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Impact of the chlorophyll bias on tropical mean states with bio-geophysical feedback

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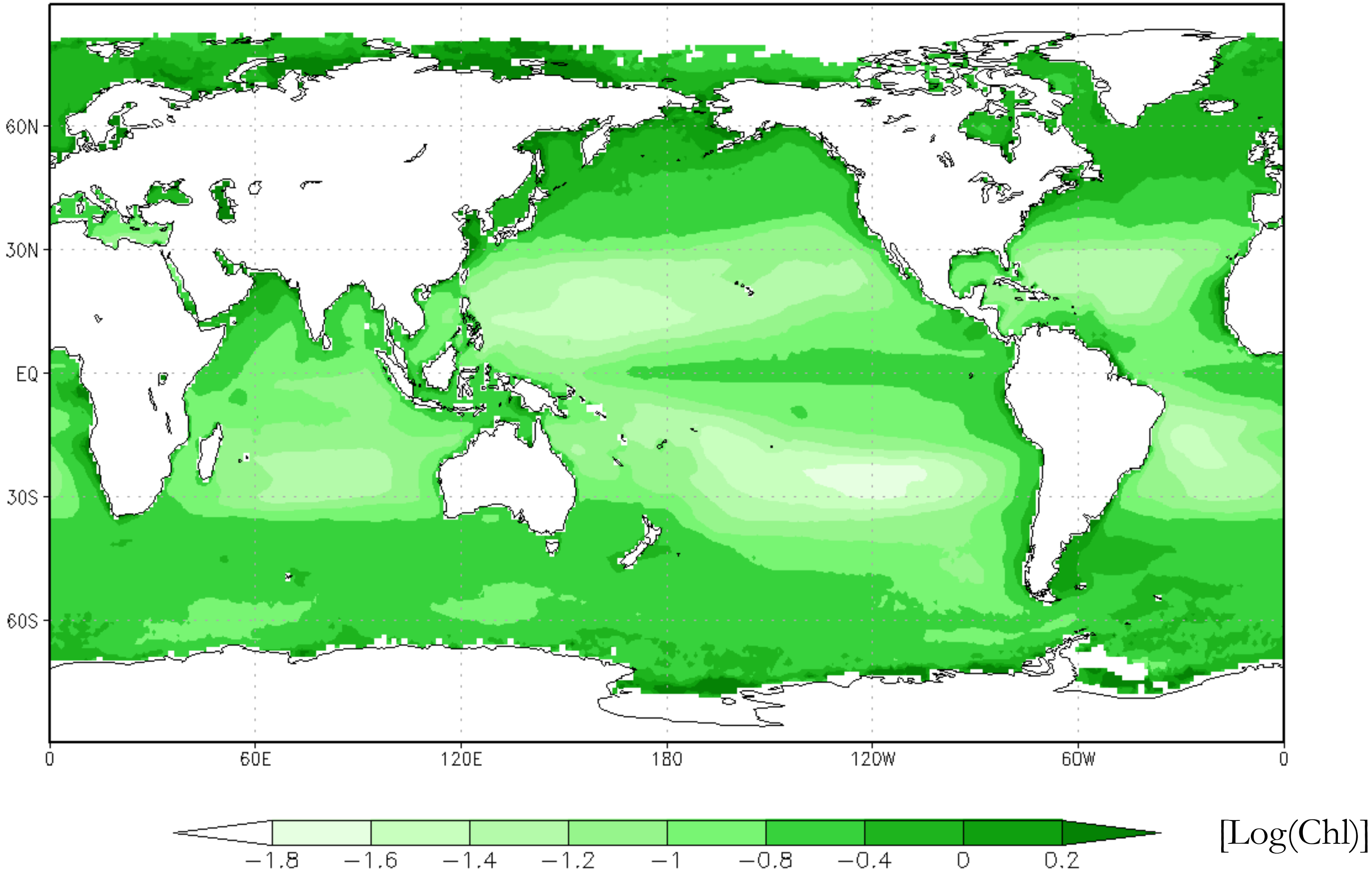
SeaWiFs_MODIS

Chl. concentration averaged [jan1998~dec2013]



GFDL CM2.1 Earth System Model

Atmospheric Model v2.1

Land model 2.1

Modular Ocean Model v4

TOPAZ v1.0 → *Primary production*, *CO2 uptake*, *Ocean mixing*

Sea-Ice Simulator

✓ **Physical model ↔ Bio-geochemistry model**

CM2.1(coupled with MOM4) coupled with bio-geochemistry model
TOPAZ(Tracers Of Phytoplankton Allometric Zooplankton)
John Dunne et al 2005; 2010 from GFDL

TOPAZ interaction with Climate variables

✓ **Climate → Biogeochem. : <u>Irradiance, Nutrient and Temperature</u>**

$$\mu = \frac{P_{C_m}}{(1+\zeta)} \cdot \left(1 - e^{(-\alpha \cdot I \cdot Chl:C / P_{C_m})}\right)$$

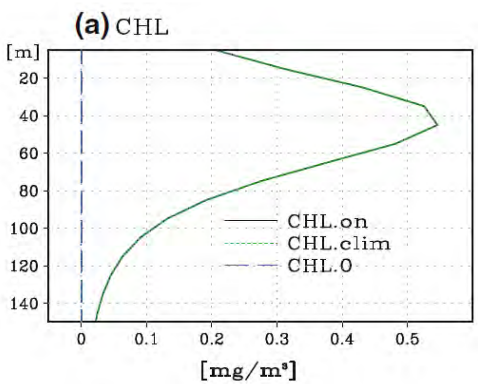
→ **Temp, nutrient** (P_{C_m})

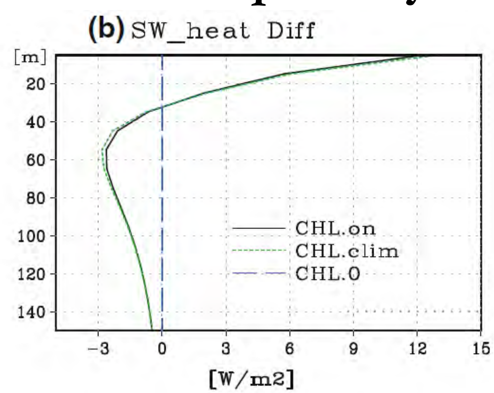
→ **irradiance** (I)

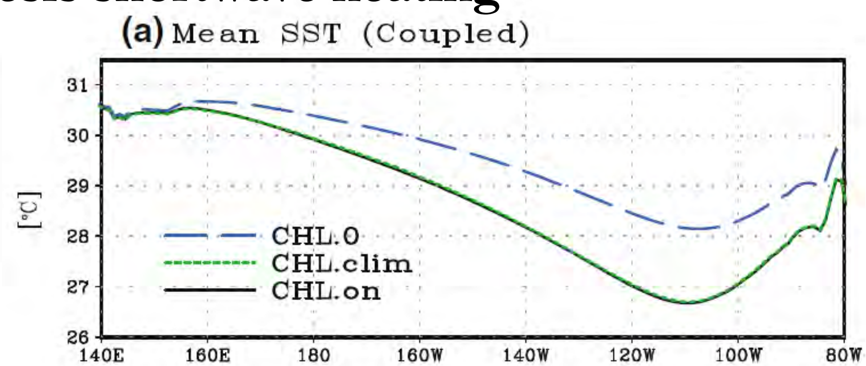
**Dunne 2010: Technical description … of TOPAZ.*
Follow continuity Eq.
Chl:C ratio : Geider et al. 1997
Pcm : Light-saturated photosynthesis rate
ζ : assimilatory efficiency (0.1 non-dimension)

