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Analysis of the vertical variability and temporal frequency of the chlorophyll forcing field on temperature in the Mediterranean Sea and potential implications for regional climate projections

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Analysis of the vertical variability and temporal frequency of the chlorophyll forcing field on temperature in the Mediterranean Sea and potential implications for regional climate projections



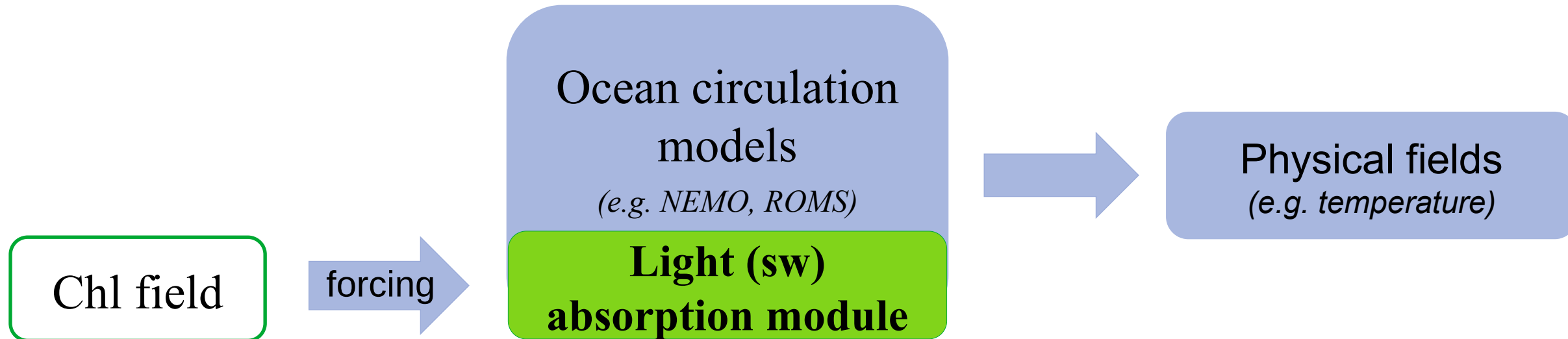
Financial Support



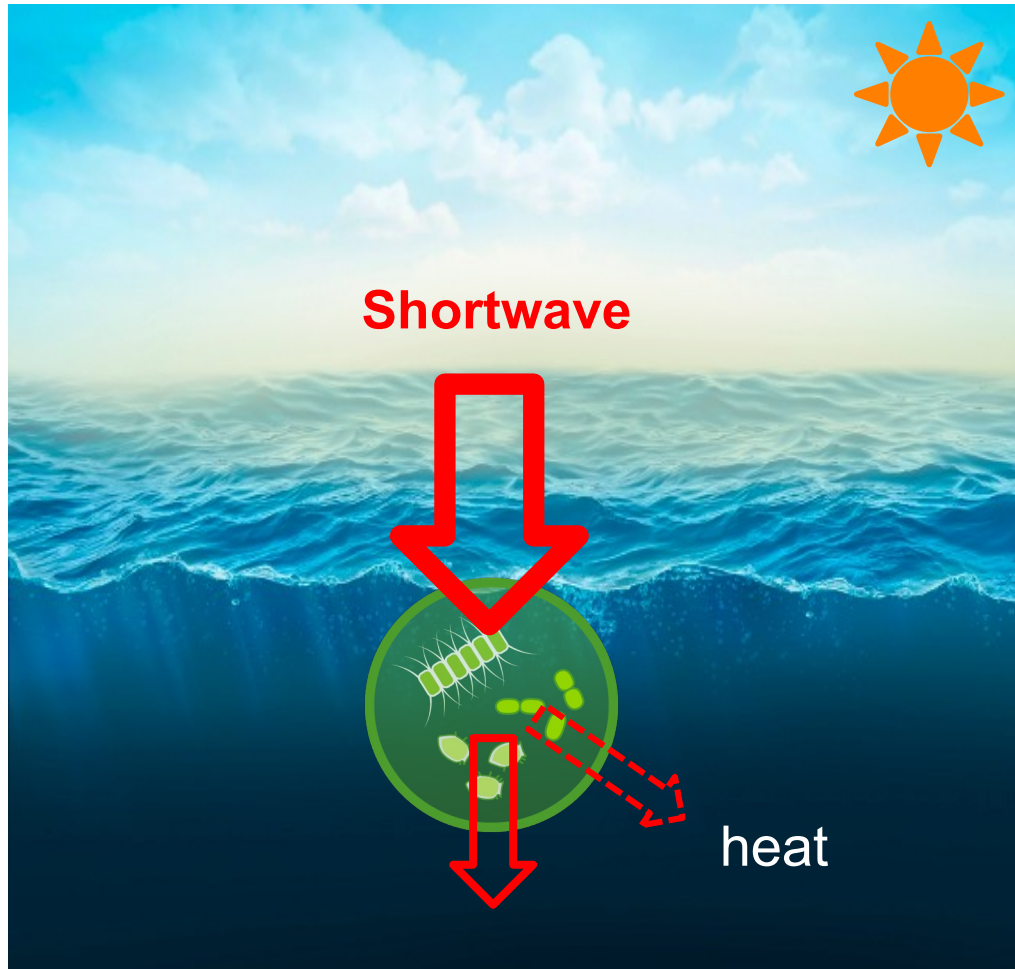
Yutong ZHANG (MIO), Melika BAKLOUTI (MIO), Florence SEVAULT (CNRM), Romain PENNEL (LMD)

**This work has recently been submitted to «Ocean Modelling »*

Chl fields as forcing for ocean circulation models



Absorption module : Solar radiation absorption by Chl



solar radiation absorption in the visible spectrum (PAR) by Chl and partly converted into heat
(all converted to heat in physical models)



solar radiation vertical penetration ↓



physical properties of the water column
e.g. temperature, salinity, density

STATE-OF-THE-ART

Chl = 0

Chl constant

Chl satellite

Chl from
biogeochemical model

1-way coupling (offline)

2-way coupling (online)

Effects of the Chl field on physical outputs

warms surface (+0.1-1.1°C), cools subsurface (-1°C)

(e.g. Manizza, et al 2005, Löptien, et al 2009)

reduction in MLD (< 5 m)

(e.g. Lengaigne, et al 2007, Skakala, et al 2022)

strengthening of the ocean current (2-4 cm/s)

(e.g. Lin, et al 2008, Ma, et al 2015)

Different Chl forcings

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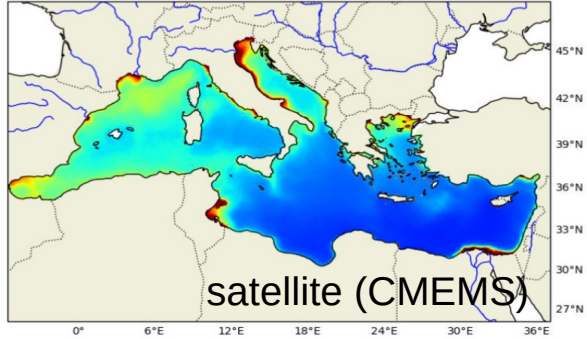
(e.g. Lengaigne, et al 2007, Skakala, et al 2022)

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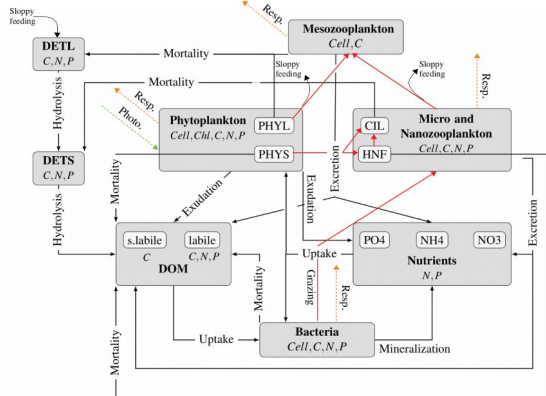
(e.g. Lin, et al 2008, Ma, et al 2015)

***No studies focusing on the Mediterranean yet.
Few studies on the entire water column.***

Objective: Impact of the Chl field used in the Mediterranean and throughout the water column on a decadal scale



OR



Biogeochemical model Eco3M-MED

(Baklouti et al. 2021)

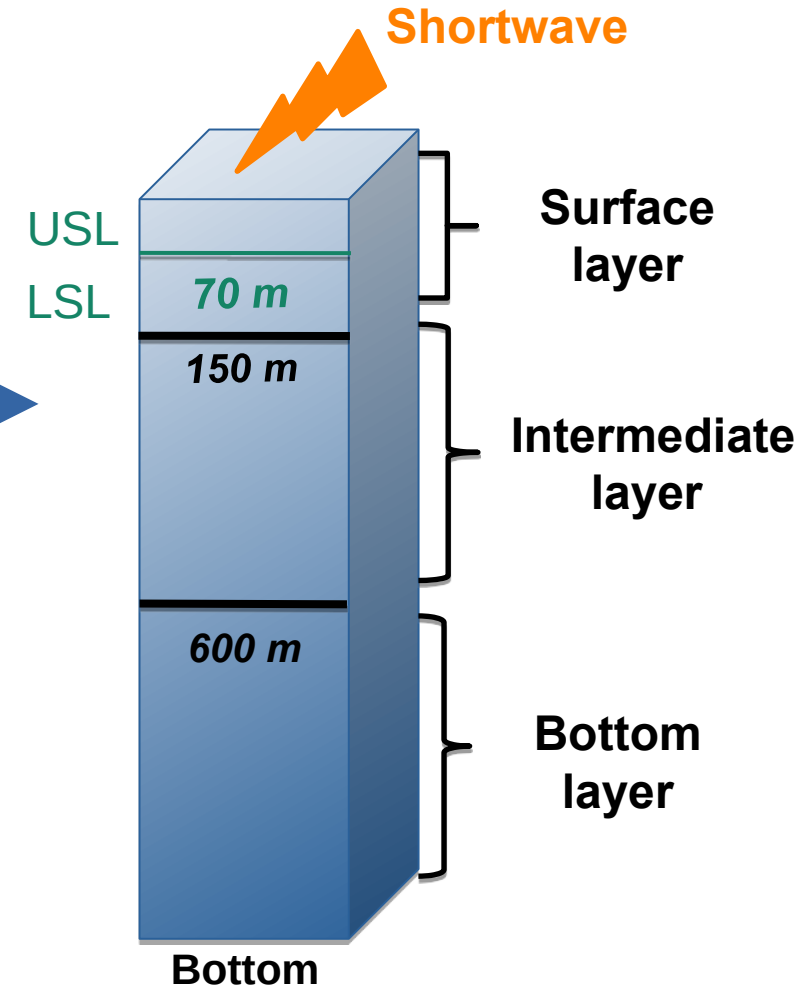
Chl fields

Temperature (T) in 4 layers

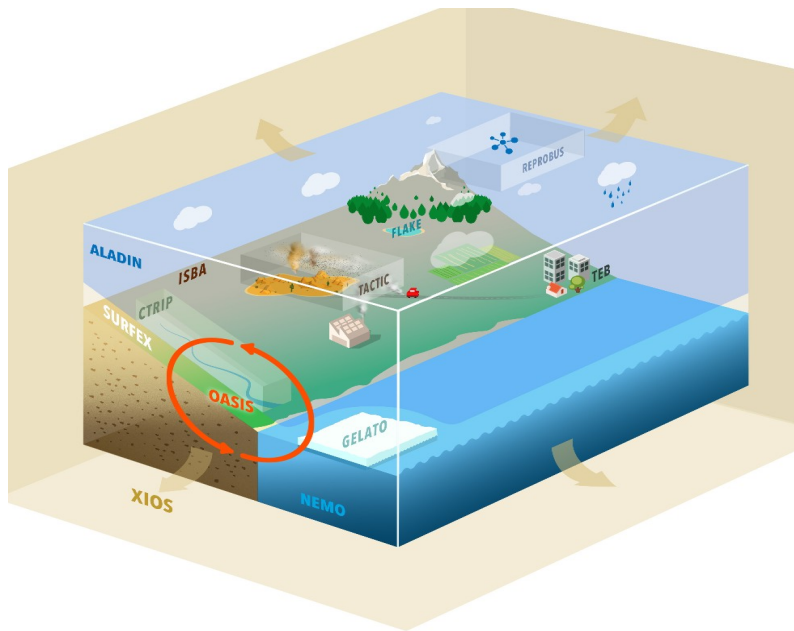
Mixed layer depth (MLD)
Stratification Index (SI)

**Ocean circulation model
NEMOMED12 (in RCSM6)**

(Beuvier et al., 2012 ; Madec et al., 2008)



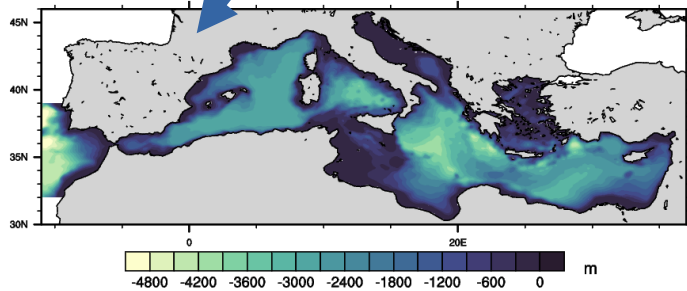
Chl field derived from the Eco3M-MED model



