PMIP-carbon: LGM intercomparison of carbon cycle change

General idea:

To organize and write a **paper to compare the carbon results in different models taking part in PMIP** (using PMIP4 simulations for models with interactive carbon cycle). We plan to start with the LGM, trying to take on board as many people and models as possible, before possibly tackling other periods such as the deglaciation and interglacials. This would require a PI run to compare the LGM and Pre-industrial.

Core simulations

Minimum simulations required: to be done as soon as you can

- Run a **pre-industrial run**

- Run a **LGM (21ka) run with PMIP4 boundary conditions if possible** (Masa et al., GMD, 2018), or as closed as PMIP4 ones otherwise (changes of orbital parameters, greenhouse gases and ice sheets). If possible, use boundary conditions consistent with the deglaciation protocol (Ruza et al., GMD, 2016) to allow a smooth transition when running the deglaciation.

For the carbon cycle CO_2:

1. **If possible: run simulations with freely evolving atmospheric CO_2 for the carbon cycle part (NOT for the radiative part) -> this is the preferred solution**
2. if 1 is not possible: run simulations with fixed atmospheric CO_2 for the carbon cycle part (the CO_2 value should be the same as for the radiative part)
3. even better: run both (1 and 2), especially for EMICs

- No change of code between LGM and PI, only change of boundary conditions.
- For the LGM run, also increase salinity, nutrients and alkalinity to account for the volume change between LGM and PI (unless it is already accounted for)
- No sediment nor permafrost if possible in the basic LGM run (as most models won't have them)
- For the C14: fixed atmospheric concentration

Additional optional simulations: -> first for EMICs, + we need to prioritize those

A) Simulations focused on more physical and chemical aspects:

- LGM with no increase in salinity, nutrients and alkalinity
- effect of temperature: set the temperature to PI? SST?
- effect of salinity: set the salinity to PI?
- effect of sea ice for air sea exchange: fixed sea ice cover for fluxes of carbon
- effect of winds: fixed LGM-PI wind anomaly?

B) Simulations focused on boundary conditions
- simulation with only ice sheet forcing
- simulation with only insolation forcing
- simulation with only GHG forcing
- LGM with CO2 for the radiative code set to the PI value / simulation with only ice sheet and insolation

C) sediments
- PI and LGM with sediments

D) Terrestrial biosphere
- LGM simulation with common fixed terrestrial biosphere
- PI and LGM with permafrost

E) simulations focused on ocean circulation changes
- simulations with fresh water flux
- simulations with sinking of brines

F) Simulations focused on marine biology
- productivity efficiency
- iron fertilization

- with other processes...

For ocean-only models?

First ideas of analysis:

How much carbon is stored in the different reservoirs: atmosphere, ocean, terrestrial biosphere in each model (depending on what reservoirs the models have?

- How does it relate to temperature/salinity/wind patterns?
  - How does it relate to ocean circulation changes (gyres and deep ocean) and sea ice?
  - Link with how diffusion is implemented in the model?
- How is marine productivity changing in the models? (increased, decreased, global value and regional changes)
- How does it relate to distribution of nutrients?
- How does the c13 and c14 distribution change? Comparison with data
- Link between c13 and c14 changes, as well as atmospheric CO2, with ocean circulation changes, productivity changes, sea ice changes (for the models which have them)
  - Carefully compare PI simulations between models as differences during PI might induce differences for LGM
  - Terrestrial biosphere: link with complexity of model? With PI model biases of temperature and precipitation? CO2 fertilization effect?
  - Do a figure like the one from Kohfeld and Ridgwell for LGM CO2?

Outputs:

- **netCDF files**
- **cmip6 variable names (see table below)**
- **Mean of the last 100 years**
- **If possible on regular grid (discuss with JY Peterschmitt)**
- Variables :

High level of priority

(Note: variables based on CMIP5, there might be some changes for CMIP6, need to be checked again)

Priority	*Long names*	*units*	*Output variable name*	*Standard name*
1	Ocean grid cell volume	m3	volcello	ocean_volume
1	Ocean Grid-Cell Area	m2	areacello	cell_area
1	Ocean Model Cell Thickness	m	thkcello	cell_thickness
1	Sea Water Potential Temperature	K	thetao	sea_water_potential_temperature
1	Sea Water Salinity	psu	so	sea_water_salinity
1	Ocean Meridional Overturning Mass Streamfunction	kg s -1	msftmyz	ocean_meridional_overturning_mass_streamfunction
1	Sea Ice Area Fraction	%	sic	sea_ice_area_fraction
1	Sea Ice Thickness	m	sit	sea_ice_thickness
1	Dissolved Inorganic Carbon Concentration	mol m -3	dissic	mole_concentration_of_dissolved_inorganic_carbon_in_sea_water
2	Dissolved Organic Carbon Concentration	mol m -3	dissoc	mole_concentration_of_dissolved_organic_carbon_in_sea_water
1	Total Alkalinity	mol m -3	talk	sea_water_alkalinity_expressed_as_mole_equivalent