****μ (photosynthesis rate) = F(Irradiance, Temperature, Nutrient)***

✓ **Biogeochem. → Climate via photosynthesis shortwave heating**



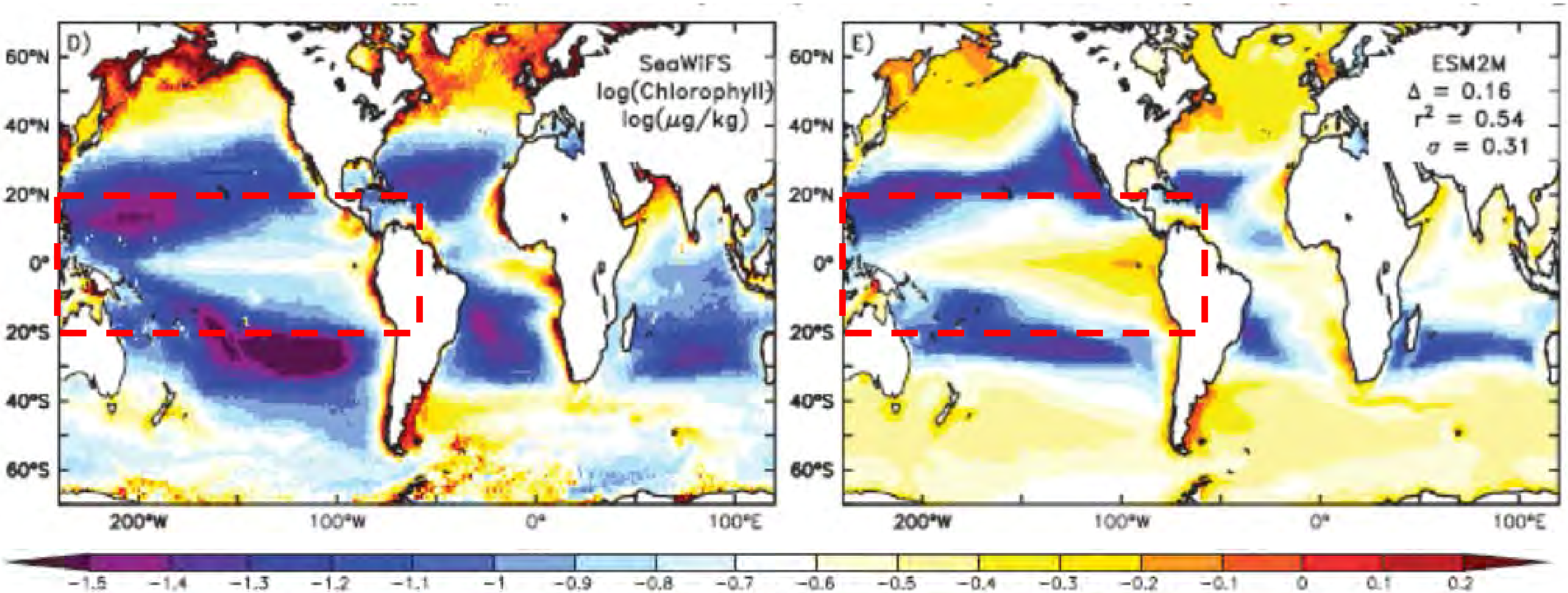




- *Bio-geophysical feedback :* ***Chlorophyll can intensify cool SST response*** *in* Equatorial eastern Pacific(150W–90W; 5S–5N) *[Sweeney et al 2005; Park et al 2013].*

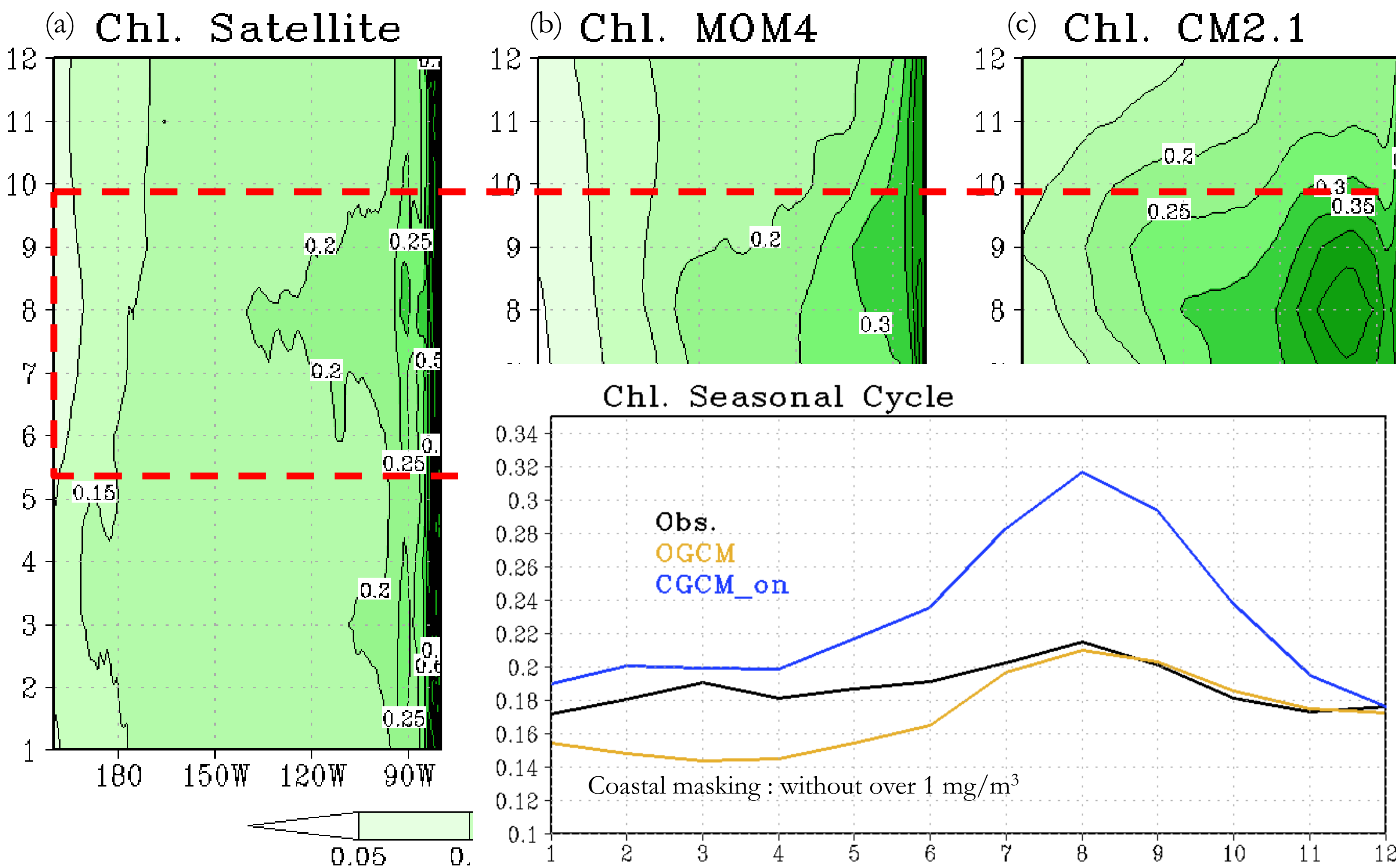
Chlorophyll concentration (Dunne et al 2013)

Satellite Chl. concentration [1998~2007] **GFDL ESM2M**



✓ Accumulated satellite-derived chlorophyll data from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) + Moderate Resolution Imaging Spectroradiometer (MODIS)

Chlorophyll EQ. SC



Q) How does impact of the <u>chlorophyll bias</u> affect to tropical mean states in ESM?

