration: 179 days
Dominant Driver: Hor.Advection
2nd Driver: Vertical Advection
4th Driver : Atm. Flux

ML Temperature anomaly before, during and after W.Australia MHW 2011



Grid Box: Lat (-32, -28) Lon (112-116)

Duration: 153 days
Dominant Driver: Hor.Advection
2nd Driver: Atm. Flux