



Tracking improvement in simulated marine biogeochemistry between CMIP5 and CMIP6

Mostly based on CRESCENDO WP5 activity

Centre National de Recherches Météorologiques (CNRM), Université de Toulouse, Météo-France, CNRS, Toulouse, France
roland.seferian@meteo.fr

Introduction

Dominant paradigm in climate modelling:

“the higher the model realism ...

... the higher its reliability in future projections”

3 pathways to improve model realism :

Climate Model
of **generation #N**

Climate Model
of **generation #N+1**

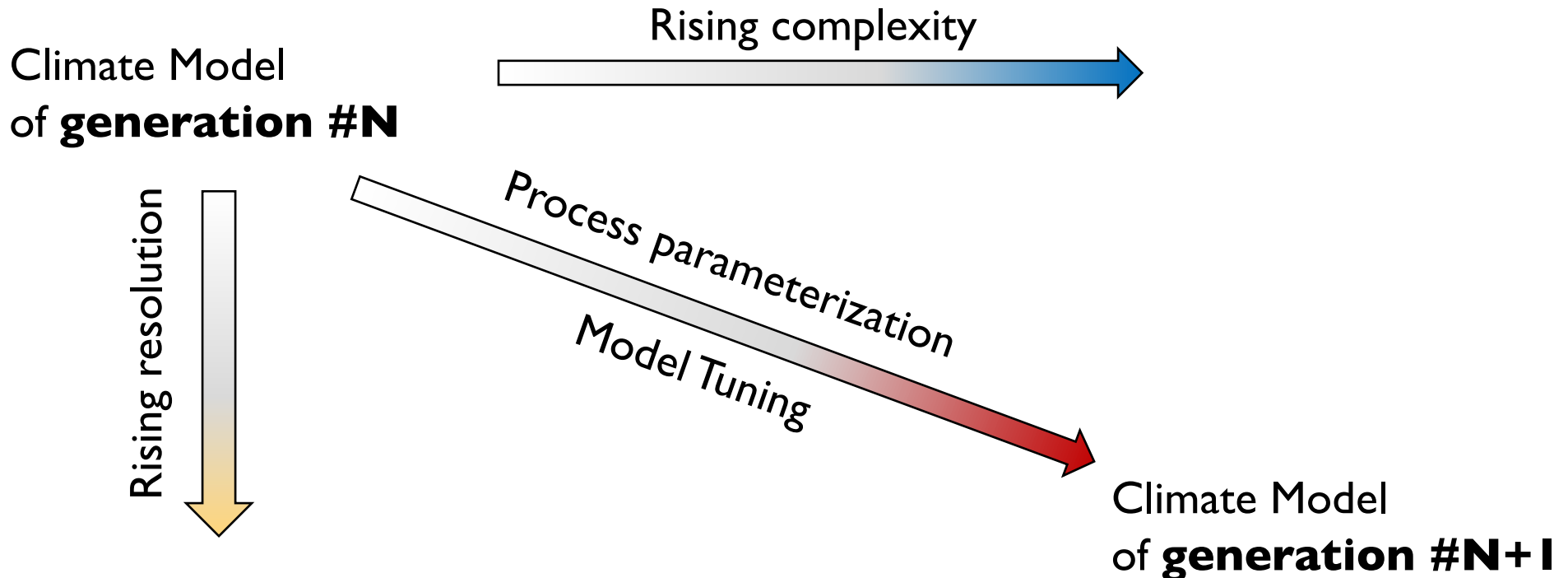
Introduction

Dominant paradigm in climate modelling:

“the higher the model realism ...

... the higher its reliability in future projections”

3 pathways to improve model realism :



How much a given pathway can influence model performance and projections ?

Part 1:

Does simulated marine biogeochemistry has been improved in CMIP6 wrt CMIP5 ?

Ocean physics			Ocean-sea ice model
Resolution			
Vertical layers	Horizontal		
		MOM4-SIS	BCC-CSM1.1-M1
		MOM4-SIS	BCC-CSM2-MR2
		CanOM4	CanESM23
		NEMOv3.4.1-LIM2	CanESM54
		NEMOv3.4.1-LIM2	CanESM5-CanOE4
		POP2-CICE4	CESM1-BGC5
		POP2-CICE5	CESM26
		NEMOv3.2-GELATOv5	CNRM-ESM17
		NEMOv3.6-GELATOv6	CNRM-ESM2-18
		MOM5	GFDL-ESM29
		MOM6-SIS2	GFDL-CM410
		MOM6-SIS2	GFDL-ESM411
		GISS-E2-R	GISS-E2-R-CC12
		GISS-E2-R	GISS-E2-1-G-CC13
		UM	HadGEM2-ES14
		NEMO v3.6-CICE	UKESM1-0-LL15
		NEMOv3.2-LIM2	IPSL-CM5A-LR16
		NEMOv3.6-LIM3	IPSL-CM6A-LR17
		COCO	MIROC-ESM18
		COCO	MIROC-ES2L19
		MPI-OM	MPI-ESM-LR20
		MPI-OM	MPI-ESM1-2-LR21
		MRICOM3	MRI-ESM122
		MRICOM4	MRI-ESM2-023
		MICOM-CICE4	NorESM1-ME24
		BLOM-CICE5	NorESM2-LM25

Review of key model properties

Top red cells= CMIP6 ESMs

Top pink cells = CMIP5 predecessors

Ocean Physics:

Hor. Resolution

250 km 100 km 50 km 25 km

Vert. layers

31-40 41-50 51-60 61-70 71-80

Bold text = upgraded internal model physics

Darker colors means 'increase in resolution'