Model experiment

- *OGCM experiment : hindcast run forced by 6 hourly winds (NCEP/NCAR R1) 3 ensemble mean.*
- *Model experiment using the GFDL CM2.1p1 / MOM4p1*

Exp	Details	CO_2
CGCM_on	200 year Free run (after 1000yr control run)	Fixed CO_2 (353ppm)
CGCM_off_clim	200 year prescribed chlorophyll	

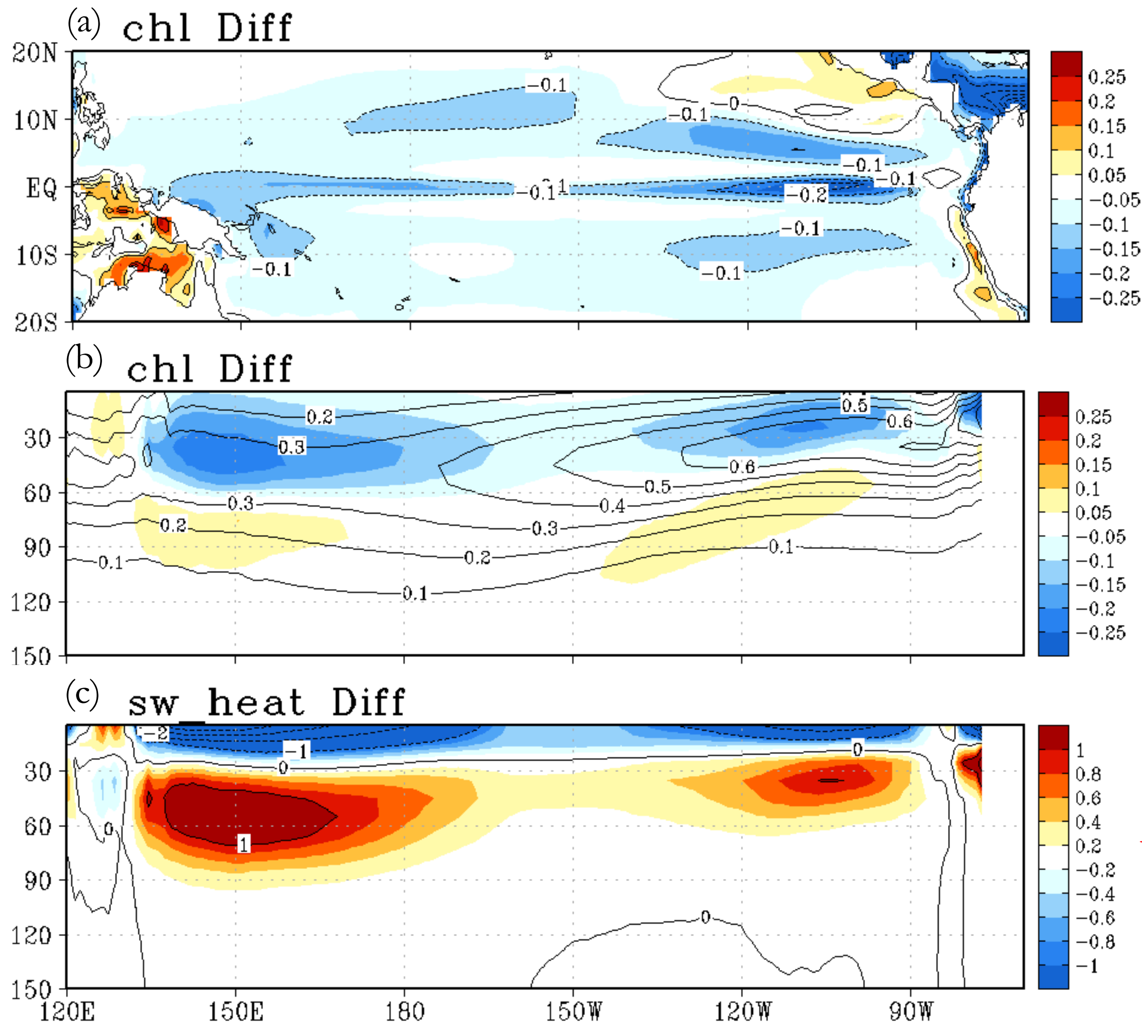
- *Difference of two experiments : [CGCM_off_clim] – [CGCM_on] focused "**Impact of reduced chlorophyll**" on tropical Pacific*

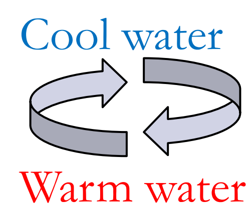
Shortwave heating change

Reduced Chlorophyll

↓

Shortwave cooling at ocean surface



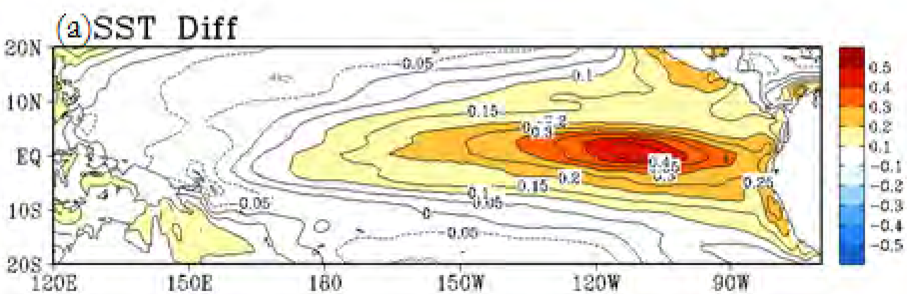


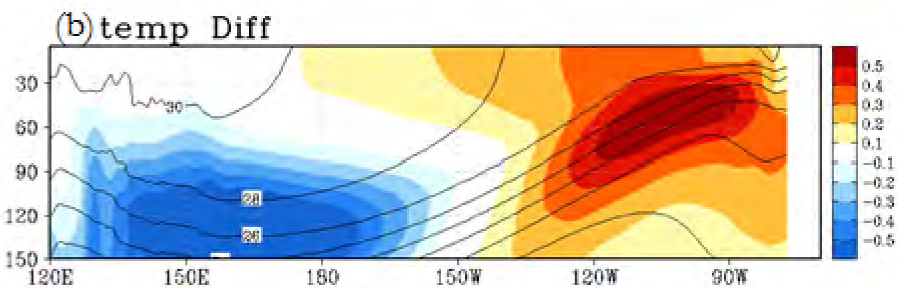
Vertical redistribution of SW heat -> Less stratification (Mixing more)=> MLD deepening

Mean State Change

[Reduced chlorophyll forcing]

[Ocean feedback]





Ocean Feedback

Chlorophyll reduce

↓

Stratification decrease is able to enhance MLD deepening

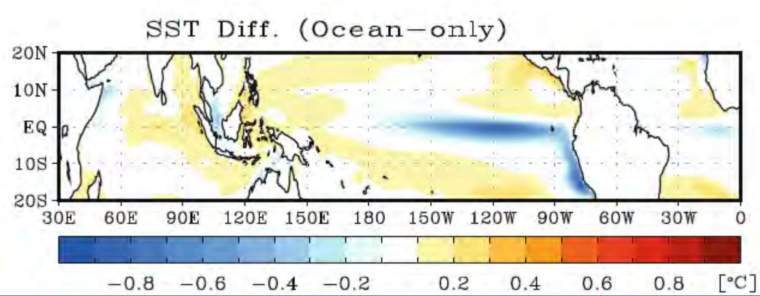
↓

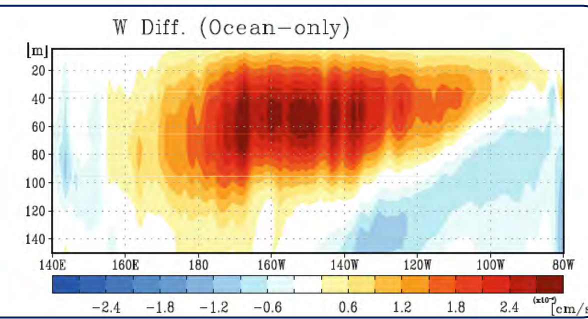
Thermocline depth deepening via Less pole-ward volume transport