CNRM-RCSM6, improved from CNRM-RCSM4 (Sevault et al. 2014)

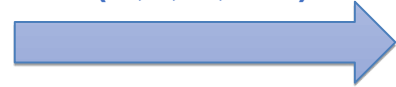
- Atmospheric model [**ALADIN climat**, Nabat et al., 2020]
- Externalised surface system [**SURFEX**, Voldoire et al., 2017]
- Hydrological model for continental surfaces [**ISBA-CTRIP**, Decharme et al., 2019]
- Ocean circulation model [**NEMOMED12**, Beuvier et al., 2012]
- Coupling library [**OASIS3-MCT**, Craig et al., 2017]

Bathymetry of NEMOMED12

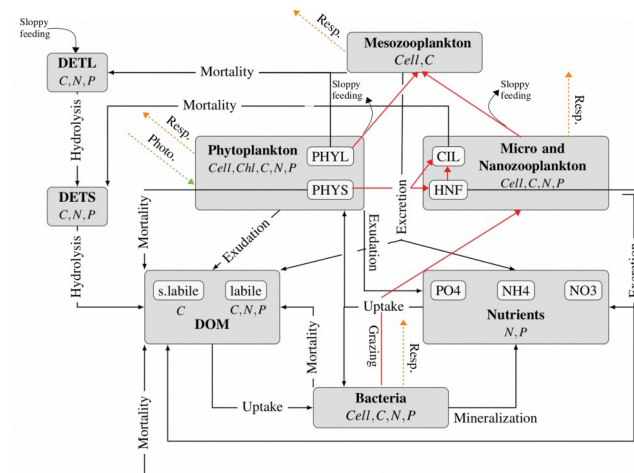


Ocean circulation model
NEMOMED12

Physical fields
(U,V,W, etc)



1-way coupling



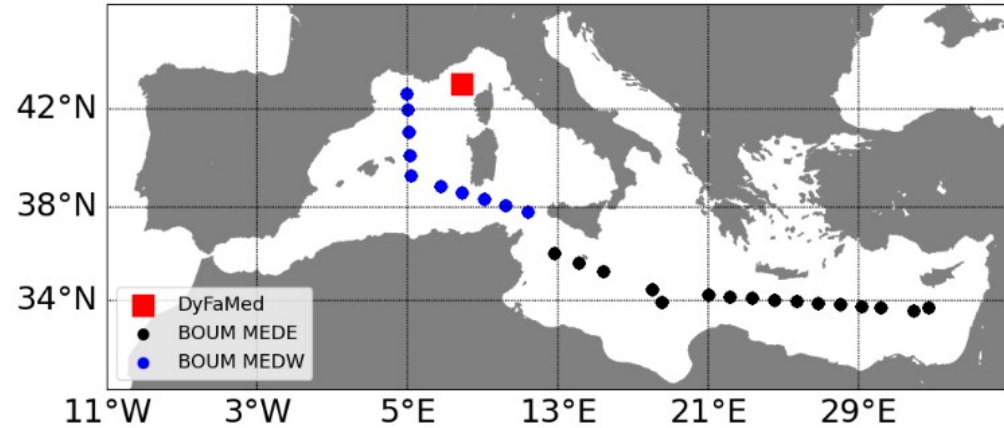
Biogeochemical model

Eco3M-MED (Baklouti et al. 2021)



Chl 3D
field

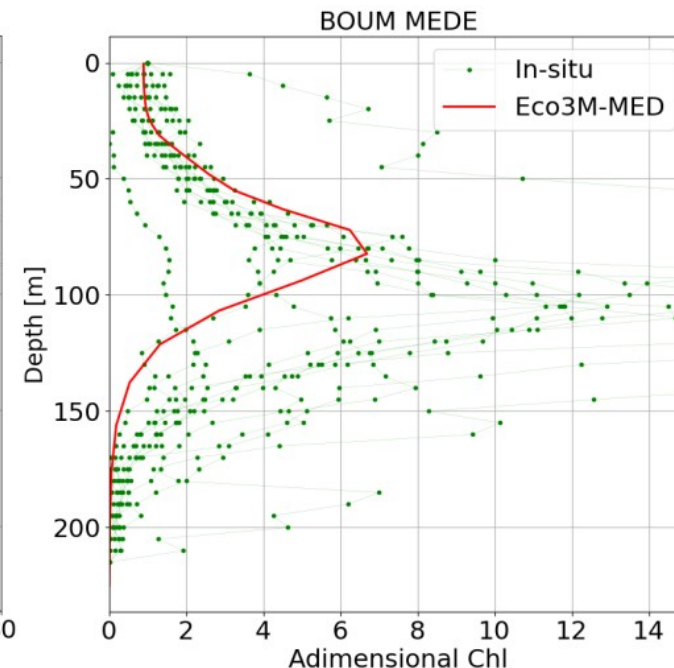
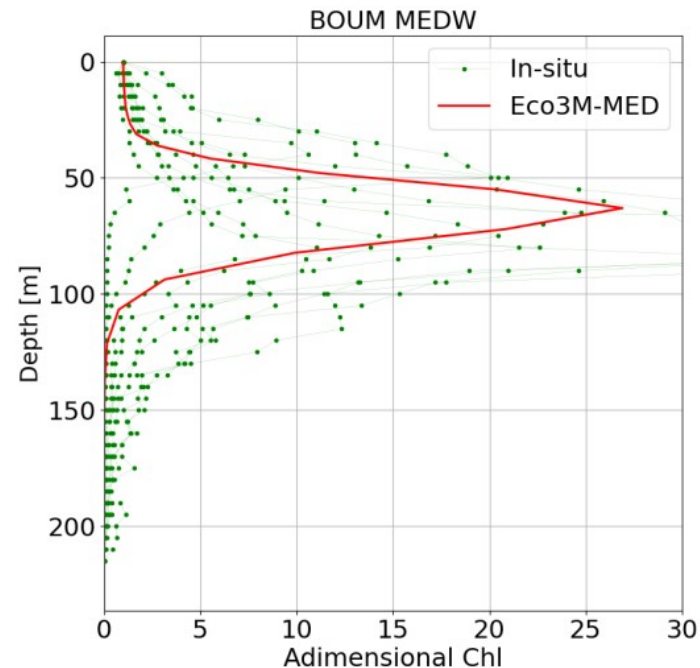
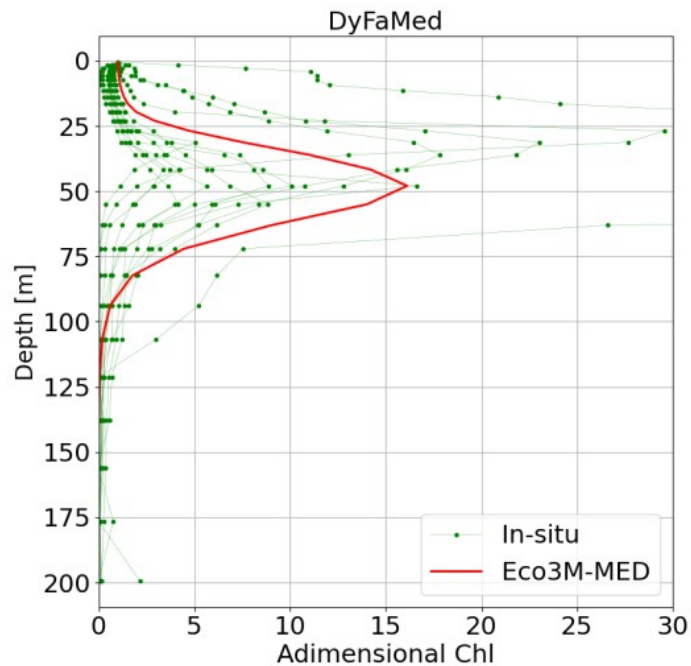
Comparison of the Eco3M-Med model Chl with in-situ data