Ocean biogeochemistry												
Complexity												
Nutr./Element cycling			Sediments			Org. Mat. Cycling		Int. physio.		Trophic web.		Ocean biogeochemical model
Fe	O ₂	Si	P	N	C			Stoch	Chl	Bac	Zoo	
						No						OCMIP-2a
						No						OCMIP-2a
						No	Gen. Cat.	R				CMOC _b
						No	Gen. Cat.	R				CMOC _b
						Balance	Size Cat.	V				CanOE _c
						No	Flux att.	sV		+	+	BEC _d
						No	Flux att.	V		+	+	MARBL-BEC _d
						No	Size Cat.	sV		+	+	PISCESv1 _e
						Meta-mod.	Size Cat.	sV		+	+	PISCESv2-gasr
						Sed-Box	Refr. Cat.	V		++	++	TOPAZv2 _g
						Sed-Box	Gen. Cat.	sV		+	++	BLINGv2 _h
						Sed-Box	Refr. Cat.	sV		+	+	COBALTv2 _i
						No	Size Cat.	R				NOBM _j
						No	Size Cat.	R				NOBMext _s
						No	Gen. Cat.	R		+		Diat-HadOCC _i
						Sed-Box	Size Cat.	V		+	+	MEDUSA-2.0 _m
						No	Size Cat.	sV		+	+	PISCESv1 _e
						Meta-mod	Size Cat.	sV		+	+	PISCESv2 _r
						No	Flux att.	R				OECO1 _p
						Meta-mod	Flux att.	R		+		OECO2 _q
						12-layers	Gen. Cat.	R		+		HAMOC5 _r
						12-layers	Flux att.	R		+		HAMOC6 _s
						No	Gen. Cat.	R				NPZD _i
						No	Flux att.	R				NPZD _i
						12-layers	Gen. Cat.	R		+		HAMOC5.1 _u
						12-layers	Flux att.	R		+	+	HAMOC6 _v

Review of key model properties

Top red cells= CMIP6 ESMs
Top pink cells = CMIP5 predecessors

Ocean Physics:

Hor. Resolution	250 km	100 km	50 km	25 km	
Vert. layers	31-40	41-50	51-60	61-70	71-80

Ocean biogeochemistry:

Trophic web	1	2	3	Plankton types	+	Implicit Plankton types
Internal physiology	simple		complex			
Stoichiometry	R=Redfield	sV=semi-variable	V=variable			
Org. Mat. cycling	1	2	3	Carbon pools		
Nutrients	Not represented	Represented				
		+ = NH ₄ ⁺				

Bold text = upgraded internal model parameterization

Darker colors means 'increase in complexity'

Ocean biogeochemistry											
Complexity											
Nutr./Element cycling			Sediments			Org. Mat. Cycling		Int. physio.		Trophic web.	
Fe	O ₂	Si	P	N	C			Stoch	Chl	Bac	Phy
						No					
						No					
						No	Gen. Cat.	R			
						No	Gen. Cat.	R			
						Balance	Size Cat.	V			
						No	Flux att.	sV		+	+
						No	Flux att.	V		+	+
						No	Size Cat.	sV		+	
						Meta-mod.	Size Cat.	sV		+	
						Sed-Box	Refr. Cat.	V		++	+
						Sed-Box	Gen. Cat.	sV		++	++
						Sed-Box	Refr. Cat.	sV		+	+
						No	Size Cat.	R			
						No	Size Cat.	R			
						No	Gen. Cat.	R		+	
						Sed-Box	Size Cat.	V		+	
						No	Size Cat.	sV		+	+
						Meta-mod	Size Cat.	sV		+	+
						No	Flux att.	R			
						Meta-mod	Flux att.	R		+	
						12-layers	Gen. Cat.	R		+	
						12-layers	Flux att.	R		+	
						No	Gen. Cat.	R			
						No	Flux att.	R			
						12-layers	Gen. Cat.	R		+	
						12-layers	Flux att.	R		+	

Review of key model properties

Top red cells= CMIP6 ESMs

Top pink cells = CMIP5 predecessors

Ocean Physics:

Hor. Resolution	250 km	100 km	50 km	25 km	
Vert. layers	31-40	41-50	51-60	61-70	71-80

Ocean biogeochemistry:

Trophic web	1	2	3	Plankton types	+	Implicit Plankton types
Internal physiology	simple		complex			
Stoichiometry	R=Redfield	sV=semi-variable	V=variable			
Org. Mat. cycling	1	2	3	Carbon pools		
Nutrients	Not represented	Represented				
		+ = NH ₄ ⁺				

Noticeable changes/updates:

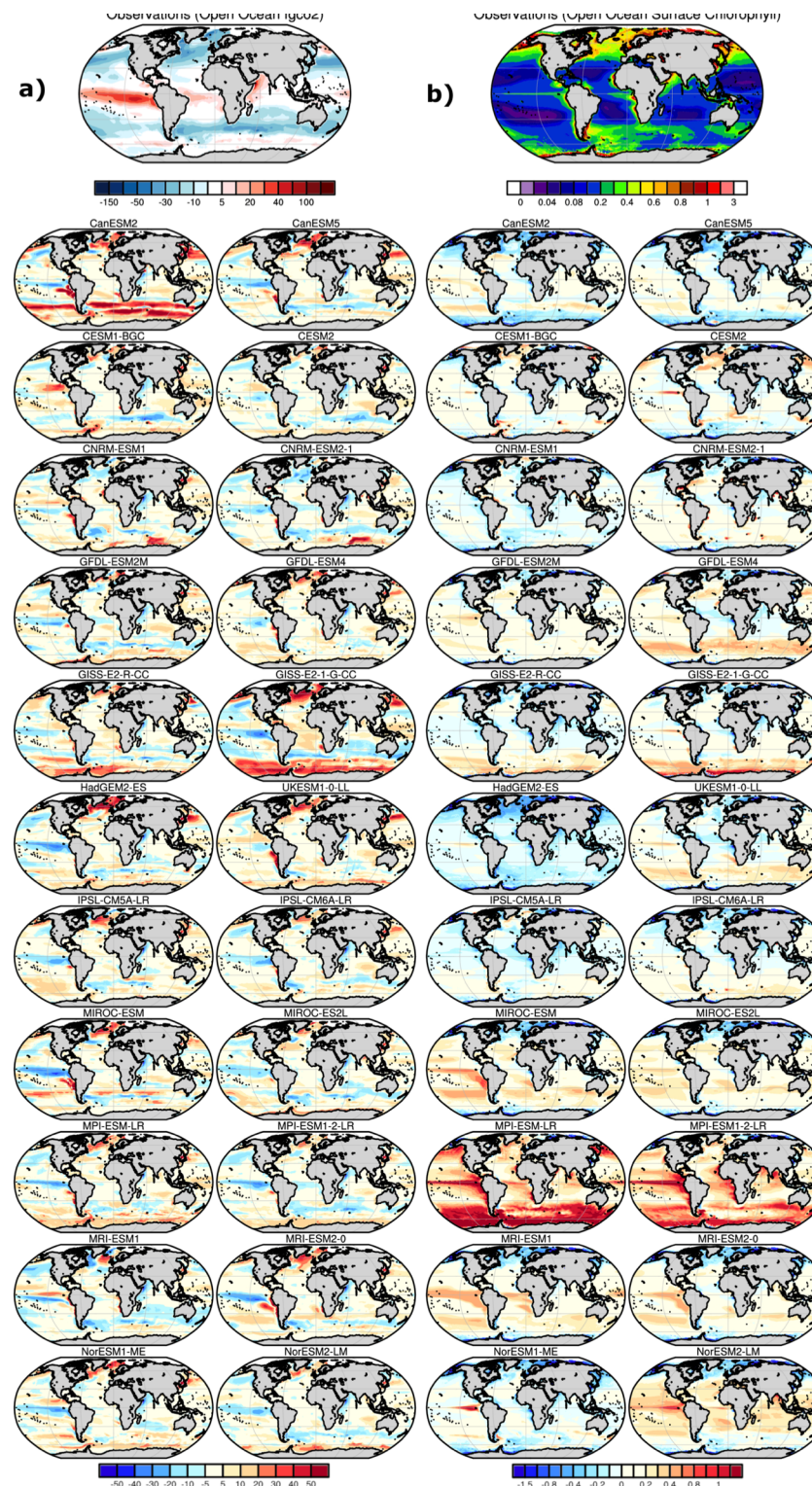
1. enhance vertical resolution, nominal horizontal resolution is 1°
2. controlled increased in complexity (key variables and processes have been added)
3. Exploration of trade-off between reduced complexity and increased resolution (GFDL-CM4, CanESM)

- What are the impact of these updates on the model performance ?

Overview of the model performance in simulating modern Ocean carbon fluxes

Obs: Landschützer et al.
 NNET dataproduct
 Model: all available CMIP5-
 CMIP6 ESMs
 Period:1995-2014