↓

SST warming

OGCM Exp.
Park et al. 2013

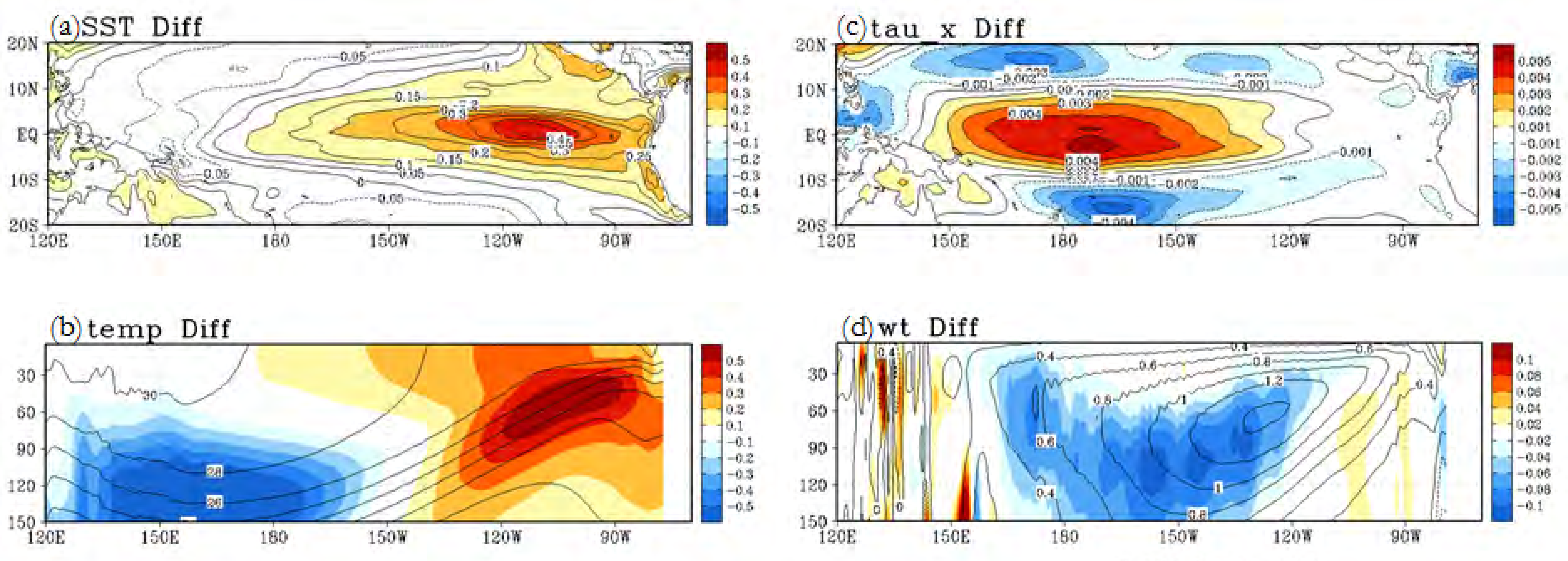




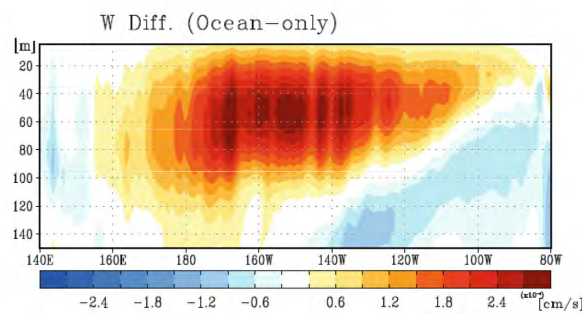
Mean State Change

[Reduced chlorophyll forcing] ≈ 3.0 K sst ↑ per 1 ug·m^3 chl. ↓

[Ocean feedback] + *[Atmospheric feedback]*



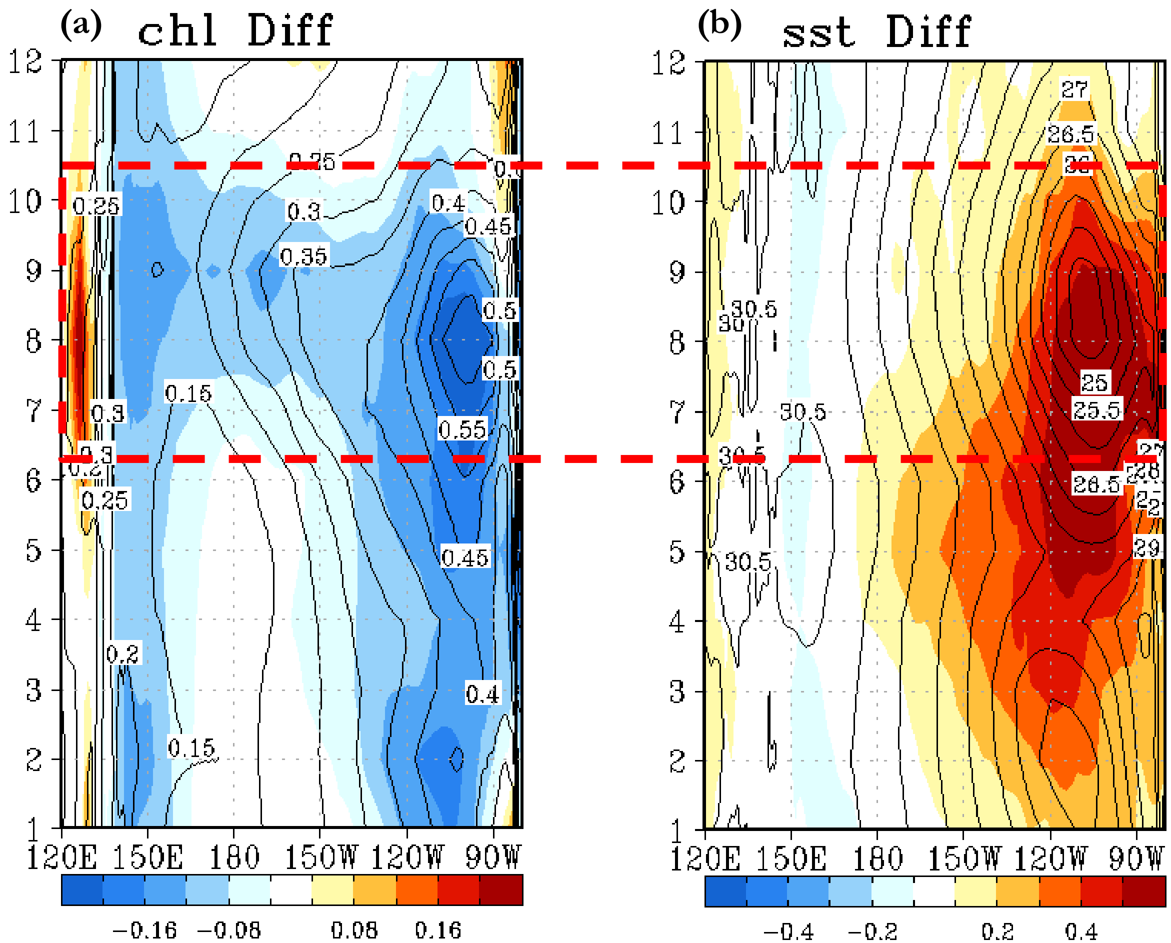
- ✓ *Mean SST is changing* ***due to decrease concentration of Chlorophyll.*** *Atmospheric feedback is working CGCM*, ***enhance less upwelling and deepening thermocline depth in equatorial eastern Pacific.***