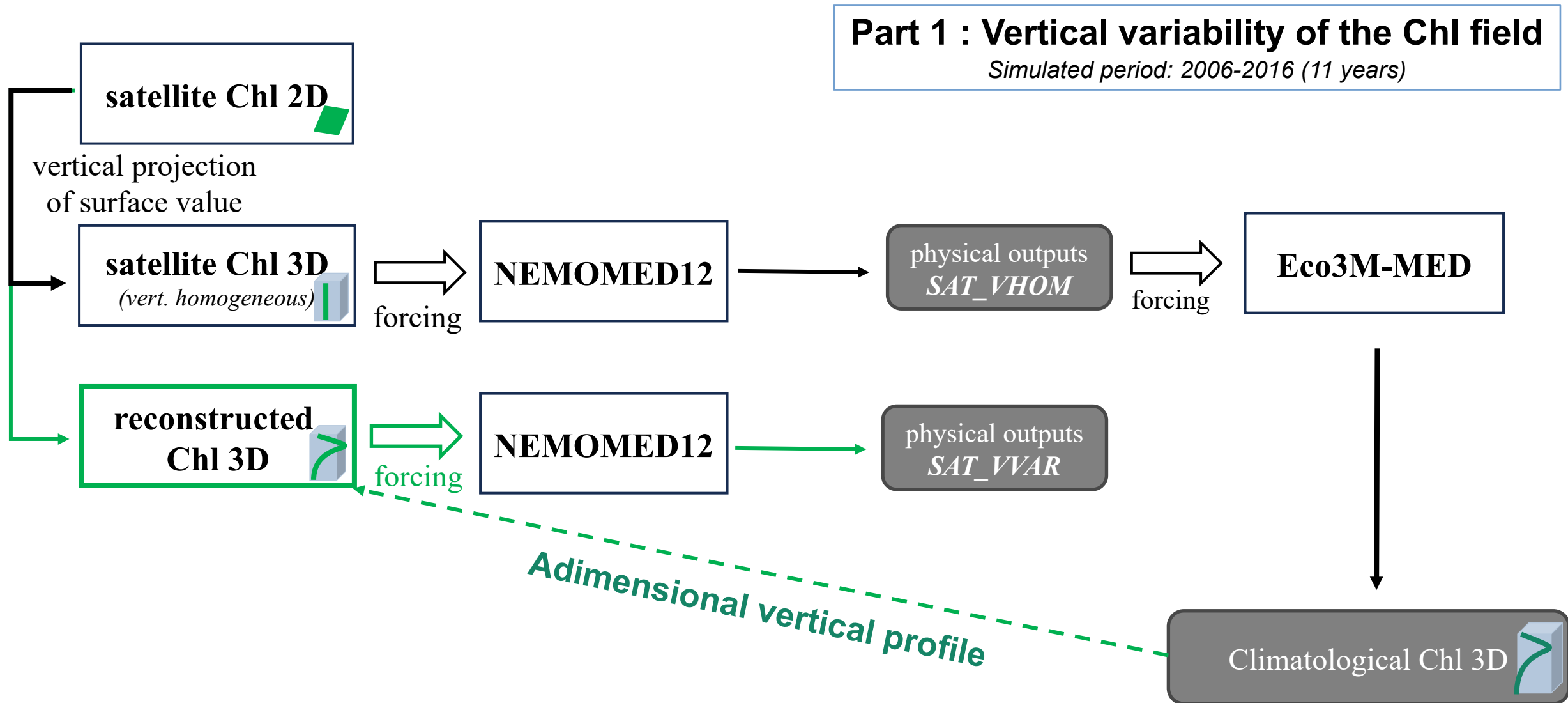


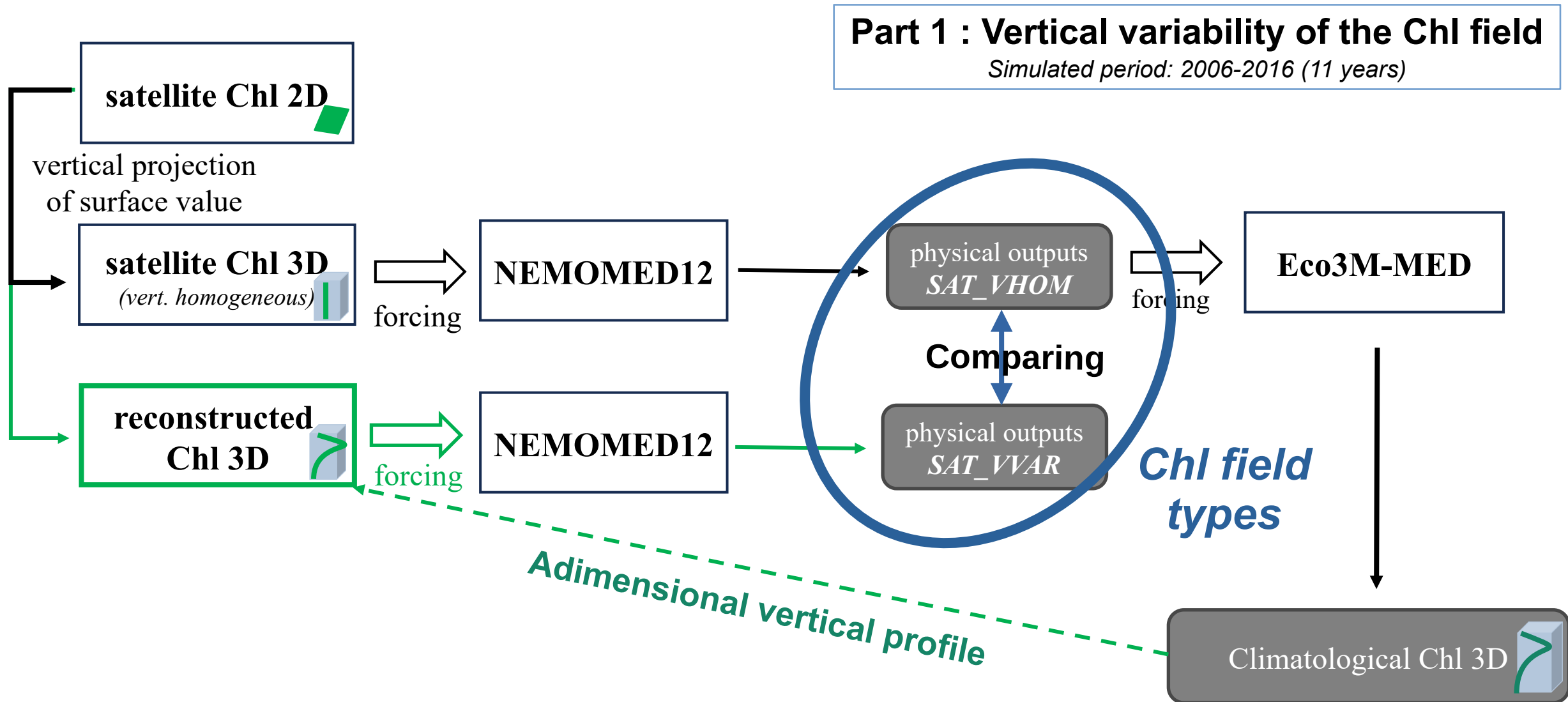
See also previous comparisons in Pagès et al. 2020 and Baklouti et al., 2021

Adimensional Chl vertical profile
= vertical profile / surface value

The Eco3M-Med model can be used to represent the vertical variability of Chl in time and space



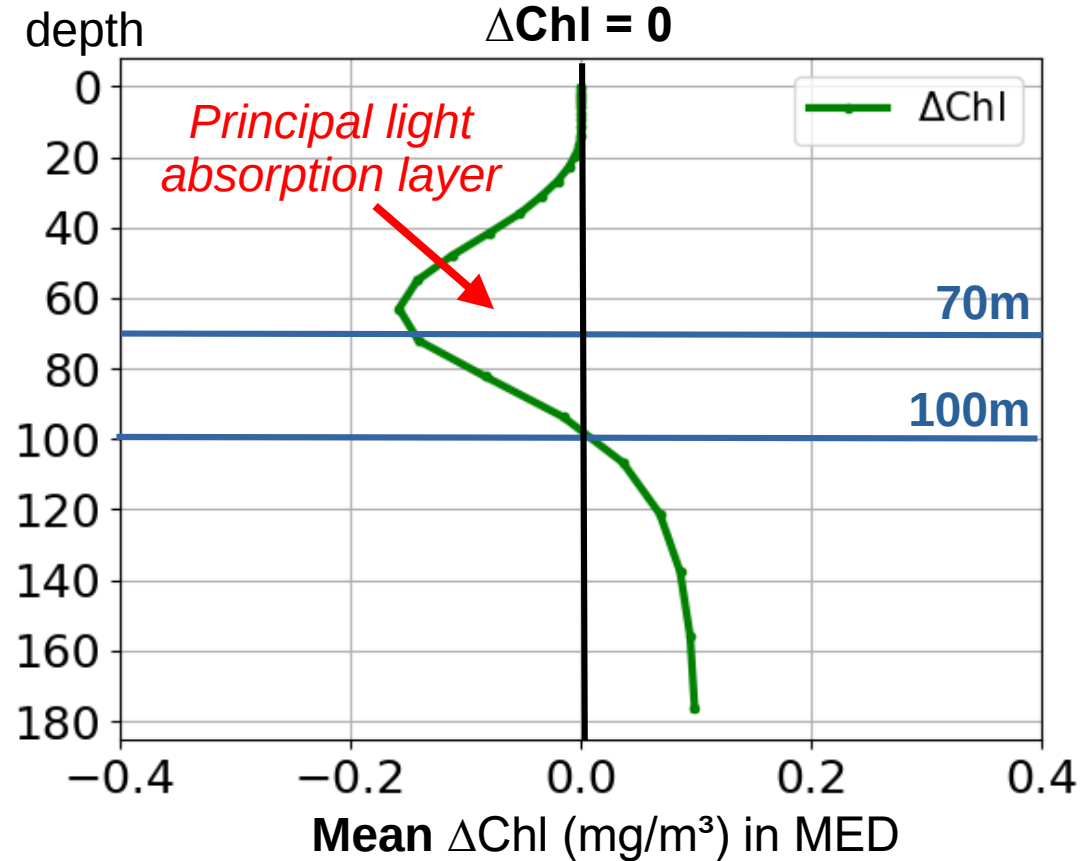




Comparison of the two Chl fields (Difference in cumulative Chl over one year)

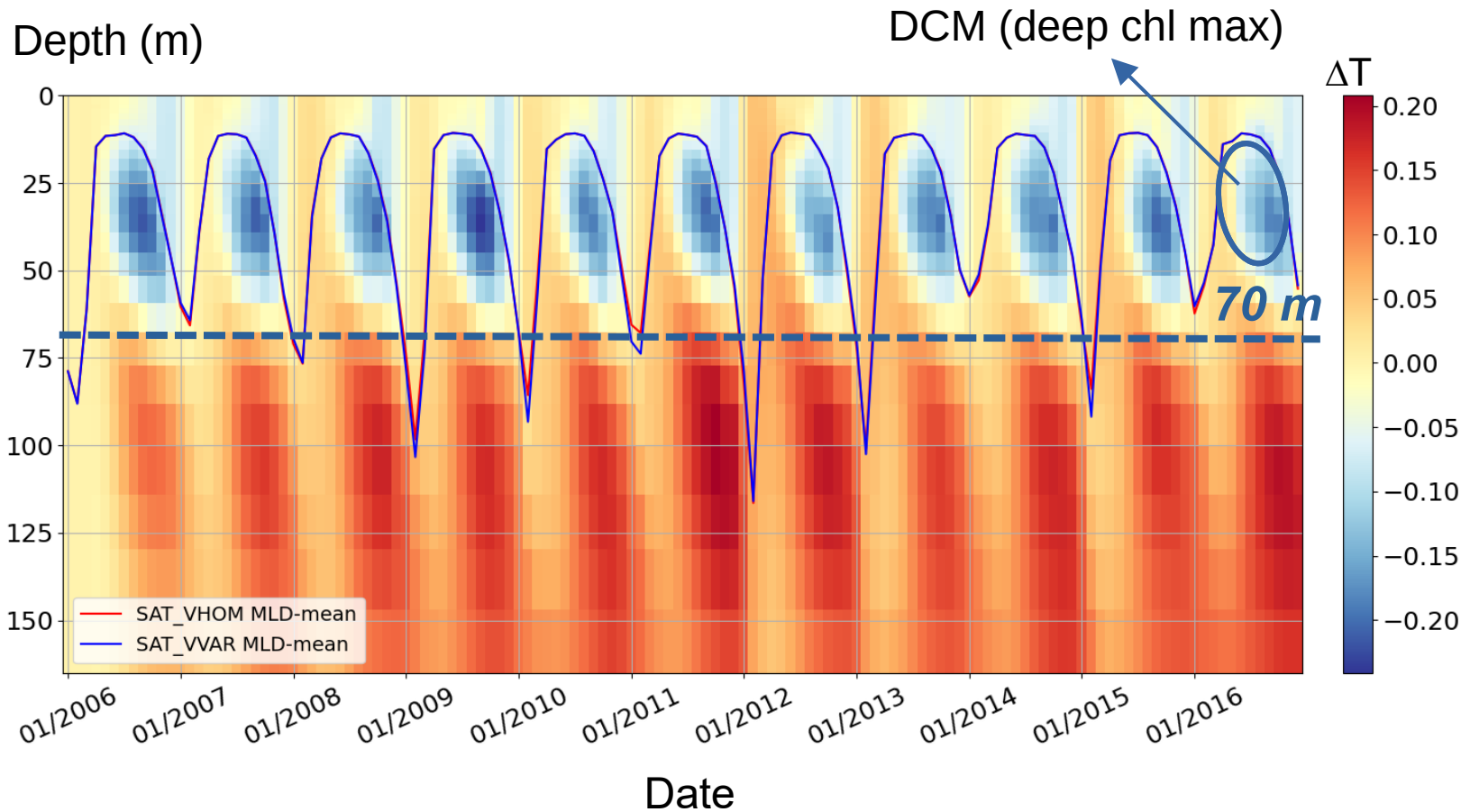
$$\text{relative } \Delta\text{Chl} = (\text{Chl (SAT_VHOM)} - \text{Chl (SAT_VVAR)}) / \text{Chl (SAT_VHOM)}$$

sub-bassins layers	MED
relative ΔChl 0-70m	-66.2%
relative ΔChl 70-150m	36.4%
relative ΔChl 150-600m	98.8%



more Chl in SAT_VHOM below ~ 100m

Surface layer



Upper surface layer (0-70m): *seasonality*

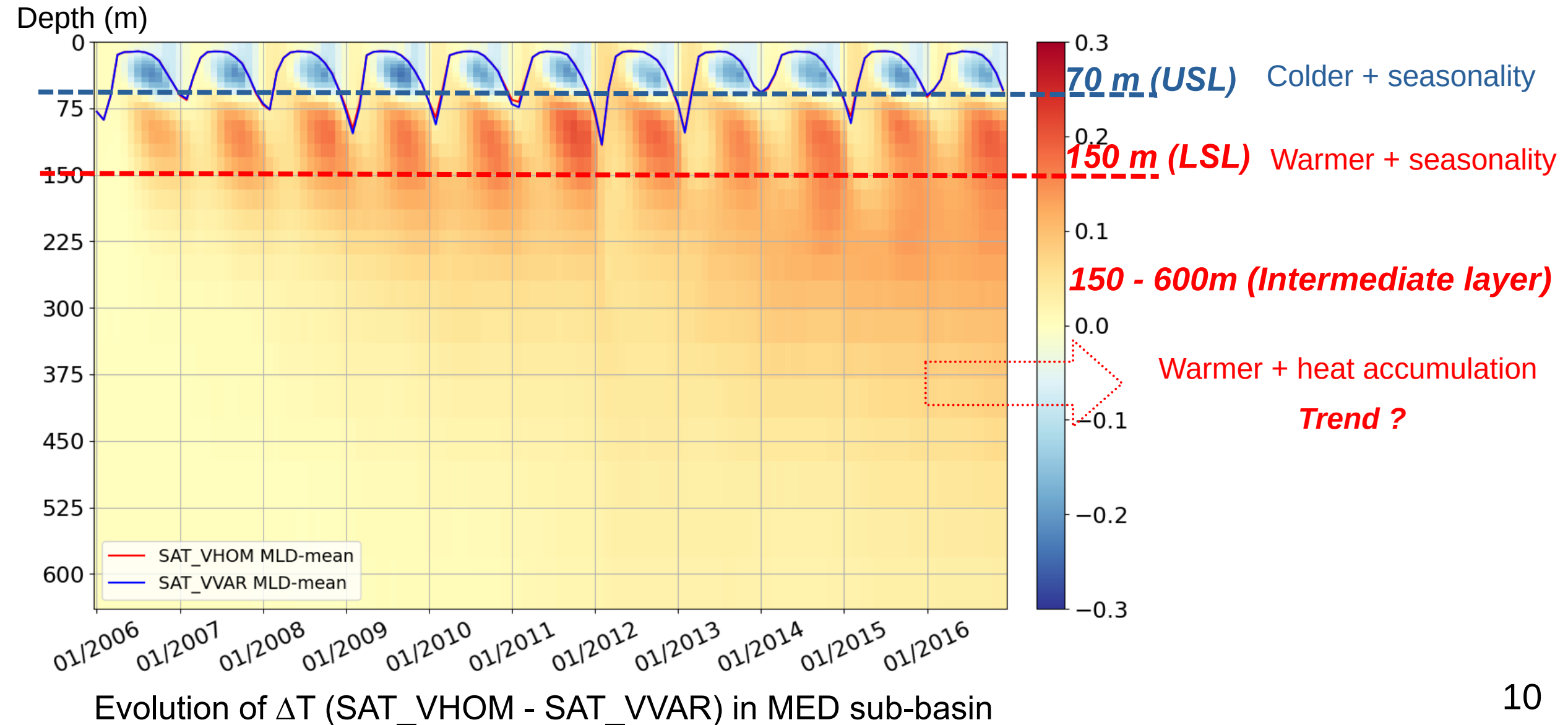
Less Chl in SAT_VHOM \Rightarrow **colder**
Strongly controlled by winter mixing