2	Dissolved Oxygen Concentration	mol m -3	o2	mole_concentration_of_molecular_oxygen_in_sea_water
1	Mole Fraction of CO2	1e-6	co2	mole_fraction_of_carbon_dioxide_in_air
1	Atmosphere Grid-Cell Area	m2	areacella	cell_area
1	Land Area Fraction	%	sftlf	land_area_fraction
2	Tree Cover Fraction	%	treeFrac	area_fraction
2	Natural Grass Fraction	%	grassFrac	area_fraction
2	Bare Soil Fraction	%	baresoilFrac	area_fraction
1	Carbon Mass in Vegetation	kg m -2	cVeg	vegetation_carbon_content
1	Carbon Mass in Litter Pool	kg m -2	cLitter	litter_carbon_content
1	Carbon Mass in Soil Pool	kg m -2	cSoil	soil_carbon_content
1 if possible	Dissolved Inorganic Carbon-13 Concentration	mol m-3	dissi13c	
2	Mass of 13C in All Terrestrial Carbon Pools	kg m-2	c13Land	
2	Eastward Near-Surface Wind	m s -1	uas	eastward_wind
2	Northward Near-Surface Wind	m s -1	vas	northward_wind
2	Temperature at 2m			
2	Precipitation			

- C13 in atmosphere ?
- carbon 14
- nitrate
- phosphate

Low level of priority?
u
v
pH
iron
silicate
chlorophyll
Pa/Th
εNd

Possible list of models and people participating:

Model	Group	People
7 EMICs		
Bern3D-LPX	University of Bern, Switzerland	Fortunat Joos, Aurich Jeltsch-Thömmes, Jurek Müller
CLIMBER-X	PIK, Germany	Matteo Willeit
cGenie	University of California, Riverside; University of Bristol, UK; University of St Andrews, UK, University of Cardiff, UK; Stockholm University, Sweden	Carlye, Andy Ridgwell, Andrea Burke, James Rae, Katherine Crichton, Malin Odalen
iLOVECLIM	LSCE/IPSL, France; Vrije Universiteit Amsterdam, The Netherlands	Didier Roche, Nathaelle Bouttes, Fanny Lhardy
LOVECLIM	UNSW, Australia	Laurie Menviel, Anne Mouchet
UVic/MOBI	Oregon State University, US; CCT-Conicet Cenpat, Argentina	Juan Muglia, Andreas Schmittner, Sophie Wilmes
UVic	UNSW, Australia	Katrin Meissner
6 Atmosphere-ocean GCMs		
FAMOUS	University of Leeds, UK	Ruza Ivanovic, Lauren Gregoire, Jennifer Dentith
HadCM3	University of Leeds, UK	Ruza Ivanovic and Lauren Gregoire
IPSL-CM5 / IPSL-CM6	LSCE/IPSL, France	Pascale Braconnot, Masa Kageyama, Didier Roche,

		Laurent Bopp, Nathaelle Bouttes
MIROC-ES2L	JAMSTEC, Japan; The University of Tokyo, Japan	Akitomo Yamamoto, Ayako Abe-Ouchi
MPI (HAMOCC)	MPI, Germany	Tatyana Ilyiana (PalMod)
NorESM1/NorESM2	Uni Research Climate, Norway; University of Bergen, Norway	Jerry Tjiputra, Christoph Heinze, Augustin Kessler
1 ocean-only model		
REcoM	AWI, Germany	Martin Butzin, Peter Köhler and Christoph Völker

+
Alice Marzocchi (not sure)
Christiano Chiessi (maybe later)
+ analysis, data…
Sandy P. Harrison

Information on the models

Model	Fixed winds?	Fixed clouds?	Fixed terrestrial biosphere?	Fixed atmospheric CO2 for carbon cycle?	Ice sheet reconstruction? Ice-6G, Glac-1D or both?	
Bern3D-LPX						
CLIMBER-X						
cGenie						
iLOVECLIM						
LOVECLIM						
UVic/MOBI						
UVic						
FAMOUS						
HadCM3						
IPSL-CM5 / IPSL-CM6						
MIROC-ES2L						
MPI (HAMOCC)						
NorESM1/NorESM2						
REcoM						

State of the simulations

Model	Basic LGM with prognostic atmospheric CO2	Basic LGM with diagnostic atmospheric CO2		
Bern3D-LPX				
CLIMBER-X				
cGenie				
iLOVECLIM	running	Not planned		
LOVECLIM				
UVic/MOBI				
UVic				
FAMOUS				
HadCM3				
IPSL-CM5 / IPSL-CM6				
MIROC-ES2L				
MPI (HAMOCC)				
NorESM1/NorESM2				
REcoM				

Done/running/long-term/not planned