Seasonal Change of SST

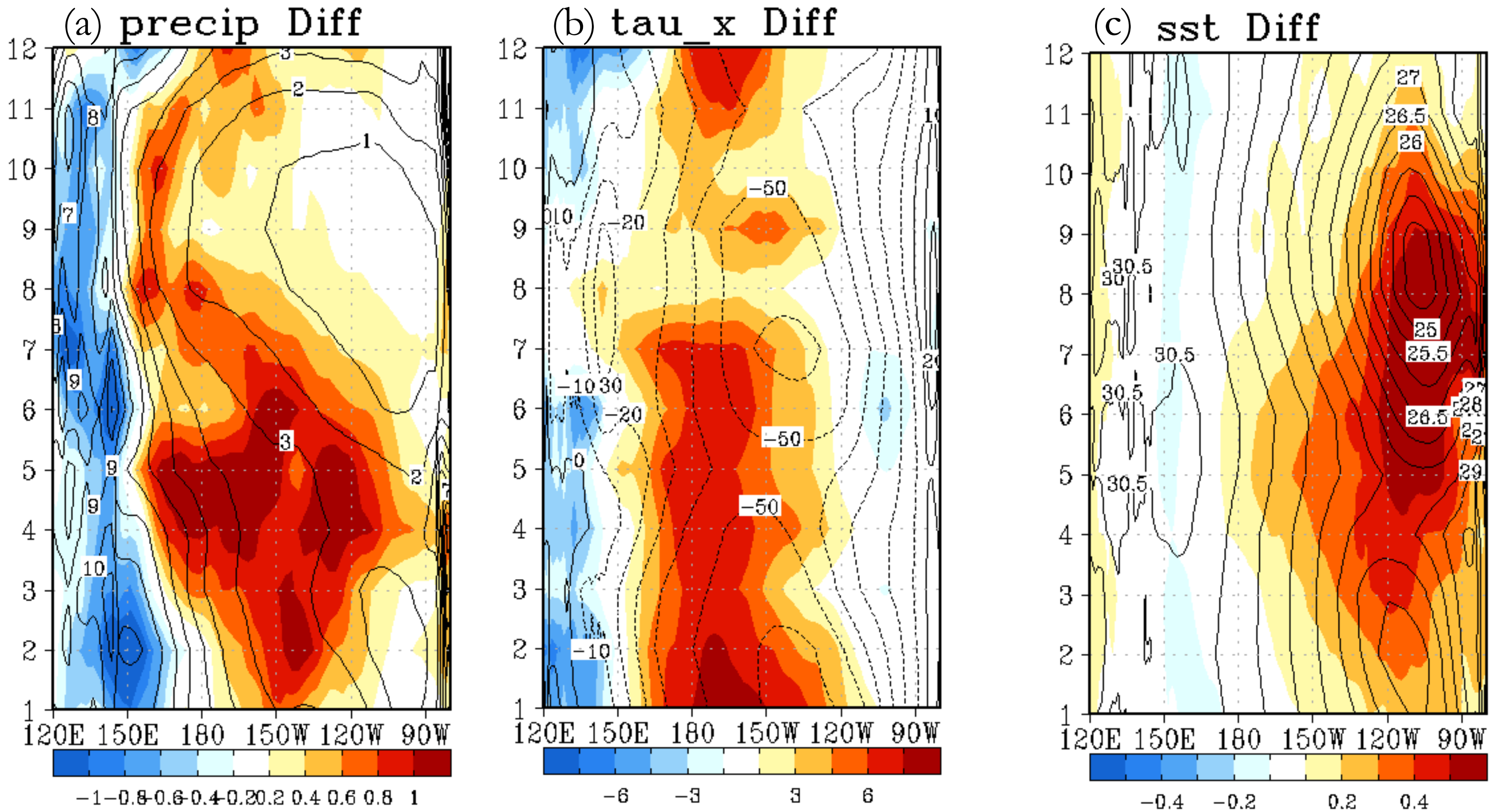
✓ SST response is <u>not equal</u> to chlorophyll maximum bias month.

- ***Most reduced chlorophyll season of chlorophyll is August.***
- ***However, impact of SST seasonal cycle is less than expected result and narrow response.***



Seasonal dependency of Atmos. feedback

✓ ***Dry season is suppressed by strong cool SST mean state.***



- ***Impact of Chlorophyll has seasonal dependency due to the coupling/decoupling with atmosphere. Because, sensitivity of precipitation against with SST variability is different in all season.***

Summary

- Total impact of reduced chlorophyll can enhance SST warming in Eastern Eq. Pacific ***[3.0 K sst ↑ per 1 ug·m^3 chl. ↓],*** *therefore,* impact of chlorophyll bias is **not small.**
- Ocean + Atmospheric feedback **(de-coupling Seasonal dependency)**

Ocean Feedback

Chlorophyll reduce

↓

Stratification decrease is able to enhance MLD deepening

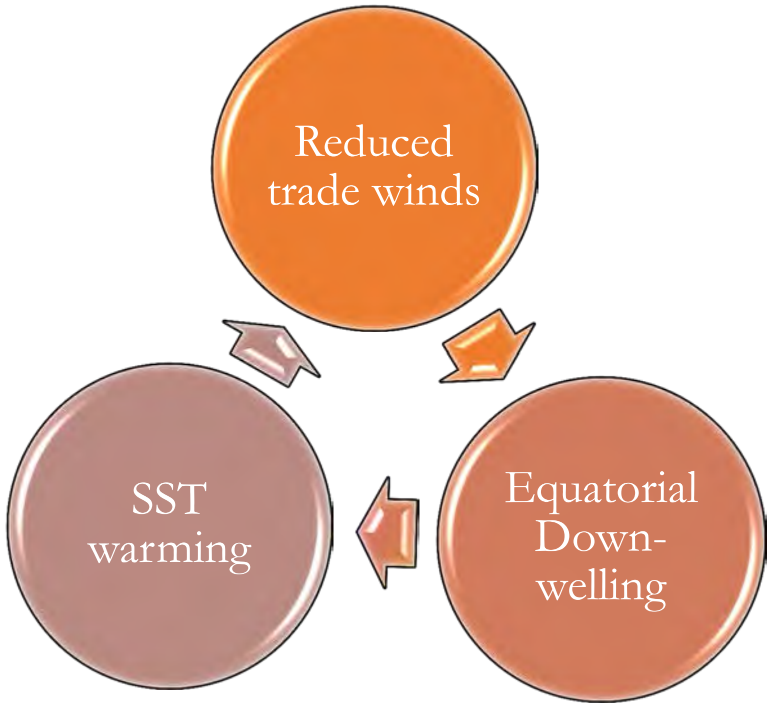
↓

Thermocline depth deepening via Less pole-ward volume transport

↓

SST warming

Atmos Feedback



Thank You !

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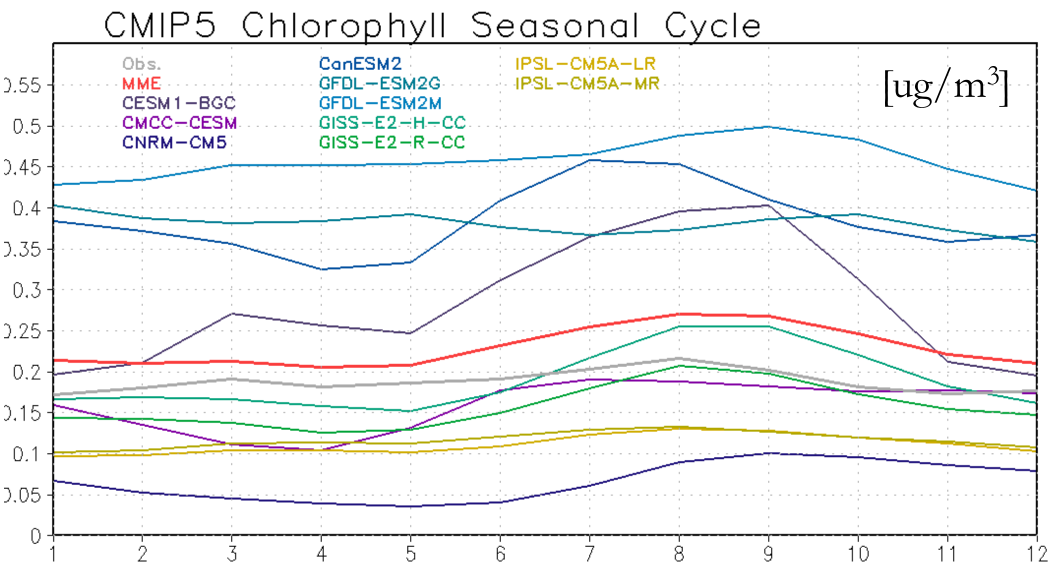
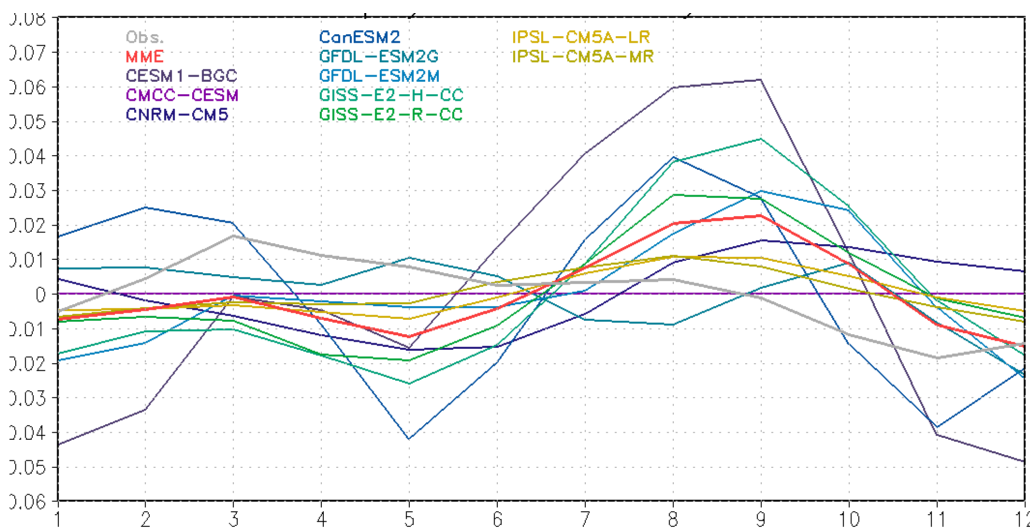
CMIP5 chlorophyll conc.