Lower surface layer (70-150m): *seasonality + heat accumulation*

\rightarrow More residual energy arrive in
SAT_VHOM + More Chl \Rightarrow **warmer**
 \rightarrow Less impacted by winter mixing (under
mean MLD) \Rightarrow **heat accumulation**

Evolution of ΔT (SAT_VHOM - SAT_VVAR) in MED sub-basin

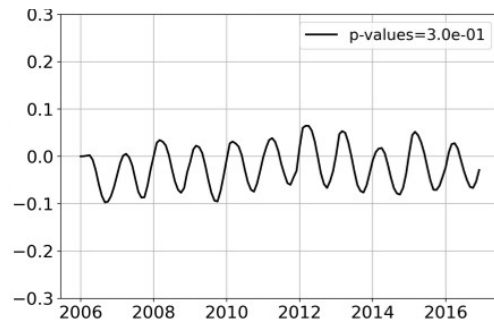
$\Delta T = T(\text{SAT_VHOM}) - T(\text{SAT_VVAR})$ over the entire water column



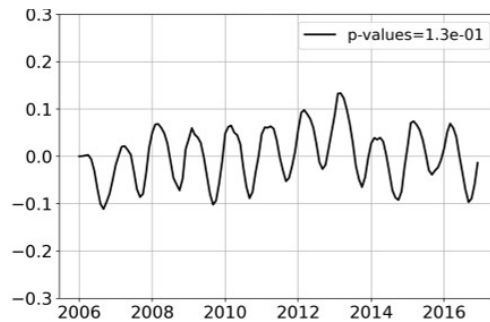
— ΔT
 - - - Trend
 (checked by Mann-Kendall test)

ΔT 0-70m

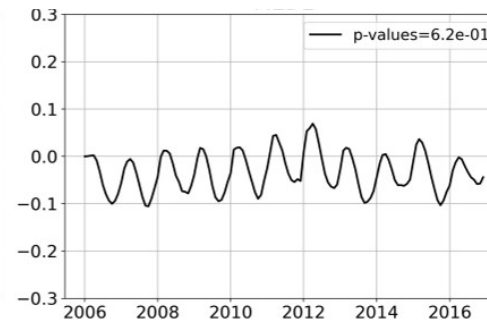
MED



MEDW

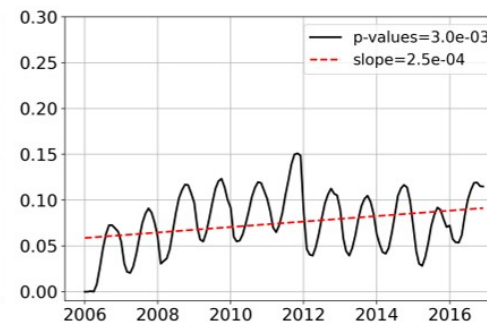
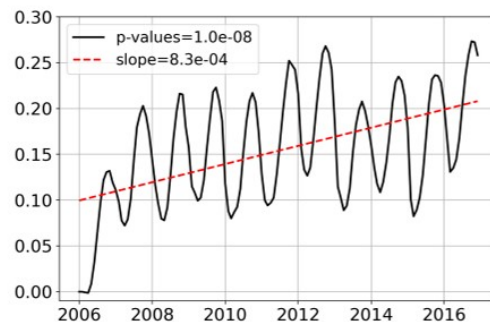
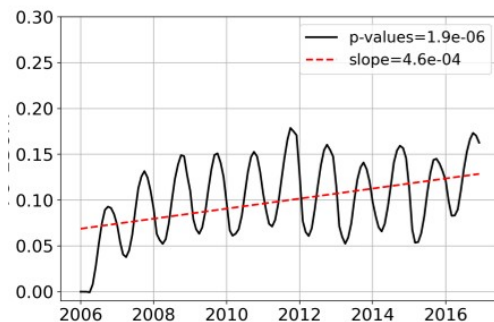


MEDE



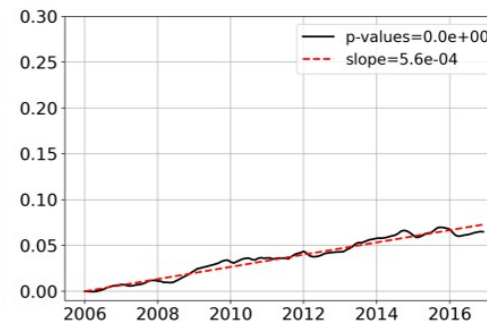
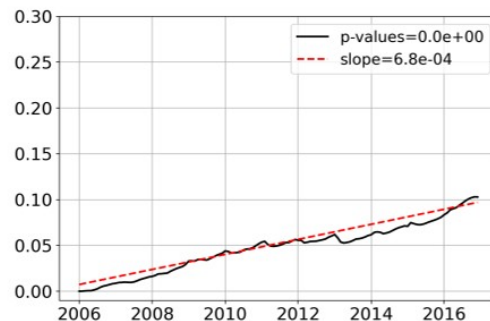
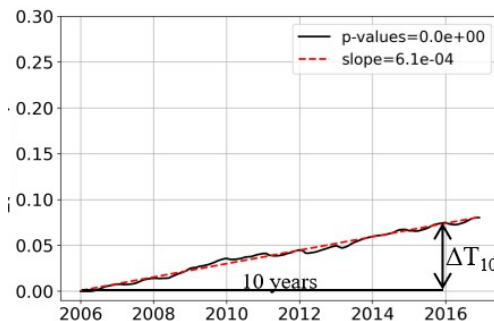
No trend ×

ΔT 70-150m



With trend ✓

ΔT 150-600m

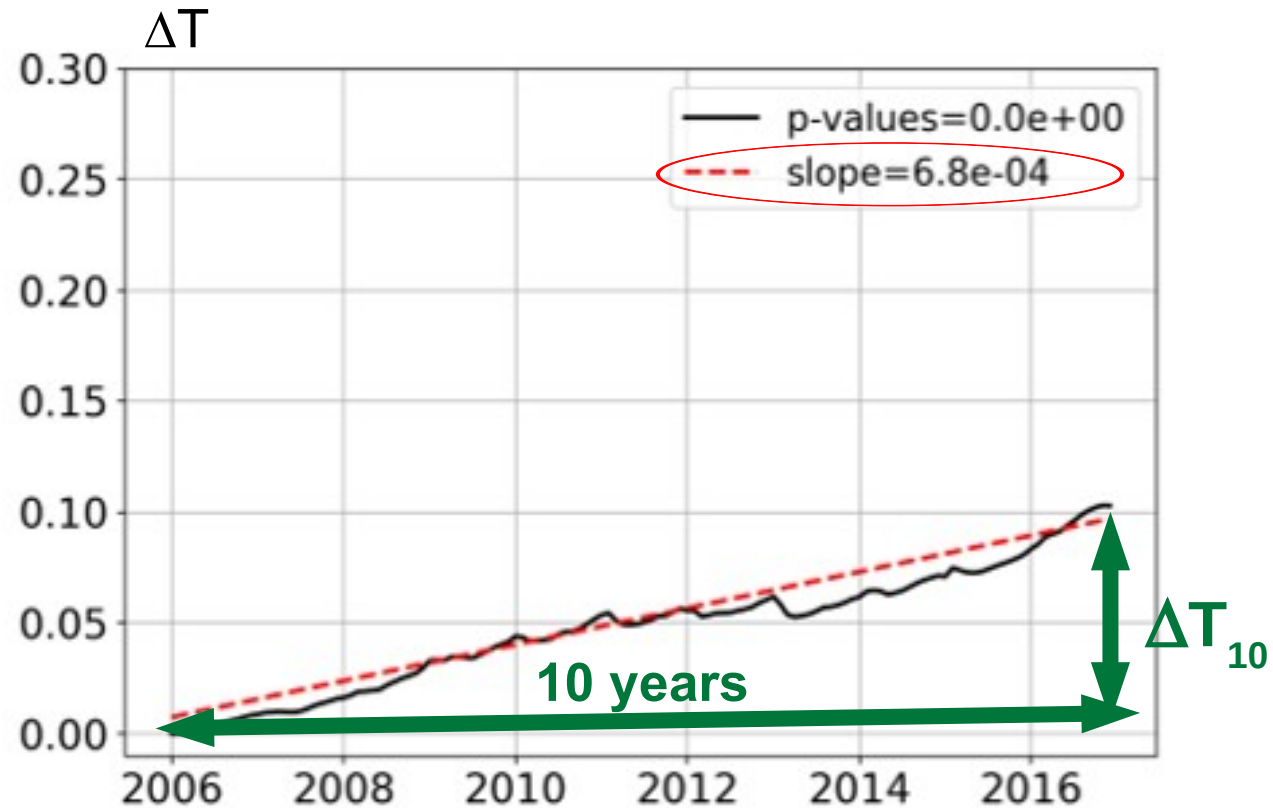


With trend ✓

Date

Two components: interannual trend + seasonal oscillation (+ residual)

Representation of the trend by ΔT_{10}



$$\text{※ } \Delta T = T(\text{SAT_VHOM}) - T(\text{SAT_VVAR})$$

※ ΔT_{10} = Average difference in T after 10 years, devried from the trend in ΔT

Trends (ΔT_{10}) in the difference between SAT_VHOM and SAT_VVAR (SAT_VHOM - SAT_VVAR)

sub-bassins Layers	MED	MEDW	MEDE	MEDNW
ΔT_{10} 0-70m	no trend	no trend	no trend	no trend
ΔT_{10} 70-150m	0.05°C	0.1°C	0.03°C	0.08°C
ΔT_{10} 150-600m	0.07°C	0.08°C	0.07°C	0.06°C
ΔT_{10} 600m-BOT	-0.0003°C	0.0001°C	-0.0002°C	0.004°C

※ Differences in heat absorption by Chl in 0-70m leads to ΔT trend in the deeper layers

※ Very weak in bottom layer (negligible)

Trends (ΔT_{10}) in the difference between SAT_VHOM and SAT_VVAR (SAT_VHOM - SAT_VVAR)

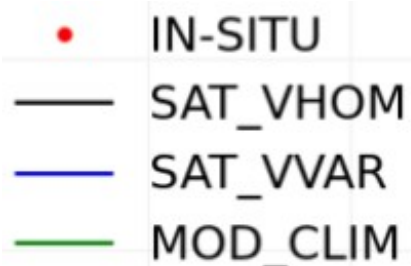
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ΔT_{10} 600m-BOT	-0.0003°C	0.0001°C	-0.0002°C	0.004°C

※ | ΔT_{10} | **max** < 0.1°C (max value in 70-150m layer), which seems negligible **BUT** :

