Is there a correlation between cloud phase and surface snowfall rate in GCMs?

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- **Why is it important to present cloud phase and snowfall accurately? Is snowfall bias in GCMs relatable to cloud phase bias?**
- How can we use GCM data using `Pangeo`?
- What was not provided by `Pangeo`?

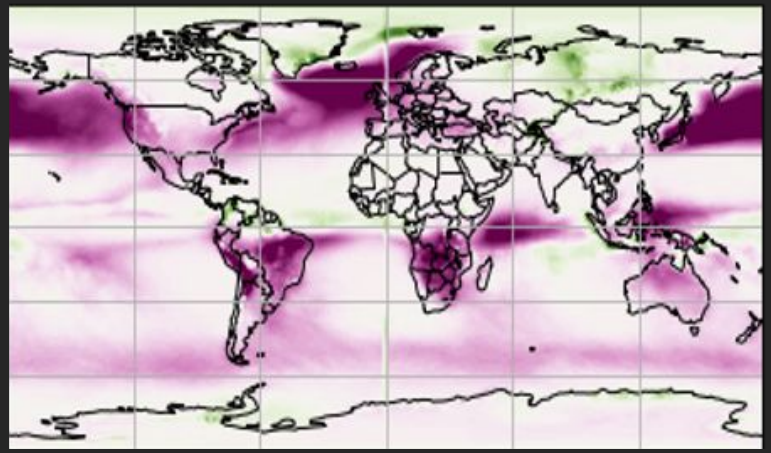
Objective

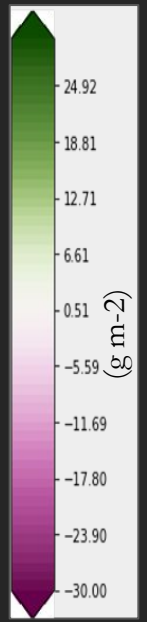
Mixed phase clouds are not well represented in GCMs.

Ice formation influences radiative effect, precipitation formation, and cloud lifetime.

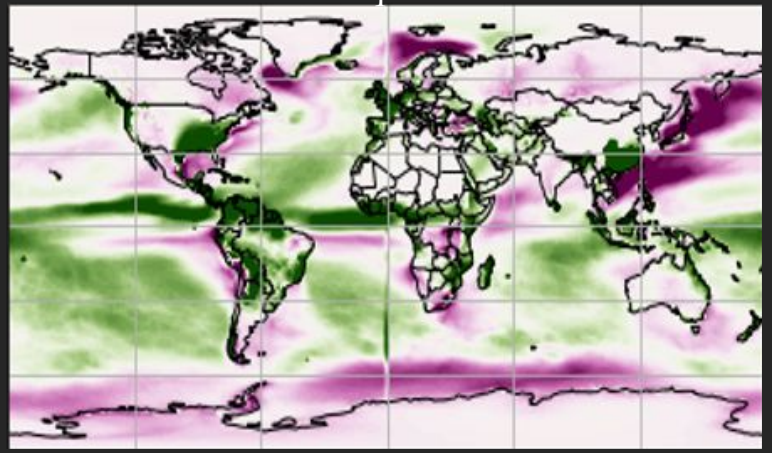
Ice water path/Liquid water path (ERA5 - CMIP6)

Ice





Liquid



Ice water path overestimate

Liquid water path underestimate

30 year, season: DJF

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CMIP6 models and variables (pangeo.io)

17 CMIP6 models
Horizontal resolution 100 km

Institution	Model name	Reference
AS-RCEC	TaiESM1	Lee et al. (2020)
BCC	BCC-CSM2-M	Wu et al. (2019)
CAMS	CAMS-CSM1-0	
CAS	FGOALS-f3-L	Bian et al. (2020)
CMCC	CMCC-CM2-SR5	Cherchi et al. (2019)
	CMCC-CM2-HR4	Cherchi et al. (2019)
	CMCC-ESM2	CMCC website
EC-Earth-Consortium	EC-Earth3-AerChem	van Noije et al. (2021)
E3SM-Project	E3SM-1-1	Golaz et al. (2019); Burrows et al. (2020) Text S8
	E3SM-1-1-ECA	
MPI-M	MPI-ESM1-2-HR	Müller et al. (2018)
MRI	MRI-ESM2-0	Yukimoto et al. (2019)
NCC	NorESM2-MM	Seland et al. (2020)
NOAA-GFDL	GFDL-CM4	Held et al. (2019)
	GFDL-ESM4	Dunne et al. (2020)
SNU	SAM0-UNICON	Park et al. (2019)
THU	CIESM	Lin et al. (2020)

shortname	Long name	Units	levels
prsn	Snowfall Flux	[kg m-2 s-1]	surface
clw	Mass Fraction of Cloud Liquid Water	[kg kg-1]	ml
cli	Mass Fraction of Cloud Ice	[kg kg-1]	ml
tas	Near-Surface Air Temperature	[K]	surface
ta	Air Temperature	[K]	plev
clivi	Ice Water Path	[kg m-2]	
lwp	Liquid Water Path	[kg m-2]	
pr	Precipitation	[kg m-2 s-1]	surface

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Horizontal grid (CMIP6 to NorESM2-MM)

```
[ ]:
ds_out = dset_dict['CMIP.NCC.NorESM2-MM.historical.Amon.gn']
ds_in  = dset_dict[model]

import xesmf

# Regridder data
regridder = xesmf.Regridder(ds_in, ds_out, "conservative")

# Apply regridder to data
 # the entire dataset can be processed at once
ds_in_regrid = regridder(ds_in)
```

https://tinyurl.com/regridder

Vertical grid (hybrid-σ-pressure to isobaric-pressure)

$$P(i,j,k) = hyam(k)p0 + hybm(k)ps(i,j)$$

```
[ ]: import geocat

geocat.comp.interpolation.interp_hybrid_to_pressure(data      =NorESM2['variable'],
                                                    ps        =NorESM2['ps'],
                                                    hyam      =NorESM2['a'],
                                                    hybm      =NorESM2['b'],
                                                    p0        =NorESM2['p0'],
                                                    new_levels=NorESM2['plev'])
```

https://tinyurl.com/hybridtopressure

Key points

- `Pangeo` provides good amount of functions
  - Vertical interpolation: `geocat.comp.interp_hybrid_to_pressure`
  - Horizontal interpolation: `xesmf.Regridder`

Next steps

- Find mixed-phase clouds in CMIP6
- Relate mixed-phase clouds to surface snowfall
- Include satellite data (CloudSat)

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My Notebooks