Poor! climatology of chlorophyll conc. on Eq. Pacific in CMIP5



Poor! Seasonal cycle despite of removed annual mean as well...

Previous studies in our group

[KIOST - POSTECH - MPI]

I. Park, Kug et al 2011 , JGR : **Variability of chlorophyll** associated with **ENSO** and its possible biological feedback in the equatorial Pacific

II. Park, Kug et al 2013, CD : Marine biological feedback associated with **Indian Ocean Dipole** in a coupled ocean/biogeochemical model

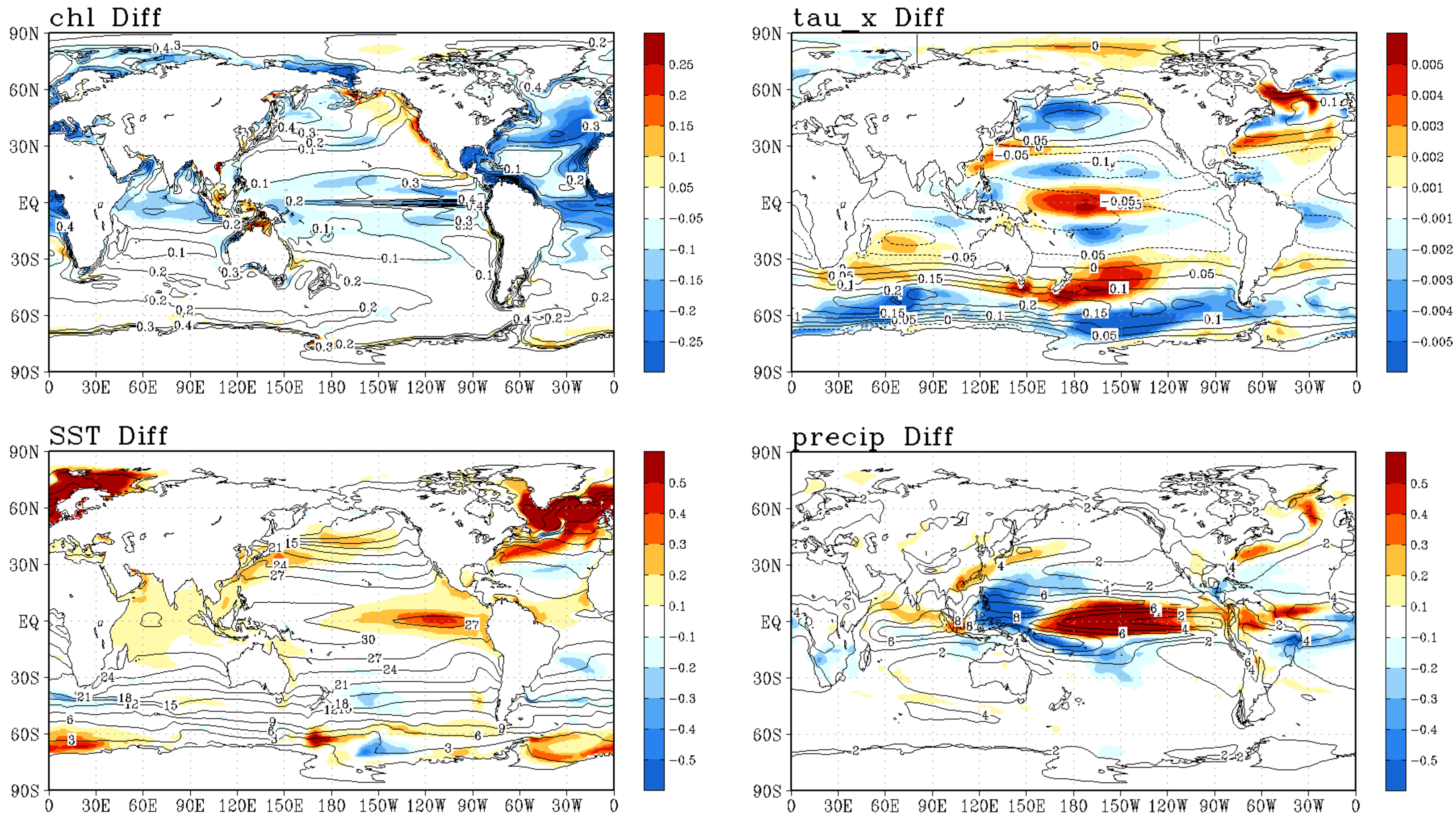
III. Park, Kug et al 2013, CD : **Impact of bio-physical feedbacks** on the tropical climate in **coupled and uncoupled GCMs**

IV. Lee, Yeh, Kug, Park et al 2013, JGR ocean : Ocean chlorophyll response to **two types of El Nino** events in an ocean-biogeochemical coupled model

V. Park, Kug et al 2014, PO : An exploratory modeling study on bio-physical processes associated with ENSO

VI. Park, Kug et al 2015, PNAS : **Amplified Arctic warming** by phytoplankton under greenhouse warming.

Reduced Chl. Response in global



Park et al 2014
: ENSO feedback with /without chl.