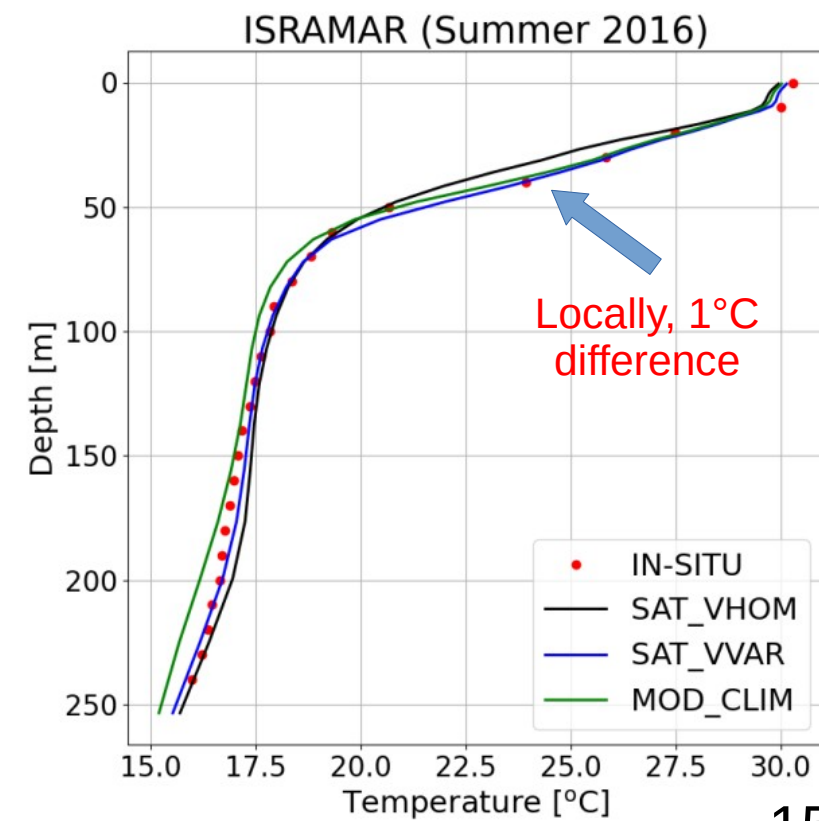
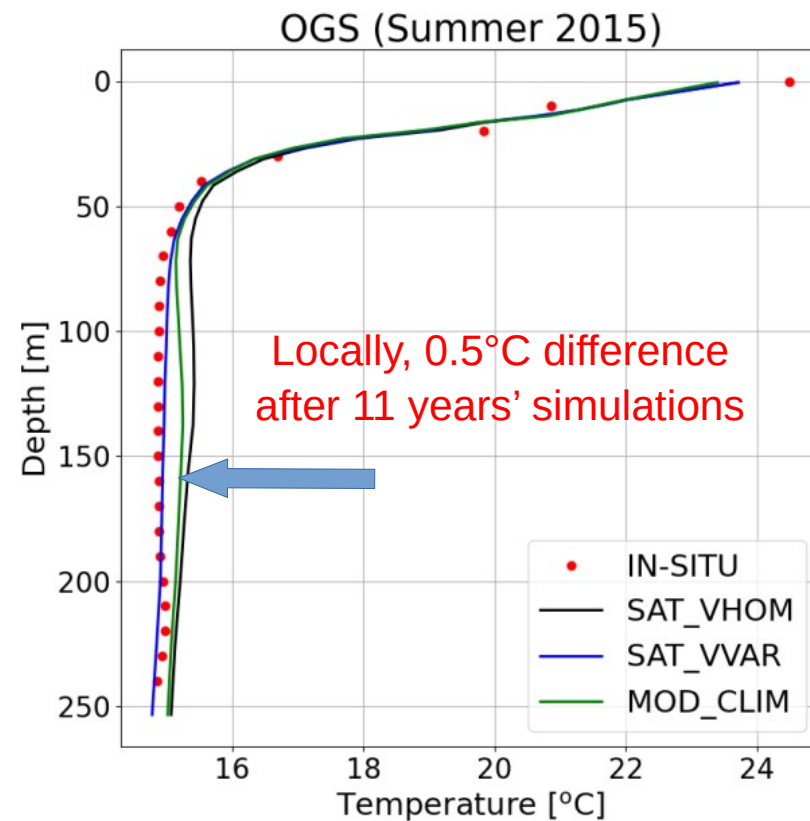
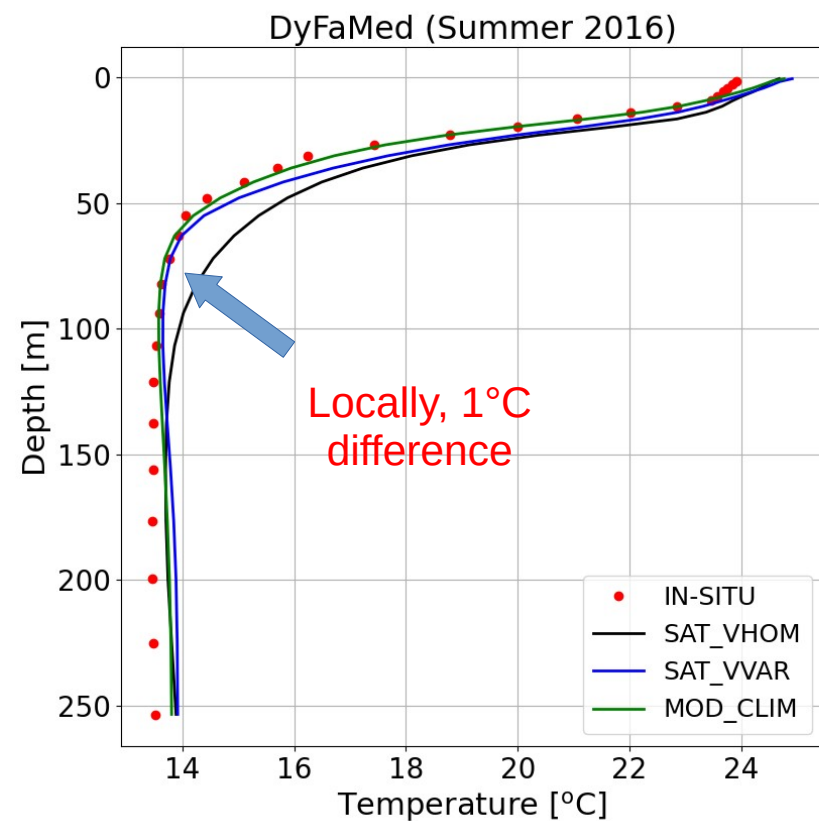
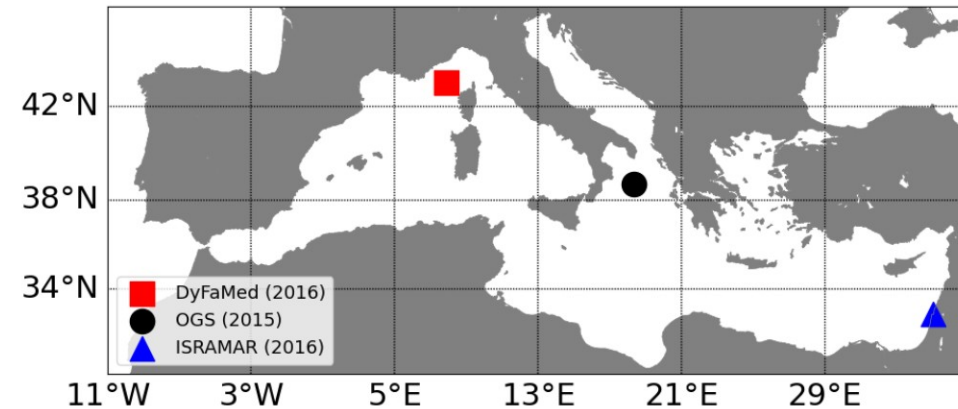
→ becomes significant on the scale of a climate projection (if the trend remains the same)

→ ΔT can be locally and ponctually higher (e.g. in summer)

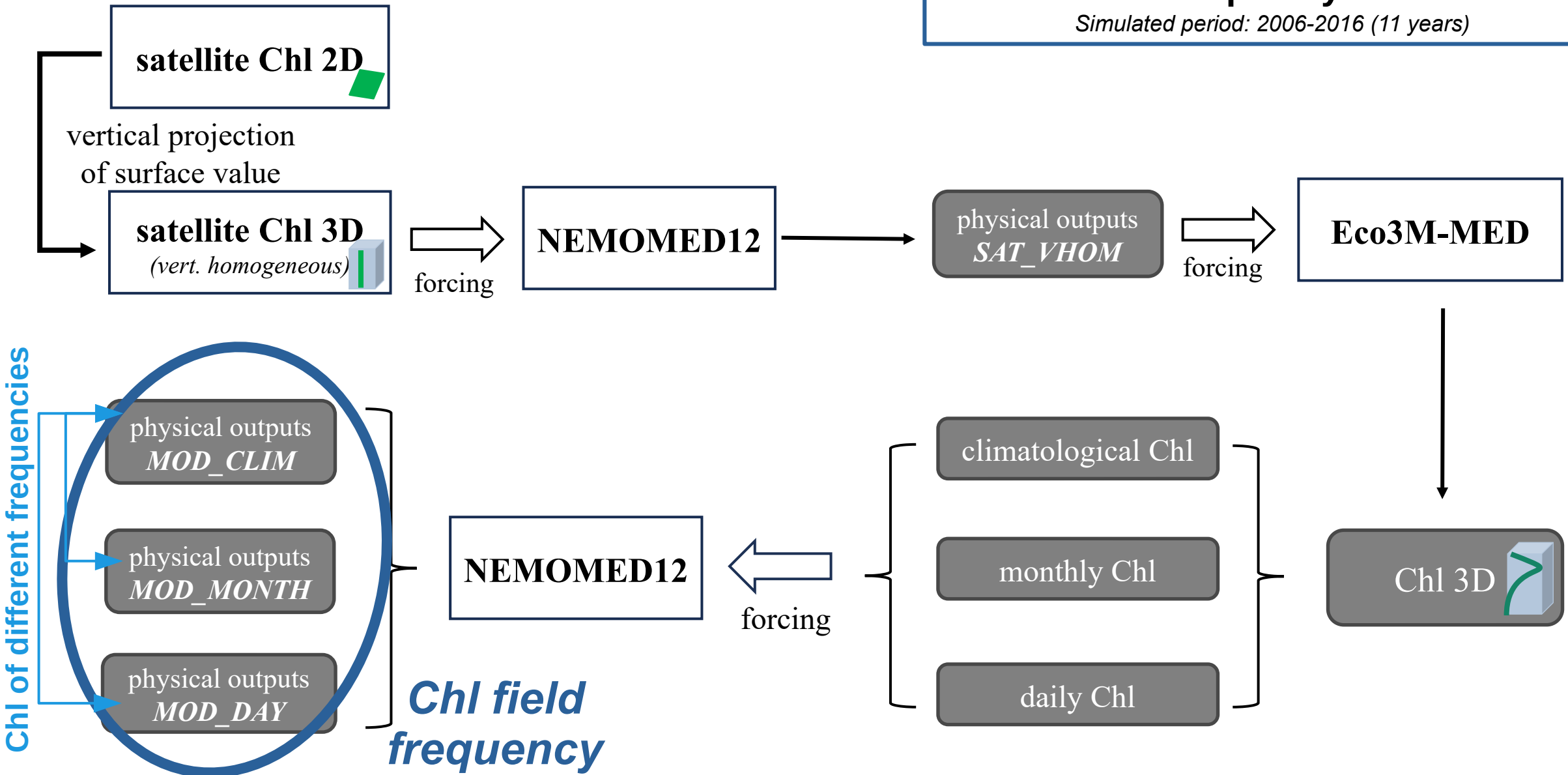
Comparison of temperature with *in-situ* data



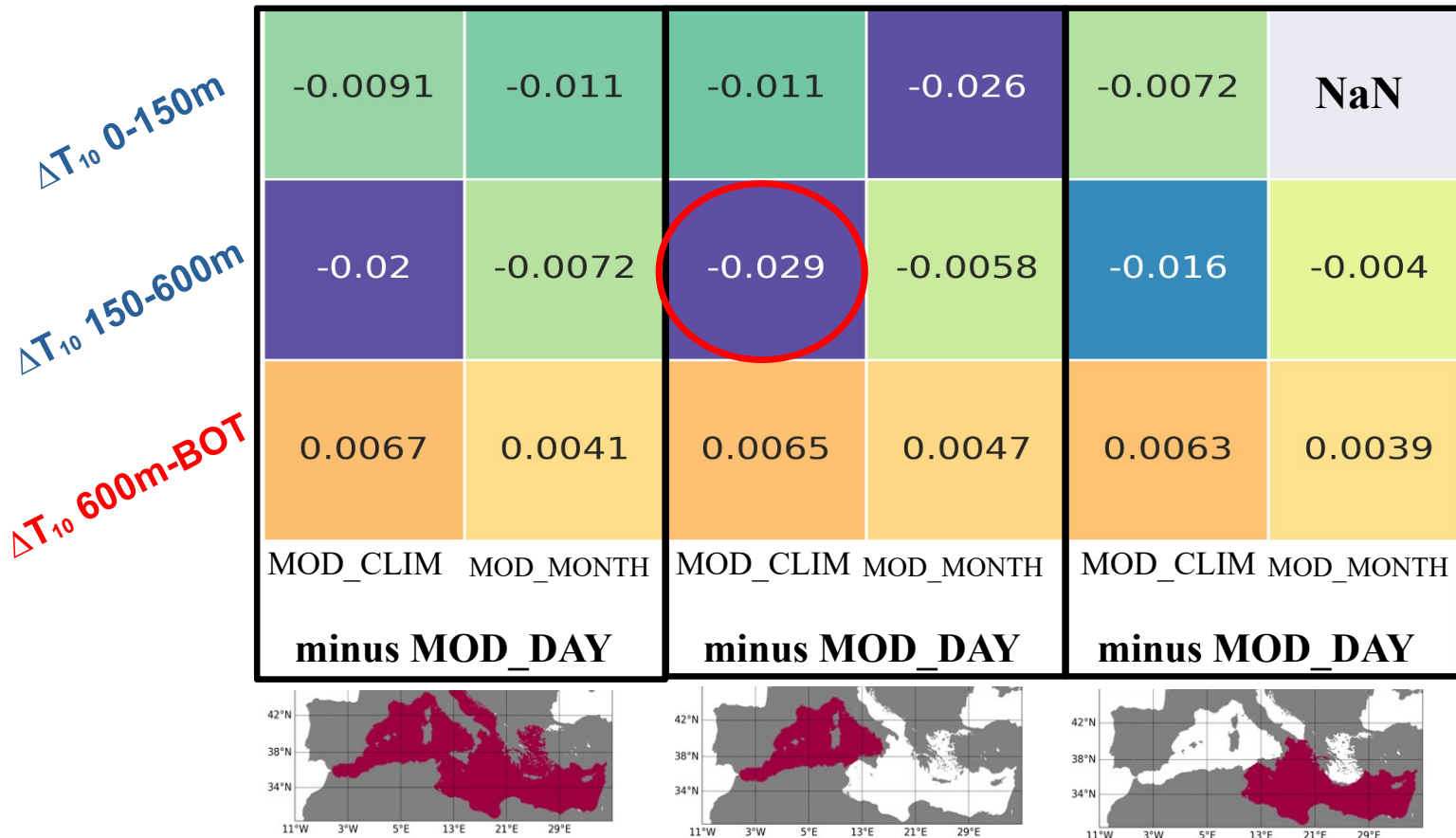
⇒ *easily avoidable bias with VVAR*



Part 2 : Time frequency of the Chl field
Simulated period: 2006-2016 (11 years)