CRESCENDO ESMs

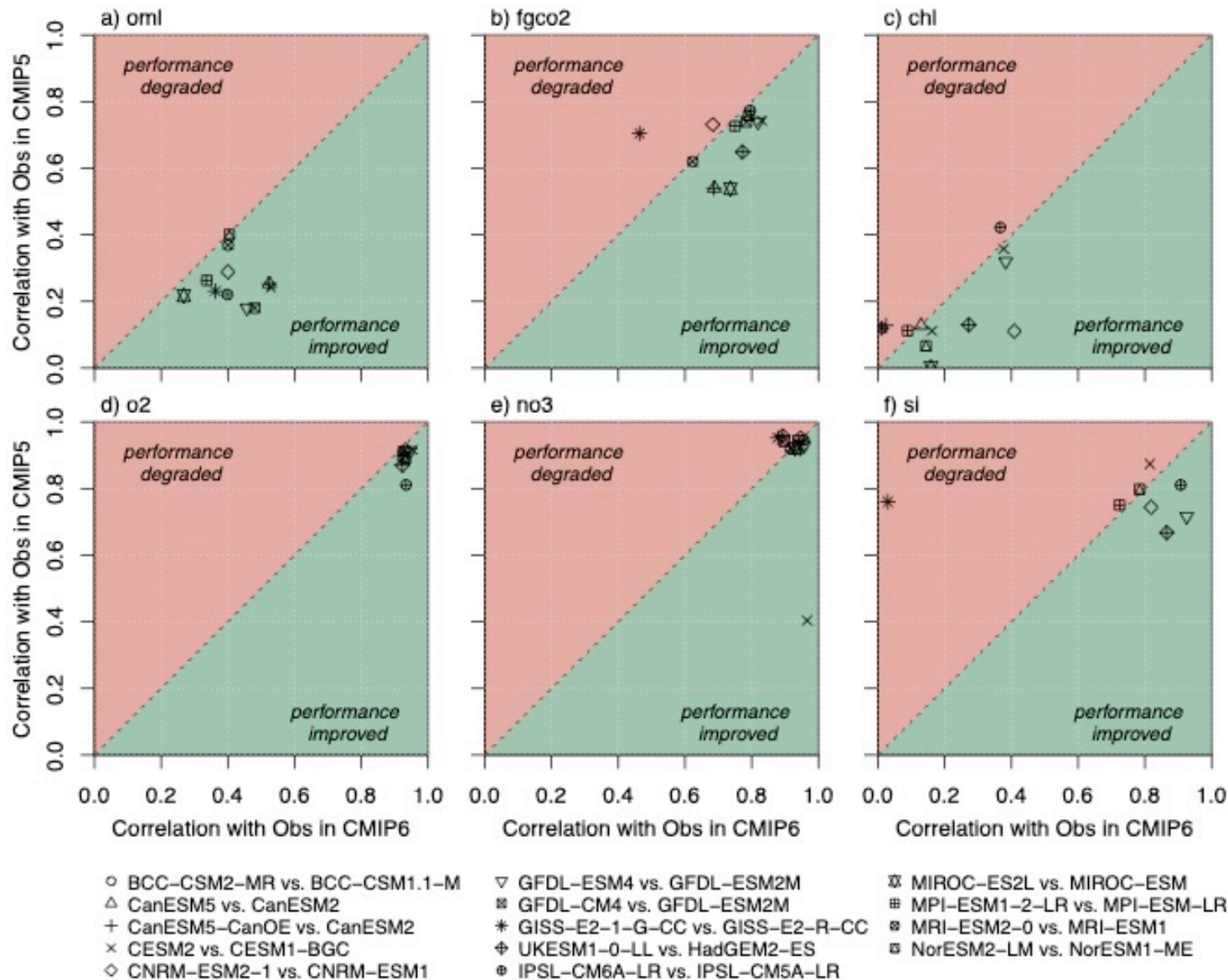


Overview of the model performance in simulating surface chlorophyll

Obs: ESA-CCI-OC
 dataproduct
 Model: all available
 CMIP5-CMIP6 ESMs
 Period:1998-2014

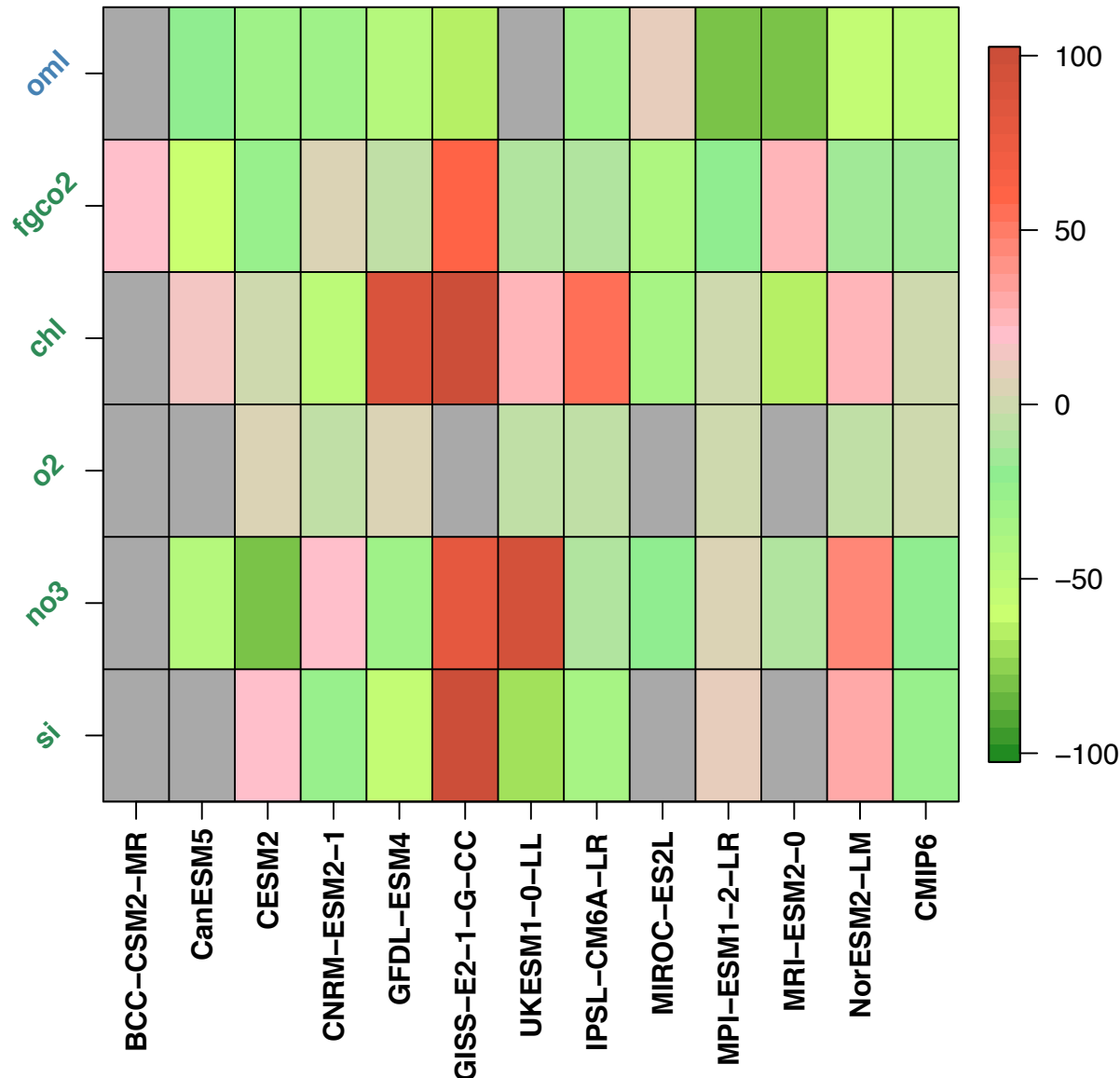
Does simulated marine biogeochemistry has been improved in CMIP6 wrt CMIP5 ?