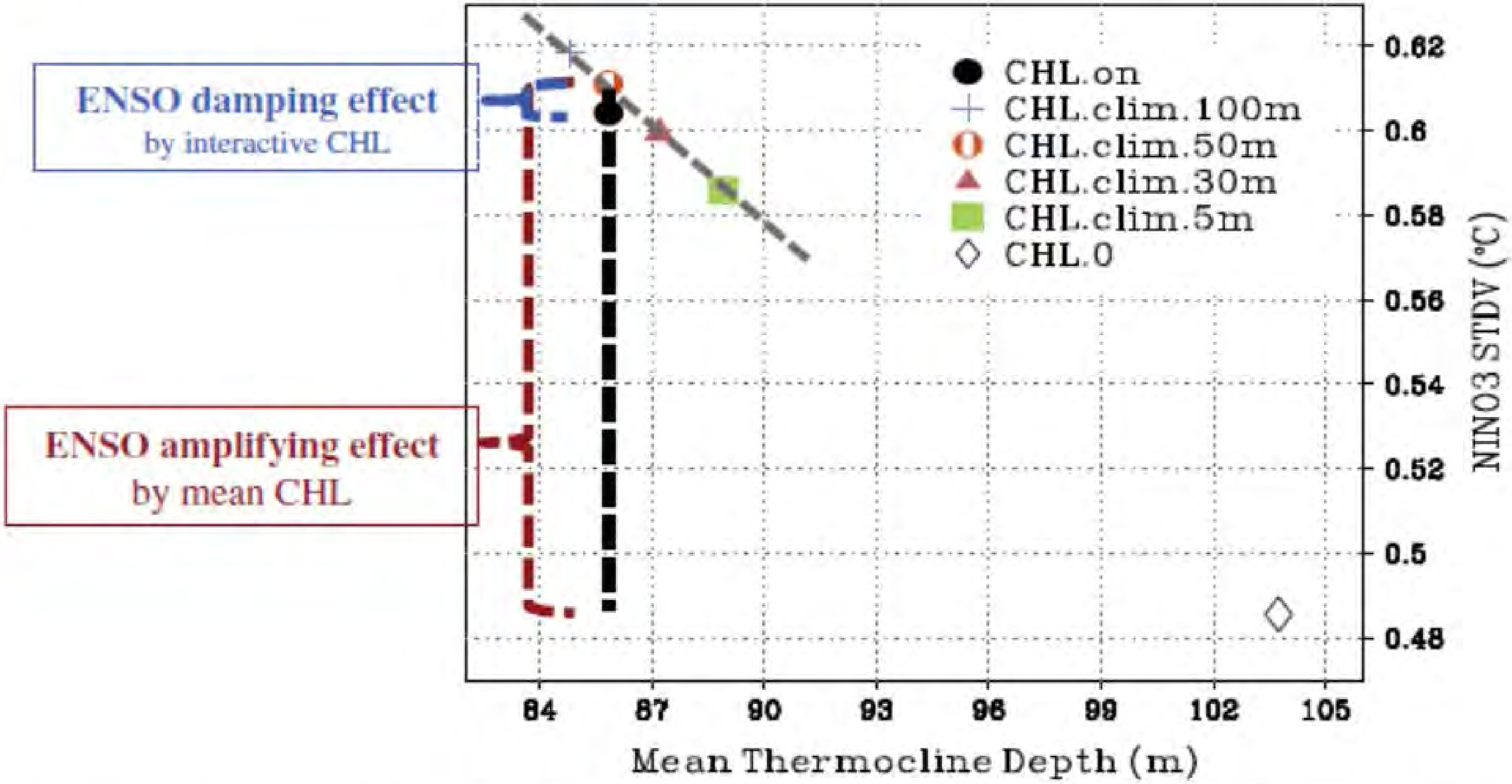


Fig. 12. Scatter plot between the mean thermocline depth and the NINO3 standard deviation in each experiment.

Bio-geochemical modeling

✓ **T**racers **O**f **P**hytoplankton with **A**llometric **Z**ooplankton (TOPAZ) v1.0

→ TOPAZ has been developed v2.0 coupled with MOM5

✓ Follow the continuity Equation

$$\frac{\partial C}{\partial t} = -\nabla \cdot \tilde{u}C + \nabla K \nabla C + S_C$$

- *Divergence term*
- *Diffusion term*
- *Sc : Source and sink term (TOPAZ)*

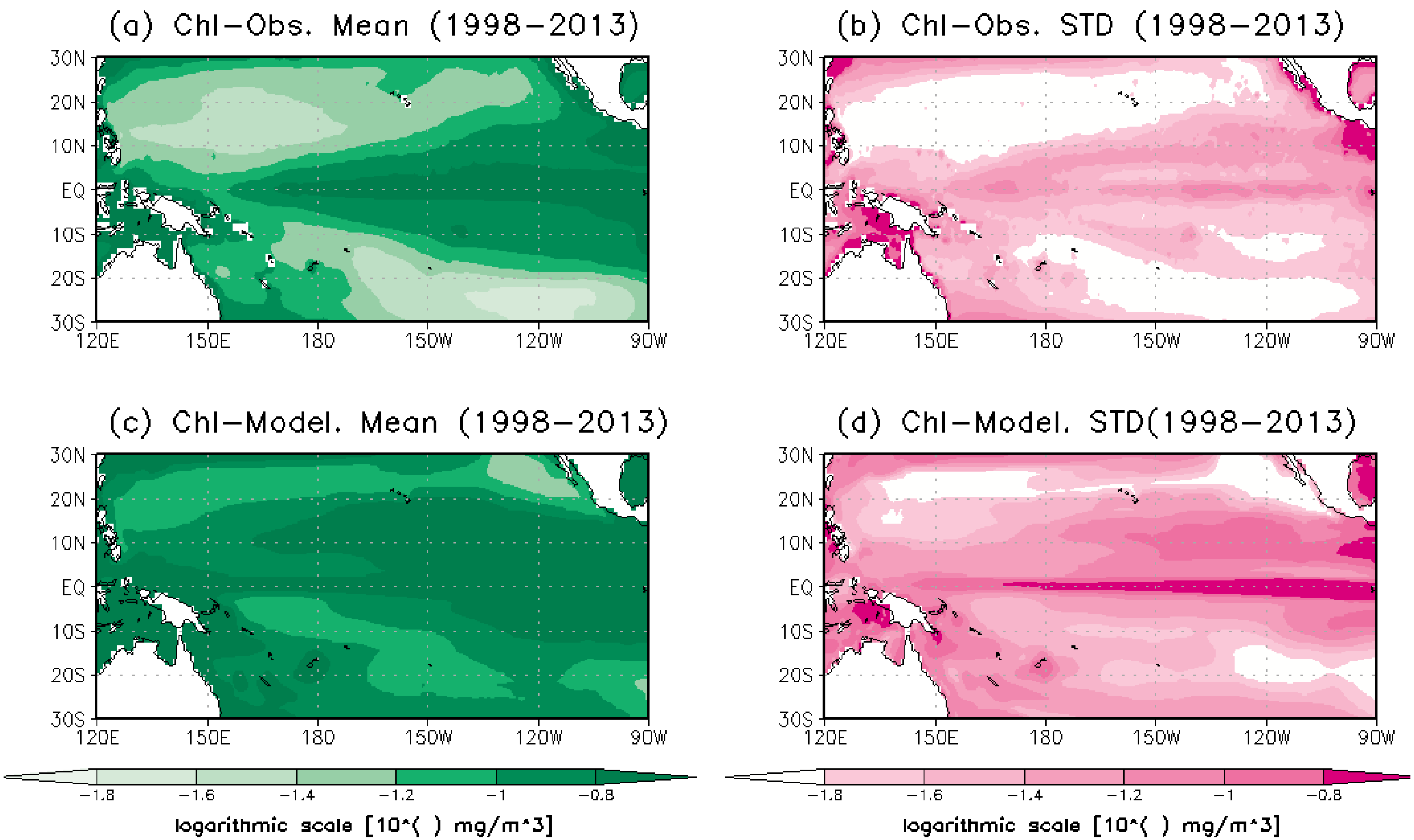
Detailed in Dunne et al. 2010 : Description of TOPAZ

	Variable	Scale
dic	Dissolved Inorganic Carbon	mol/Kg
o2	Dissolved oxygen	mol/Kg
no3	Nitrate	mol/Kg
co3_ion	Carbonate ion	mol/Kg
fed	Dissolved Iron	mol/Kg
po4	Phosphate	mol/Kg
sio4	silicate	mol/Kg
htotal	H+ ion concentration	mol/Kg
nh4	Ammonia	mol/Kg
nlg	Nitrogen in Large phytoplankton	mol/Kg
nsm	Nitrogen in Small phytoplankton	mol/Kg
ndi	Nitrogen in Diazotroph	mol/Kg
felg	Iron in Large phytoplankton	mol/Kg
fesm	Iron in Small phytoplankton	mol/Kg
fedi	Iron in Diazotroph	mol/Kg
plg	Phosphorus in Large phytoplankton	mol/Kg
psm	Phosphorus in Small phytoplankton	mol/Kg
pdi	Phosphorus in Diazotroph	mol/Kg
silg	**Silica in Large phytoplankton**	**mol/Kg**
lith	**Lithogenic Aluminosilicate**	**mol/Kg**
nhet	**Heterotrophic Nitrogen**	**mol/Kg**
sdon	**semilabile DON**	**mol/Kg**
sdop	**semilabile DOP**	**mol/Kg**
ldon	**labile DON**	**mol/Kg**
alk	**Alkalinity**	**mol/Kg**
chl	**Chlorophyll**	**ug/Kg**
irr	**Irradiance**	**watt/m^2**

Bio-geochemical model (TOPAZ)