Summary of trends (ΔT_{10})



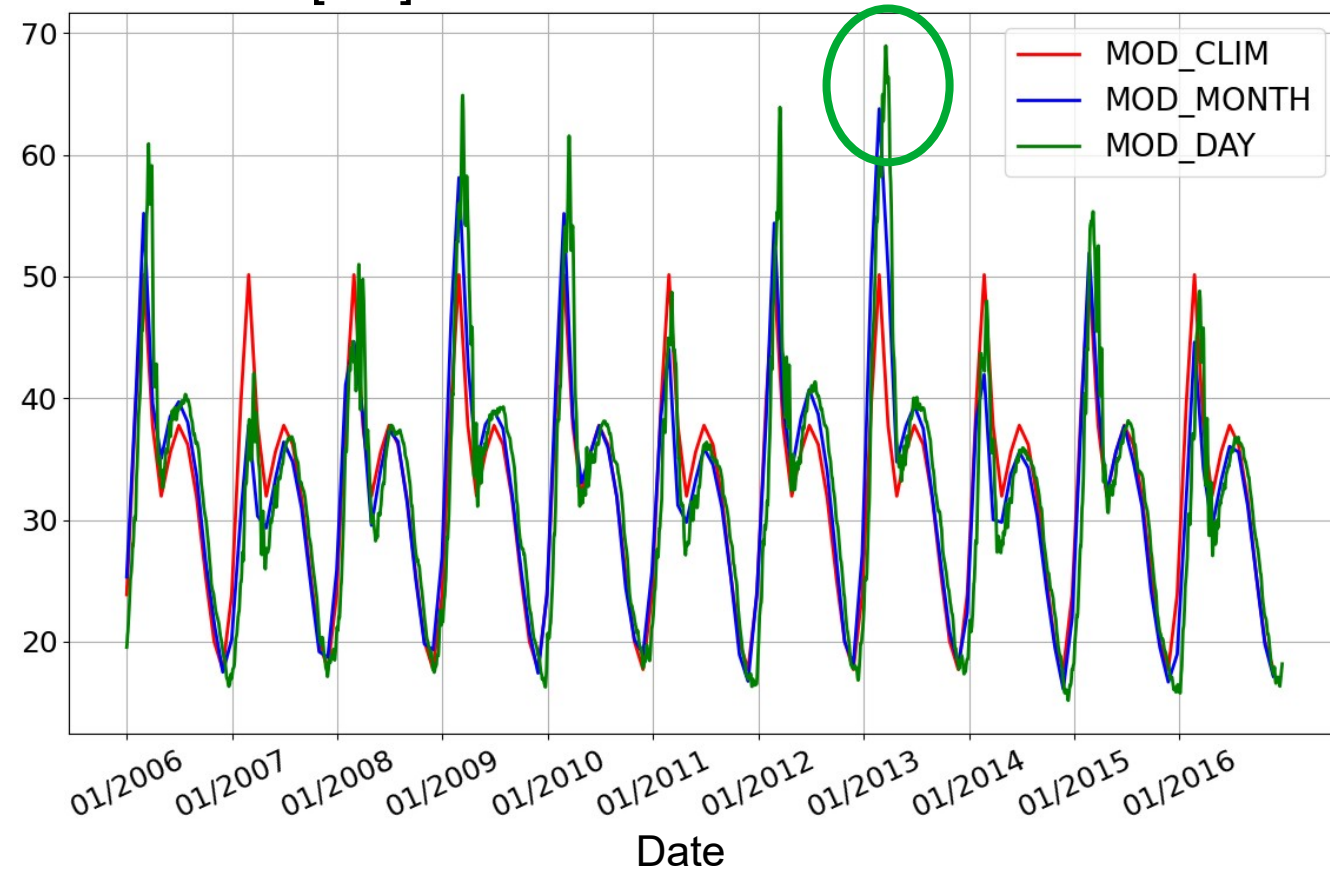
※ $|\Delta T_{10}| \text{ max} < 0.03^\circ\text{C}$

※ T of **MOD_DAY** is increasingly **higher** in surface and intermediate layers

ΔT_{10} of MOD_CLIM - MOD_DAY (left)
 ΔT_{10} of MOD_MONTH - MOD_DAY (right)
 NaN : No trend

Why MOD_DAY is warmer in the surface layers?

Chl 0-150m [ton]



※ same total amount of Chl read by model

※ smoother Chl for **MOD_CLIM**

※ Chl peak amplitude greater for **MOD_DAY**

Chl quantity "read by the model" in the 0-150m layer in MED

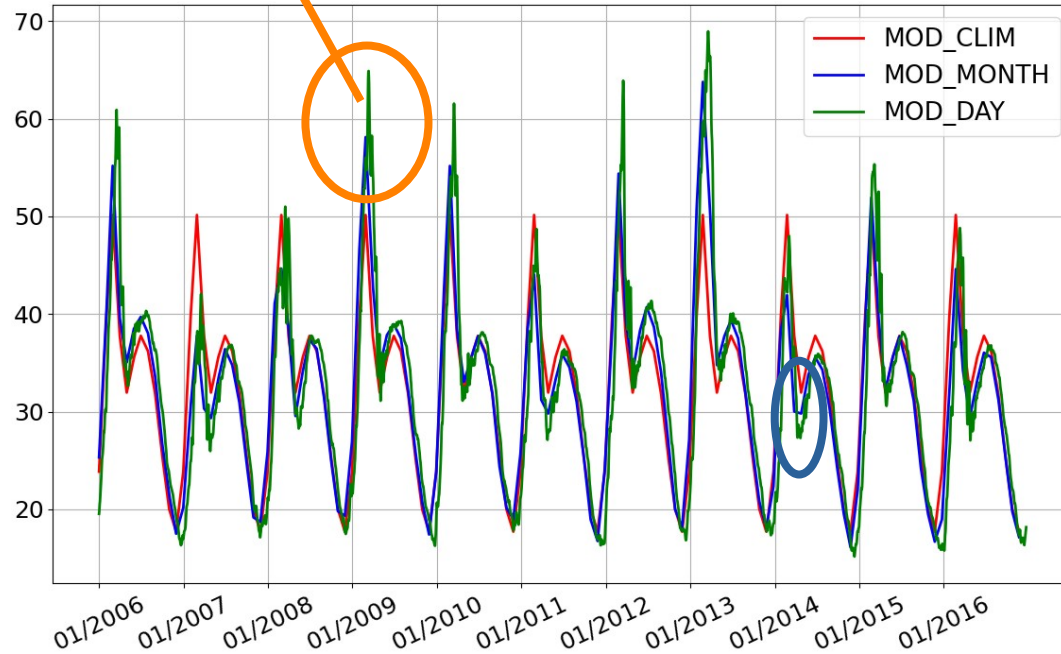
Chl max peak of
MOD_DAY

ΔT negative at
surface
(MOD_DAY warmer)

shallower solar
radiation
penetration

Excess heat **remains** on
the surface and/or is
vented to the atmosphere

Chl 0-150m [ton]



$$\Delta T = (\text{MOD_CLIM} / \text{MOD_MONTH}) \text{ minus } \text{MOD_DAY}$$

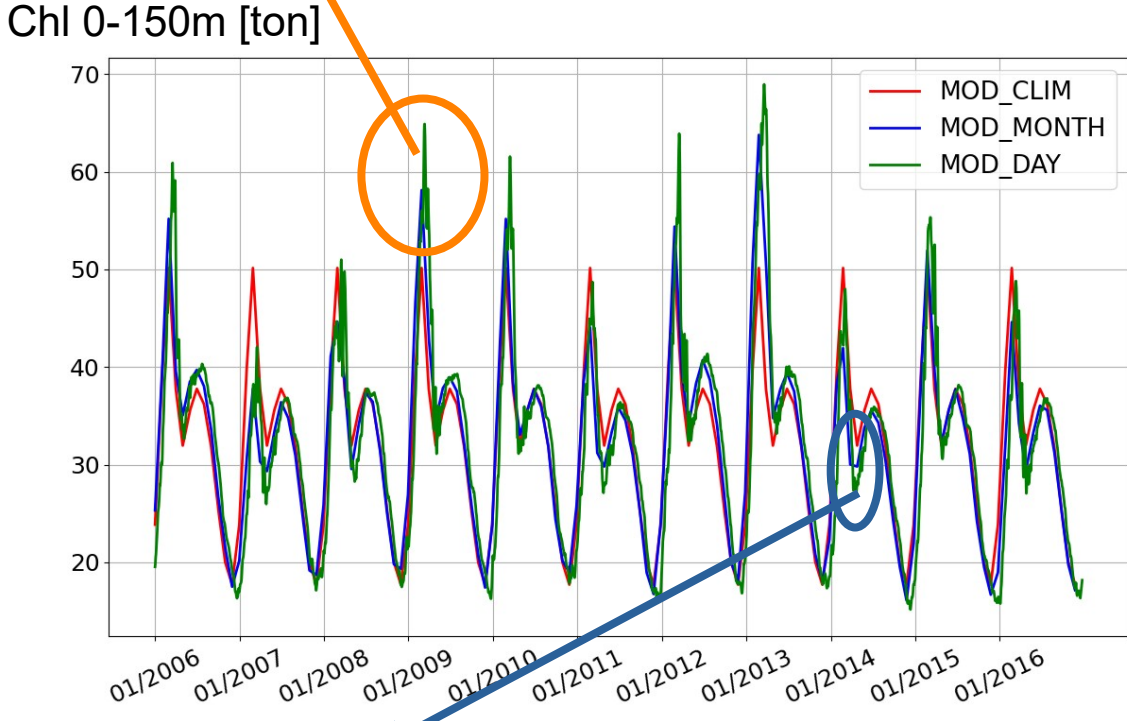
**Asymmetry of the effect of
min/max Chl**

Chl max peak of MOD_DAY

ΔT negative at surface (MOD_DAY warmer)

shallower solar radiation penetration

Excess heat **remains** on the surface and/or is vented to the atmosphere



$$\Delta T = (\text{MOD_CLIM} / \text{MOD_MONTH}) \text{ minus } \text{MOD_DAY}$$

Asymmetry of the effect of min/max Chl

Chl min peak of MOD_DAY

ΔT positive at surface (MOD_DAY colder)

deeper solar radiation penetration

Excess heat stored in the intermediate layer for MOD_DAY

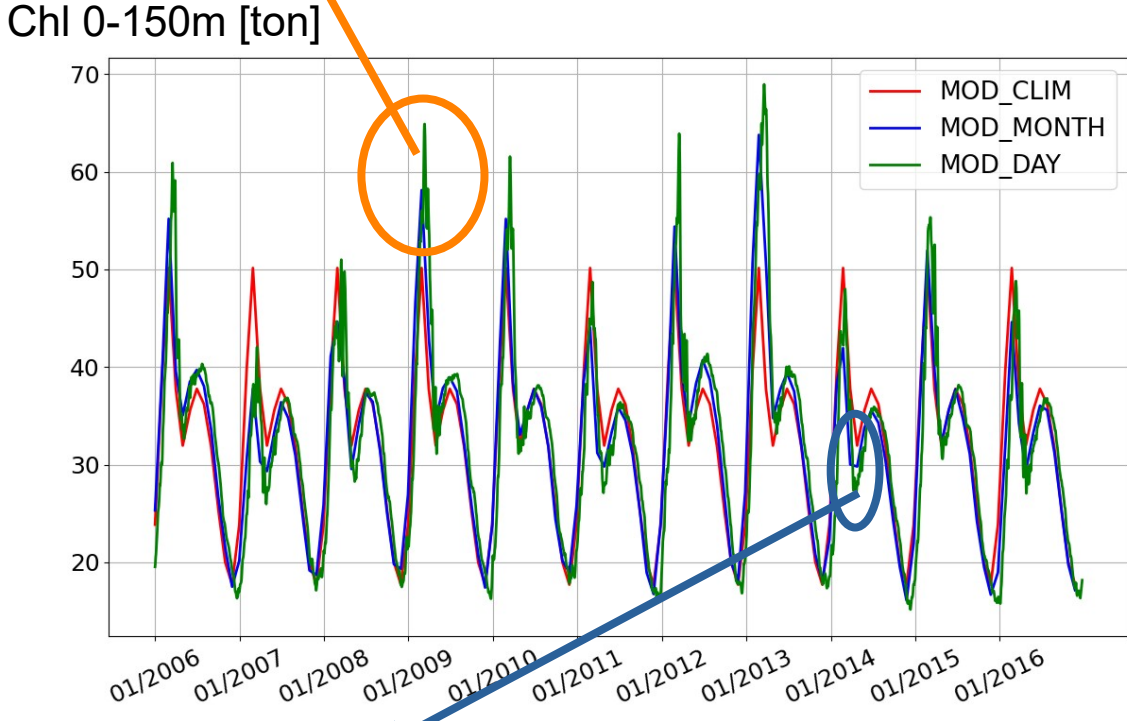
Trend

Chl max peak of MOD_DAY

ΔT negative at surface (MOD_DAY warmer)

shallower solar radiation penetration

Excess heat **remains** on the surface and/or is vented to the atmosphere



$$\Delta T = (\text{MOD_CLIM} / \text{MOD_MONTH}) \text{ minus } \text{MOD_DAY}$$

Asymmetry of the effect of min/max Chl

To be validated with a longer-term climate projection

Trend

Chl min peak of MOD_DAY

ΔT positive at surface (MOD_DAY colder)

deeper solar radiation penetration

Excess heat stored in the intermediate layer for MOD_DAY

Take Home Messages

- ※ Using of a **vertically homogeneous Chl field** results in :
 - errors in temperature that can be significant ($> 1^{\circ}\text{C}$) from time to time or locally
 - a temperature bias in the lower surface and intermediate layers, which becomes increasingly significant over time, reaching up to **1°C** on the scale of a climate projection (100 years).
- ※ The introduction of a **realistic vertical profile of Chl varying monthly** (*here provided by the Eco3M-MED model*) improves the temperature profile in the layers most affected by the concentration of Chl.
- ※ The **asymmetrical role** of Chl extremes is the reason proposed for the warmer temperatures in the simulation forced by the **daily Chl field** compared with those forced by climatological or monthly Chl fields.