Scatter plot of CMIP5 (y-axis) vs CMIP6 (x-axis) spatial correlation with observations



- All CMIP6 models have a better ocean physics (mixed-layer depth, oml)
- Key biogeochemical fields such as carbon fluxes (fgco2) and surface chlorophyll (chl) have been improved in almost all models
- Other ocean tracers such as oxygen (o2) and silicon (si) show little improvement (regional epistemic errors are not resolved in CMIP6)

Does simulated marine biogeochemistry has been improved in CMIP6 wrt CMIP5 ?



Skillscore matrix using Z-Score
Z-score= relative change in global weighted average RMSE in CMIP6 wrt CMIP5 in %

⇒ How to read it ?

Green = reduced model-data error 😊

Red= increased model-data error ☹️

In brief, no clear relationships between model performance and Resolution and/or Complexity

⇒ Mostly 'YES' but not clear improvment for all models.

Part 2:

Does the Earth system Interactions and feedbacks involving marine bgc have progressed in CMIP6 wrt CMIP5 ?

Review of represented/unrepresented Earth systems interactions and feedbacks

Top red cells = CMIP6 ESMs

Top pink cells = CMIP5 predecessors

Earth system interactions or couplings														
Represented feedbacks				Gas Exchange					External sources of nutrients					
F4	F3	F2	F1	NHx	N2O	DMS	O2	CO2	Ice melt.	Geoth.	Sed.	River inp.	Atm. Dep.	
														BCC-CSM1.1-M
														BCC-CSM2-MR
														CanESM2
														CanESM5
											Fe		Fe	CanESM5-CanOE
											Fe		N	CESM1-BGC
										Fe	Fe	C, N, P, Si, Fe	N, P, Si, Fe	CESM2
											Fe	C, N, P, Fe	N, Fe	CNRM-ESM1
											Fe	C, N, P, Fe	N, Fe	CNRM-ESM2-1
											Fe	C, N, P	N, Fe	GFDL-ESM2
											Fe	C,P, Fe	N, P, Fe	GFDL-CM4
									Fe	Fe	Fe	C, N, P, Fe	N, P, Fe	GFDL-ESM4
													Fe	GISS-E2-R-CC
												C, N, Si, Fe	Fe	GISSE-2-1-G-CC
											Fe		Fe	HadGEM2-ES
														UKESM1-0-LL
											Fe	C, N, P, Fe	N, Fe	IPSL-CM5A-LR
											Fe	C, N, P, Fe	N, Fe	IPSL-CM6A-LR
														MIROC-ESM
										Fe	Fe	N, P	N, Fe	MIROC-ES2L
													Fe	MPI-ESM-LR
													N, Fe	MPI-ESM1-2-LR
														MRI-ESM1
														MRI-ESM2-0
													Fe	NorESM1-ME
												C, N, Si, Fe	N, Fe	NorESM2-LM

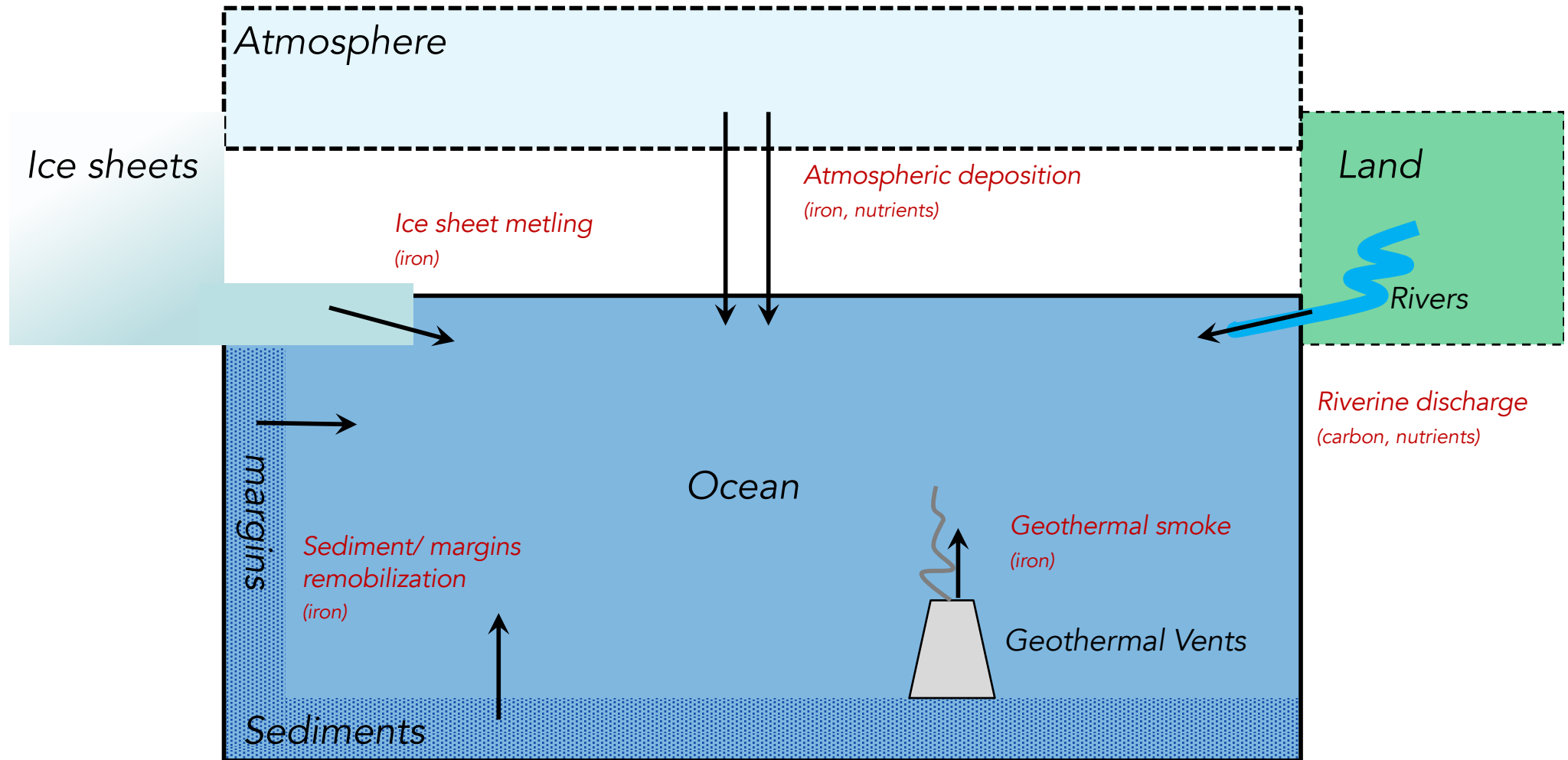
⇒CMIP6 ocean models are (in general) more comprehensive:

1. Better treatment of the nutrient and iron cycling (dust and riverine inputs interactive in some models: GFDL-ESM4/CM4, MIROC-ES2L, CNRM-ESM2-1)
2. Major/New Traces gases (chemistry or GHGs) are included in CMIP6 models

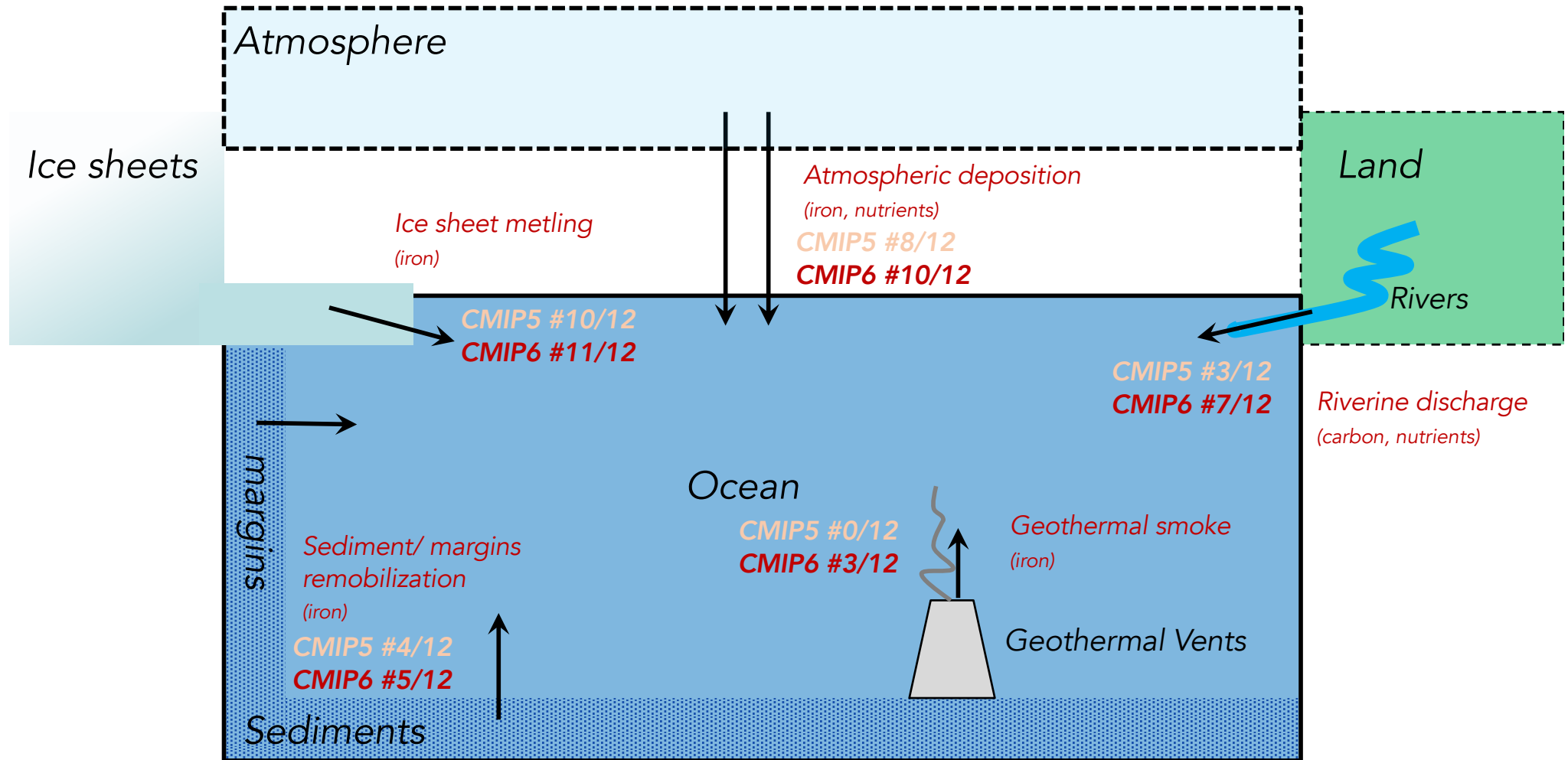
Earth system interactions or couplings:

Ext. Nut. inputs	prescribed	interactive	prognostic
Gas Exchange	Not represented	Represented	