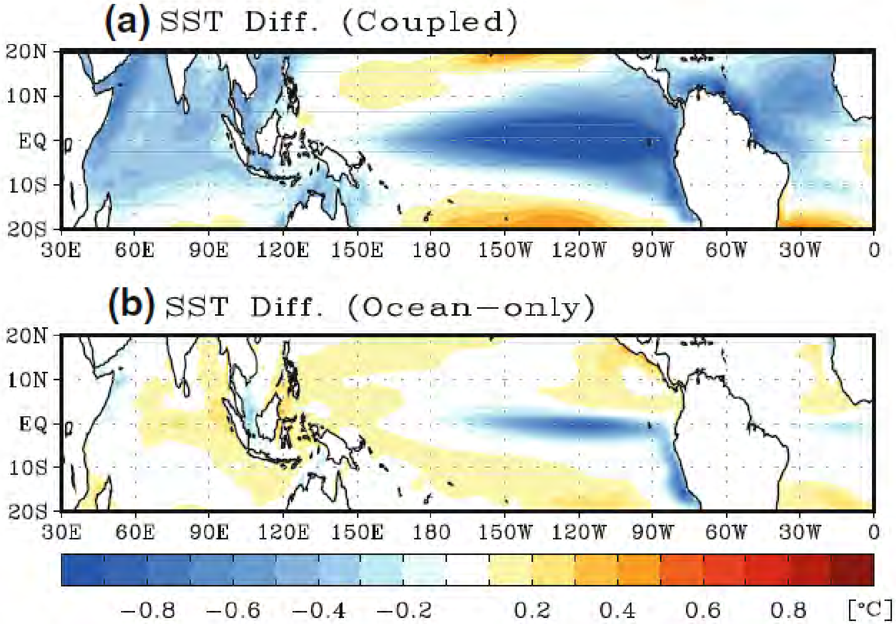
- **Chlorophyll mean states and variability in Obs. and model**

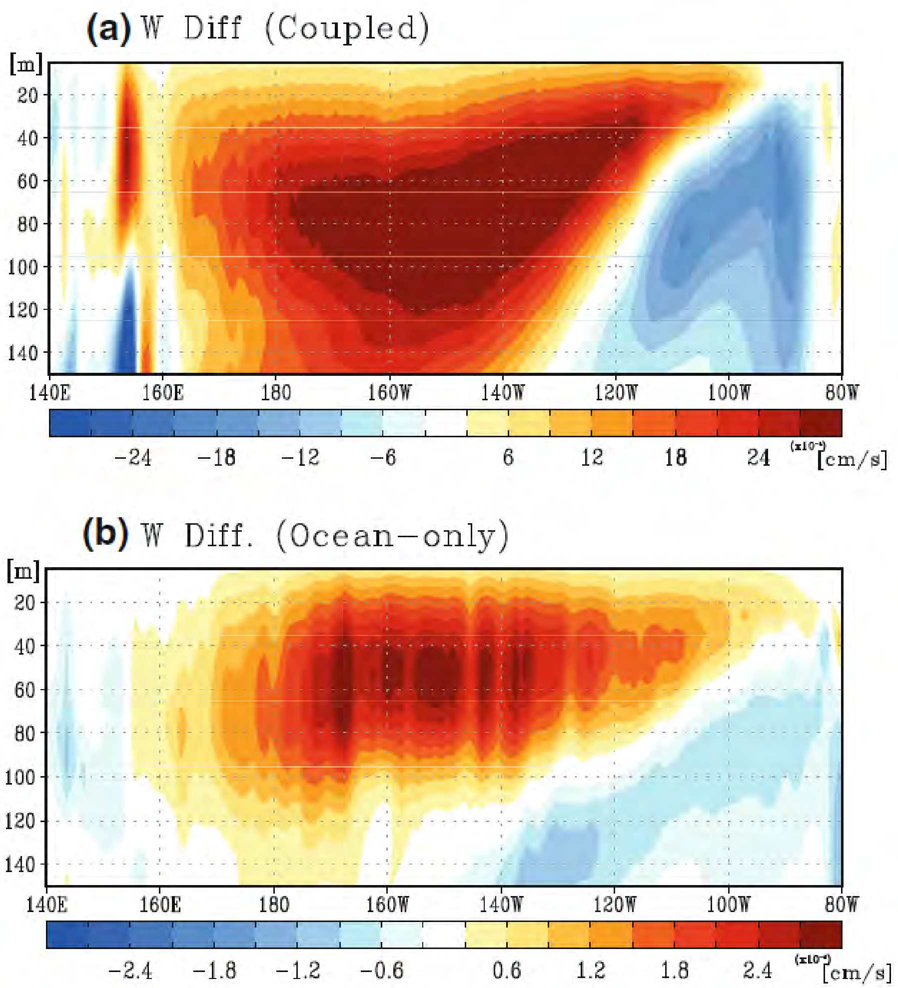
  Obs. : SeaWiFS + MODIS [1998-2013], Model : CGCM SST restoring



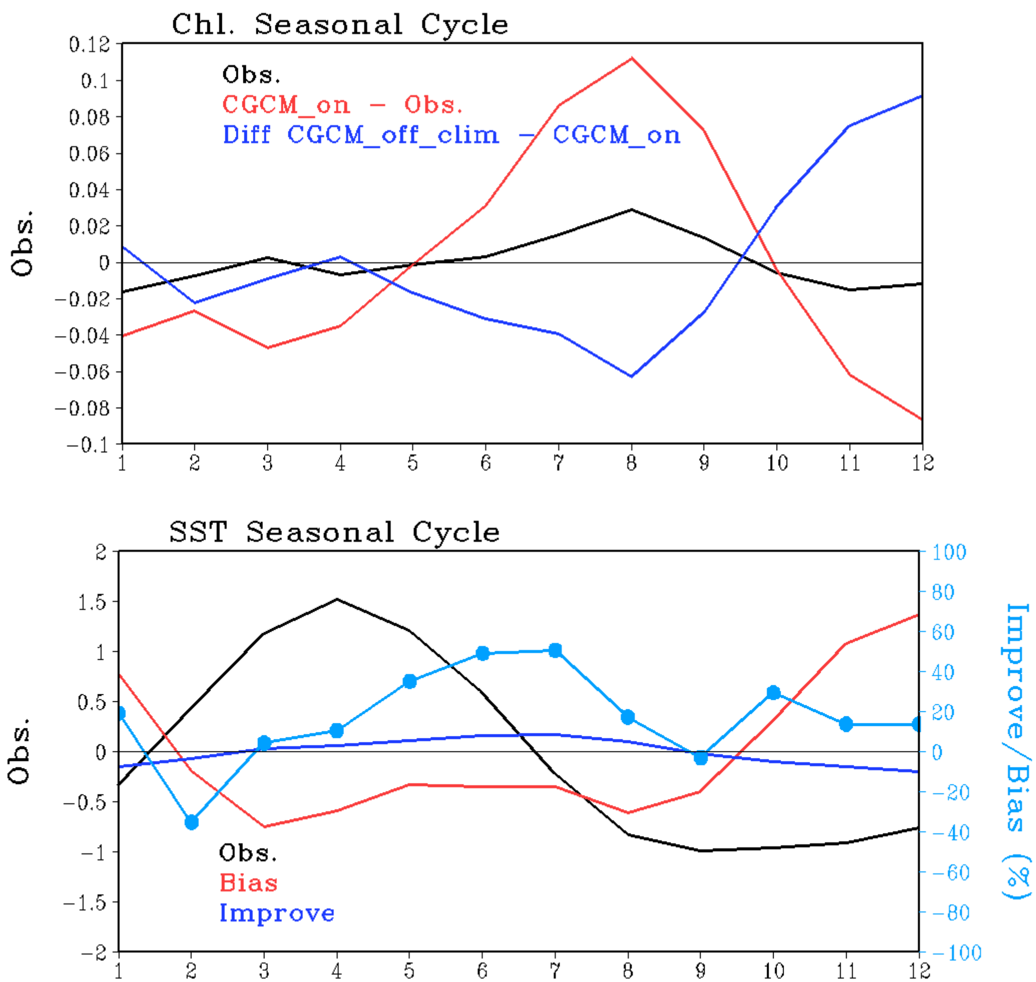
Impact of bio-physical feedbacks [Park et al 2013]

- ✓ SST can be changed due to the Biological feedback
- ✓ Figures depict SST and vertical velocity difference between [TOPAZ_on] and [TOPAZ_off] experiment using CGCM(Coupled) and OGCM(Ocean-only)





Result


Chl. Seasonal Cycle
Obs.
CGCM_on – Obs.
Diff CGCM_off_clim – CGCM_on
0.12
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
1 2 3 4 5 6 7 8 9 10 11 12
SST Seasonal Cycle
Obs.
Bias
Improve
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
1 2 3 4 5 6 7 8 9 10 11 12
100 80 60 40 20 0 −20 −40 −60 −80 −100
Improve/Bias (%)