Thank you for listening !

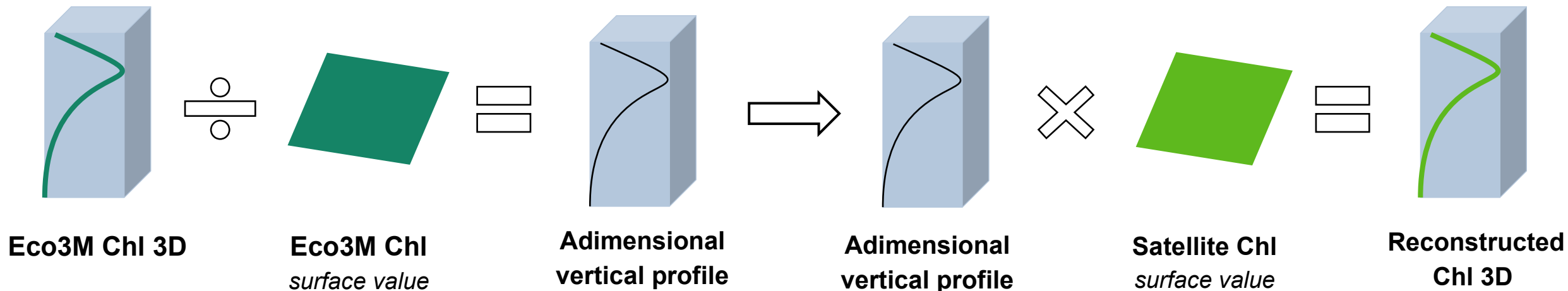
Acknowledgment

- ✂ This study was made possible through the funding of the M2 internship of Yutong Zhang by the OCEAN SCIENCES Institute.
- ✂ This study is also a contribution to the MEDIATION project funded by the French Government "France 2030" program of the French National Research Agency (ANR) through the PPR-OCEAN project (no ANR-22-POCE-0003).
- ✂ We acknowledge the MOOSE program (Mediterranean Ocean Observing System for the Environment) coordinated by CNRS-INSU and the Research Infrastructure ILICO (CNRS-IFREMER).
- ✂ We would also like to acknowledge the E.U. Copernicus Marine Service Information for providing access to ocean colour satellite data, and the PERSEUS project (Policy-oriented Marine Environmental Research for the Southern European Seas) for providing access to the *in-situ* temperature and chlorophyll databases in the Mediterranean.

Data source : DyFaMed (Coppola et al., 2023) are available : <https://www.seanoe.org/data/00326/43749/> , cruise data in the Ionian Sea during June 2015 provided by OGS (<https://www.ogs.it/en>), cruise data during July 2016 along the southeastern coast, provided by ISRAMAR (<https://www.ocean.org.il/en/>)

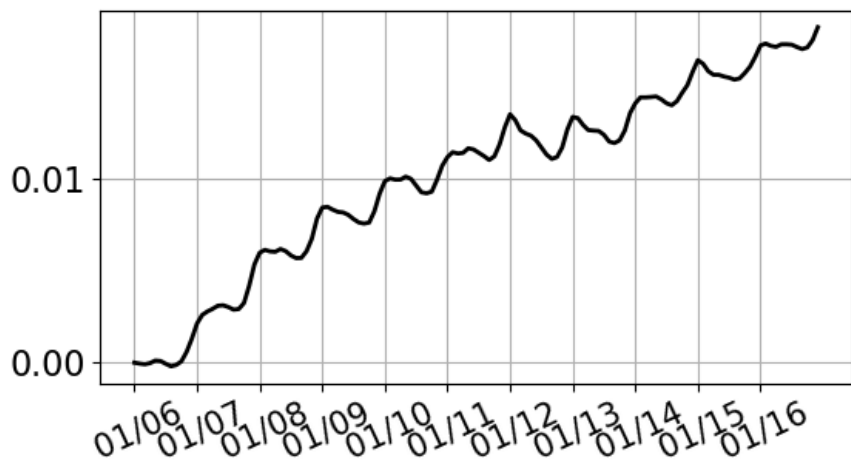
Chl 3D

Details on the reconstructed Chl 3D:



* Reconstructed Chl 3D combining both the vertical profile of the model, and satellite Chl at the surface

Study of seasonal variability

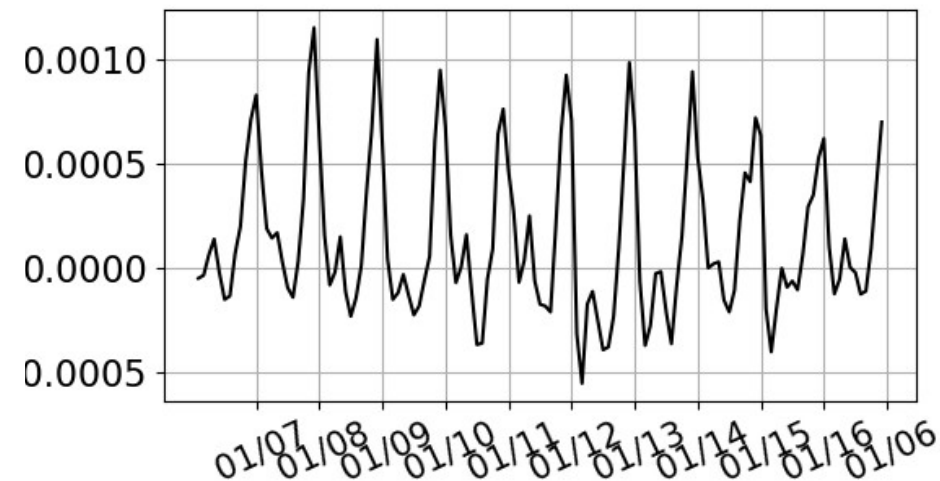


ΔT : Trend + Seasonality + Residual



**Differentiation
of order 1**

$$\tilde{X}_t = \nabla X_t = X_t - X_{t-1}$$



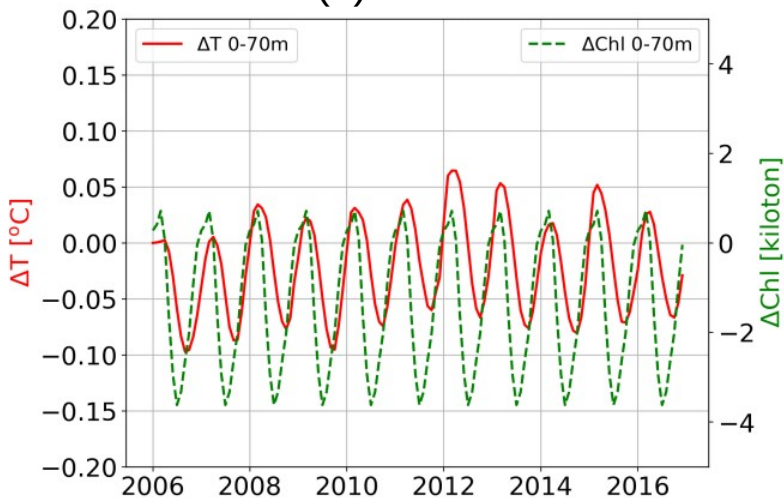
$\Delta \tilde{T}$: TSeasonality + Residual

$$\Delta T = T(\text{SAT_VHOM}) - T(\text{SAT_VVAR})$$

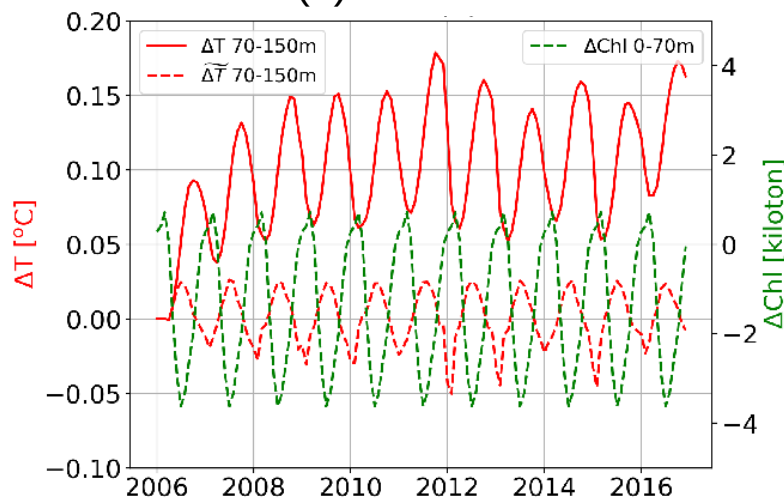
$\Delta \tilde{T}$: seasonal component of ΔT

Appendix

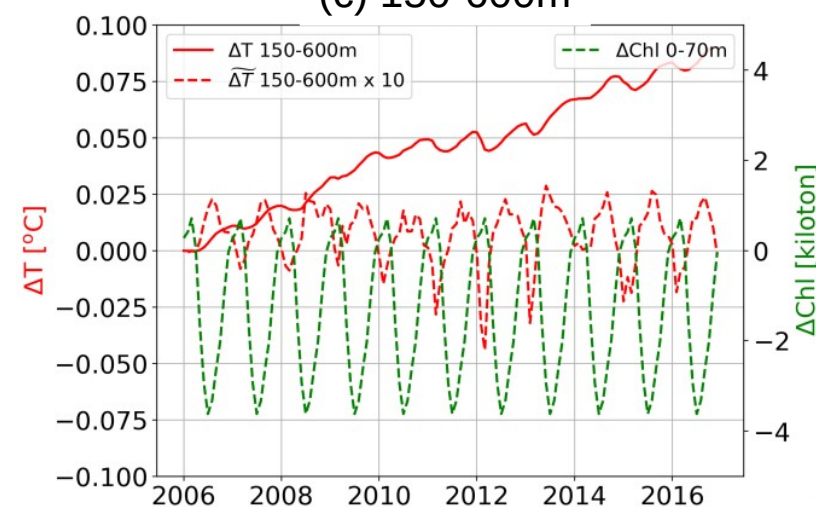
(a) 0-70m



(b) 70-150m



(c) 150-600m



Temperature difference **with and without trend** and $\Delta\text{Chl 0-70m}$ (i.e. SAT_VHOM - SAT_VVAR) in MED

Correlation Coefficient	$\Delta\text{Chl 0-70m}$
$\Delta T 0-70m$	0.53
$\Delta \tilde{T} 70-150m$	-0.83
$\Delta \tilde{T} 150-600m$	-0.77