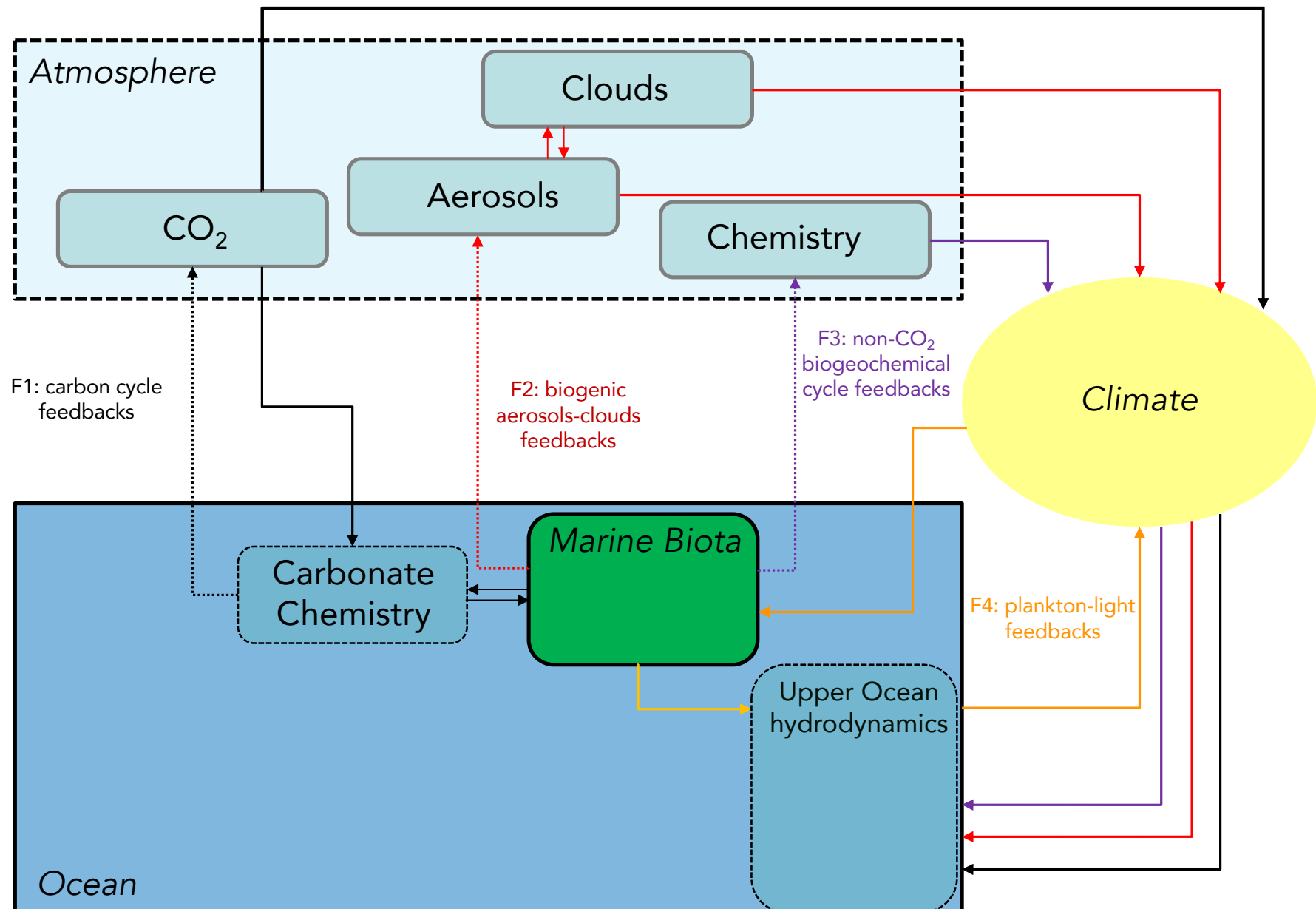
Does the Earth system Interactions involving marine bgc have progressed in CMIP6 wrt CMIP5 ?