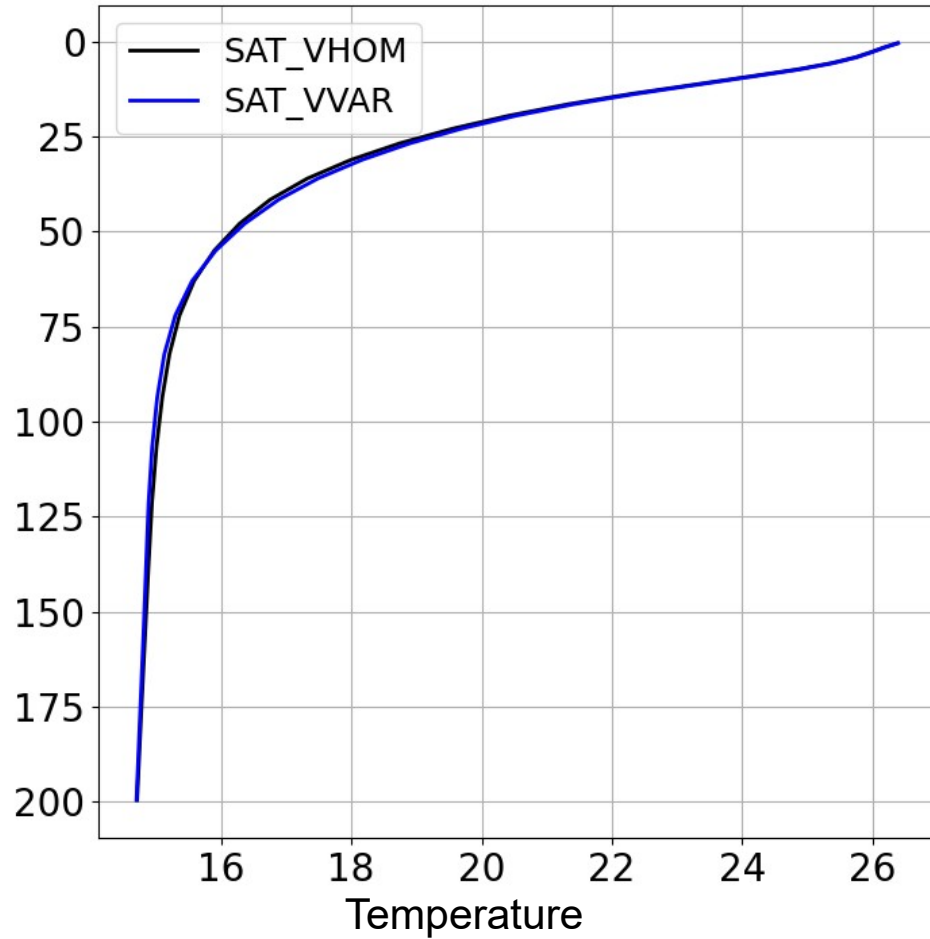
More heat absorbed in the **upper surface layer (<70m)**, and less heat would penetrate this layer



Trend of ΔT in deeper layers

Evolution of the vertical profile of temperature (Mean profil in MED)

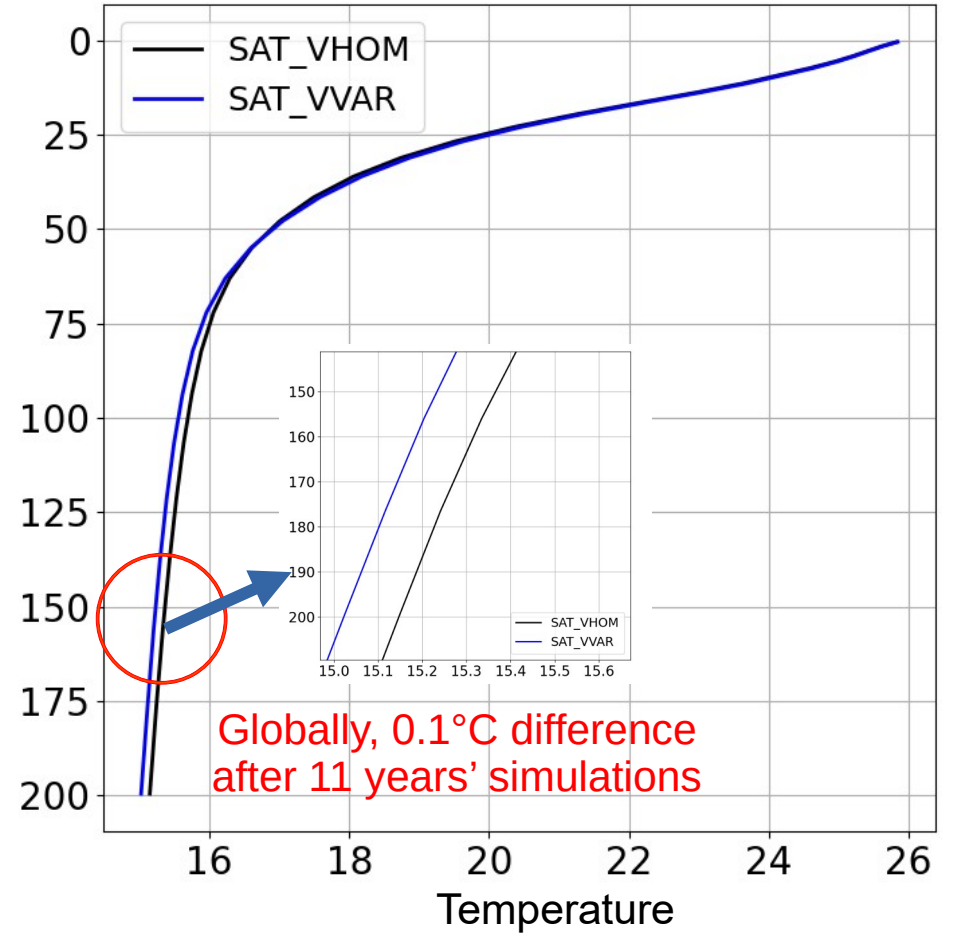
Depth (m)



Summer 2006
First summer of simus



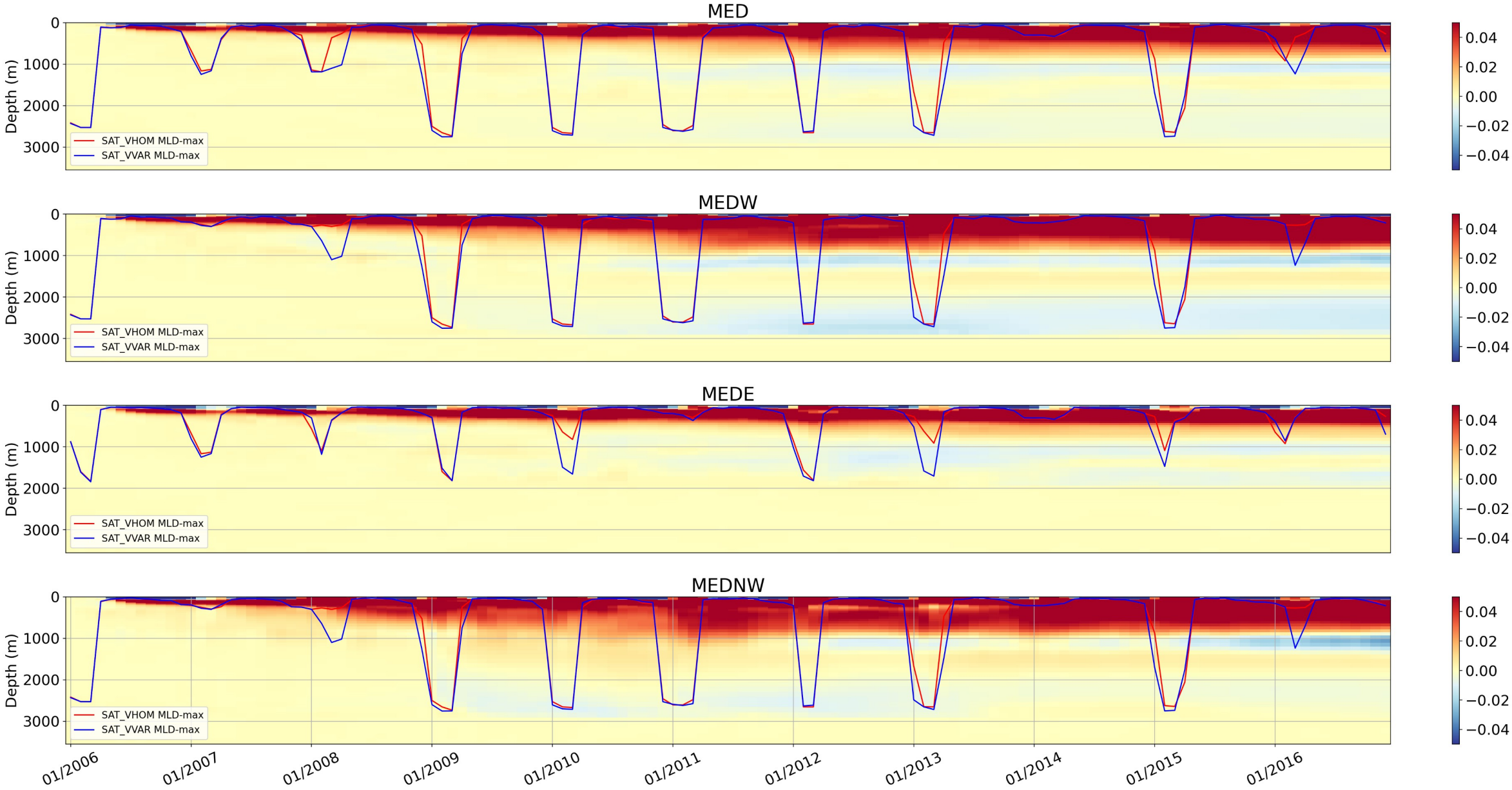
Depth (m)



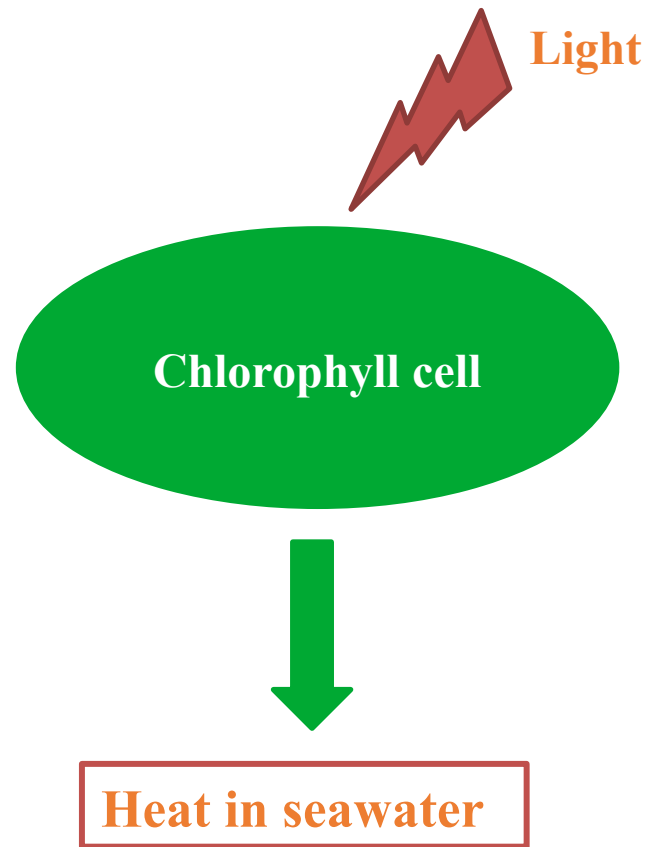
Globally, 0.1°C difference
after 11 years' simulations

Summer 2016
Last summer of simus

Entire water column

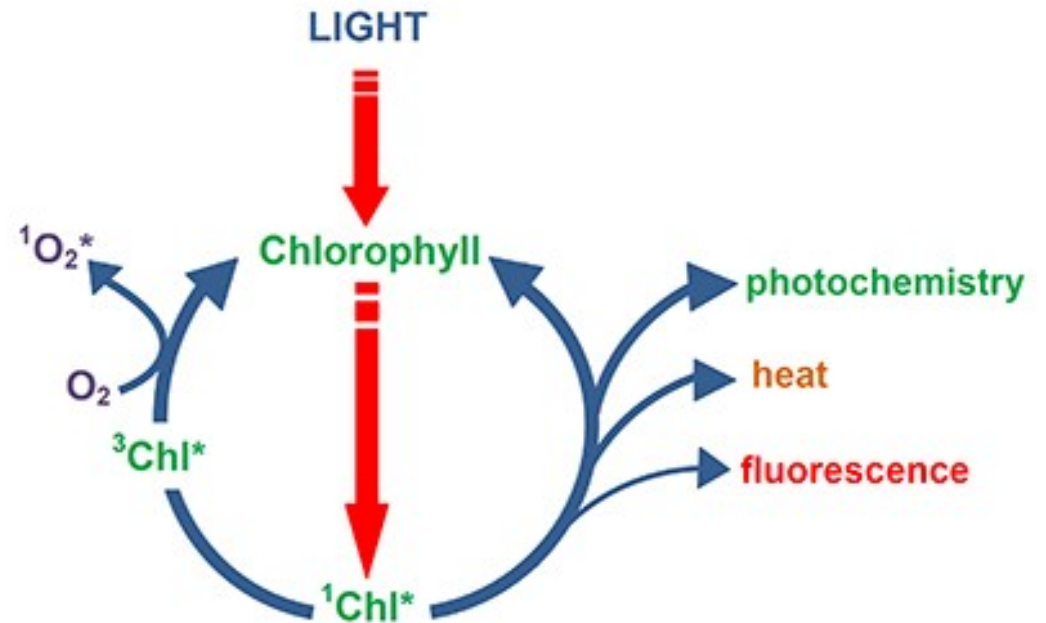


Appendix



In the case of the model
All the energy absorbed by the phytoplankton **will be transformed 100%** into heat in the water.

cf. Huner N P A, Öquist G, Sarhan F. Energy balance and acclimation to light and cold[J]. Trends in plant science, 1998, 3(6): 224-230.



In the realistic case

All the energy absorbed by phytoplankton will be transformed into **fluorescence (~3%)**, **photochemical production of organic matter** and **heat** in the water.