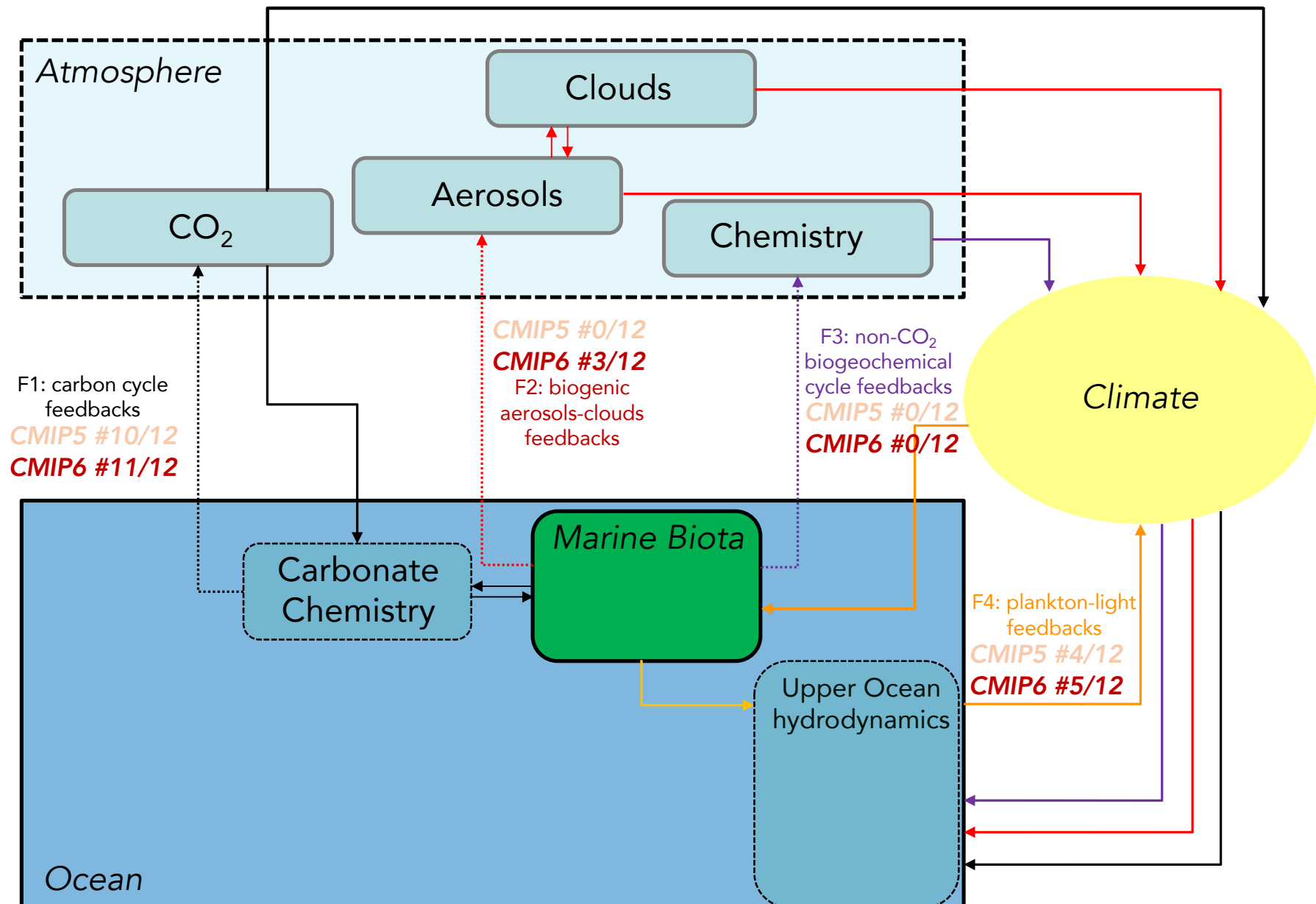
Represented Earth system interactions in ESMs



Does the Earth system feedbacks involving marine bgc have progressed in CMIP6 wrt CMIP5 ?



Represented Climate feedbacks in ESMs



Review of represented/unrepresented Earth systems interactions and feedbacks

Top red cells = CMIP6 ESMs

Top pink cells = CMIP5 predecessors

Earth system interactions or couplings															
Represented feedbacks				Gas Exchange					External sources of nutrients						
F4	F3	F2	F1	NHx	N2O	DMS	O2	CO2	Ice melt.	Geoth.	Sed.	River inp.	Atm. Dep.		
														BCC-CSM1.1-M	
														BCC-CSM2-MR	
														CanESM2	
														CanESM5	
											Fe		Fe	CanESM5-CanOE	
											Fe		N	CESM1-BGC	
										Fe	Fe	C, N, P, Si, Fe	N, P, Si, Fe	CESM2	
											Fe	C, N, P, Fe	N, Fe	CNRM-ESM1	
											Fe	C, N, P, Fe	N, Fe	CNRM-ESM2-1	
											Fe	C, N, P	N, Fe	GFDL-ESM2	
											Fe	C,P, Fe	N, P, Fe	GFDL-CM4	
									Fe	Fe	Fe	C, N, P, Fe	N, P, Fe	GFDL-ESM4	
													Fe	GISS-E2-R-CC	
												C, N, Si, Fe	Fe	GISSE-2-1-G-CC	
											Fe		Fe	HadGEM2-ES	
														UKESM1-0-LL	
											Fe	C, N, P, Fe	N, Fe	IPSL-CM5A-LR	
											Fe	C, N, P, Fe	N, Fe	IPSL-CM6A-LR	
														MIROC-ESM	
										Fe	Fe	N, P	N, Fe	MIROC-ES2L	
													Fe	MPI-ESM-LR	
													N, Fe	MPI-ESM1-2-LR	
														MRI-ESM1	
														MRI-ESM2-0	
													Fe	NorESM1-ME	
												C, N, Si, Fe	N, Fe	NorESM2-LM	

Earth system interactions or couplings:

Ext. Nut. inputs	prescribed	interactive	prognostic
Gas Exchange	Not represented	Represented	

⇒CMIP6 ocean models are (in general) more comprehensive:

1. Better treatment of the nutrient and iron cycling (dust and riverine inputs interactive in some models: GFDL-ESM4/CM4, MIROC-ES2L, CNRM-ESM2-1)
2. Major/New Traces gases (chemistry or GHGs) are included in CMIP6 models

Are we done ? Are the couplings/feedbacks involving marine bgc are well represented in ESMs ? (in other word, does the increase in model complexity align with the representation of ES feedbacks ?)

The answer is **NO...**



Thanks !

Tracking improvement in simulated marine biogeochemistry between CMIP5 and CMIP6

Full reference : Séférian, R., Berthet, S., Yool, A., Palmiéri, J., Bopp, L., Tagliabue, A., Kwiatkowski, L., Aumont, O., Christian, J., Dunne, J., Gehlen, M., Ilyina, T., John, J. G., Li, H., Long, M., Luo, J. Y., Nakano, H., Romanou, A., Schwinger, J., Stock, C., Santana-Falcón, Y., Takano, Y., Tjiputra, J., Tsujino, H., Watanabe, M., Wu, T., Wu, F., Yamamoto, A. : Tracking improvement in simulated marine biogeochemistry between CMIP5 and CMIP6, Current Climate Change Reports, doi:10.1007/s40641-020-00160-0

roland.seferian@meteo.fr