Project # 2
Run your sea ice projections
LPHYS2265 2023

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1 Objectives and steps for this part

This exercise consists in performing idealized sea ice projections with the model you built earlier in this class.

In this part, what is important is to actually provide the projections, even if you are not fully happy with them, because we'll use them collectively in Part 3 (basis for the report). In this sense, this exercise very closely approaches the reality, with climate modelling groups in a hurry to finalize their projections even if they are not perfect.

The steps of this exercise are:

- to tune and adjust the physics of your model to match a given ice thickness target,
- to run 100-yr projections.

What to deliver? 4 files with control simulation and projections (see format below). **Deadline: April 17**.

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2 The model

You will need the python / matlab model you have written. The version to use is at least from exercise 3.1 (ocean but no snow) or better 3.2 (ocean and snow). If you suspect a small bug, remember that your life depends on your ability to provide projections.

Depending on what you have achieved, copy your python script into a script "CONTROL_MYMODEL.py".

Give your model a name. Don't use the same as your neighbour, because we'll have to distinguish between the different models in the end.

3 Control experiment

In this control (CTL) experiment, the goal is to achieve a model equilibrium seasonal cycle that is as close as possible to the simulation of *Maykut and Untersteiner* (1971) (MU71). The latter data provides a seasonal cycle of ice thickness that is typical of Arctic perennial ice before the recent effects of climate change.

The target seasonal cycle of ice thickness you should achieve is given by the twelve monthly mean values of ice thickness:

```
hi_MU71 =
    [2.82,2.89,2.97,3.04,3.10,3.14,2.96,2.78,2.73,2.71,2.72,2.75]
```

To prepare comparison of your model output with MU71 data, do the following:

- Impose albedo = 0.77 and $F_w = 2$ W/m^2.
- Run your model the number of years you need to stabilize the thickness seasonal cycle. That would be typically 20 years, but if your initial thickness value is too far from equilibrium, this will take longer. You can check if equilibrium is achieved if the annual mean thickness changes from one year to the other by a negligible amount.

- Add a plot zooming on the last year of your results, together with MU71 data. You will probably find that, as coded, your simulated thickness is not very close to MU71 data. You will have to fix that.

3.1 Model improvement

To achieve a decent thickness seasonal cycle, you will have to improve and tune your model. In the real world, modellers fight a lot on model improvement and tuning, among themselves and with other scientists. Model improvement takes time and is acceptable if the added physics make sense. Tuning is necessary because models are always imperfect and have to match a reality that is neither perfectly observed nor completely understood. In this context, tuning is fine if you act on parameters that are not well measured or not measurable at all. It is less defendable if you act on well-measured quantities, like the latent heat of fusion for example. You could end up with good results but for bad reasons.

To adjust thickness, here is what I suggest you to do. Please be aware that you have the right not to like my solution, and that you are free to choose your own solution to achieve a decent equilibrium thickness seasonal cycle. It could make the exercise funnier!

Also accept that the target data are somehow uncertain, and so you do not have to stick precisely to them. **Errors on annual mean thickness within 20% can be considered as acceptable**.

The general recipe is to act on thermal conductivity and surface albedo. Thermal conductivity acts on sea ice growth. Surface albedo affects surface melting (as explained in the class).

3.2 Making thermal conductivity and albedo more elaborate

To tune your thermal conductivity and albedo, I propose you a solution outlined by Semtner that was working for me. You can adopt it fully, in part, or simply not at all, depending on the time you have and whether you are fully convinced or not that this all makes sense to you.

1. Your model misses some physics to be realistic enough. It does not store negative heat ("coldness") in winter. Hence, in summer, any incoming

heat directly melts the ice instead of warming it. The first trick (from Semtner) is to multiply all (ice and snow) thermal conductivities by a factor $\gamma^{SM} \approx 1.1$ to artificially enhance ice growth, which will increase the equilibrium thickness. Semtner is the guy who did write your model for the first time in the 70's (*Semtner*, 1976)

2. A constant albedo is a bit annoying, because it is known that albedo is related to ice or snow presence. It is going to help if you parameterize albedo as Semtner did it. Semtner proposes an albedo parameterization based on snow depth. I reinterpreted it in the following way. It works ok. If snow is deeper than $h^s_{crit} = 0.1$ m, the albedo must be that of dry snow ($\alpha_s = 0.83$). If there is no snow, the albedo is that of bare ice ($\alpha_i = 0.64$). Between 0 and 10 cm of snow, the albedo linearly increases with snow depth.

3. The last problem of your model is the following. In summer, radiation penetrates below the surface, which melts ice at the edges of brine inclusions within the ice rather than at the surface. To compensate for the absence of this process and reduce the spurious melting, *Semtner* (1976) proposes to reflect back to space a fraction $\beta^{SM} \approx 0.3 - 0.5$ of the radiation that should be stored into brine inclusions. In turn, you should recompute your albedo α using:

$$\alpha^{eff} = \alpha + \beta^{SM}(1-\alpha)i_o \tag{1}$$

where $i_o = 0.25$ is the fraction of radiation penetrating below the ice surface. This parameterization will have the effect to reflect more radiation back to space, instead of melting the ice, and reduce summer melting.

3.3 Model tuning

Now you get this working, you can start tuning your model. The goal is that, at equilibrium, you are reasonably close to the simulation of MU71.

To do this, you will have to run the model several, if not many times. If you used the tricks I provided, try values for γ^{SM} roughly between 1 and 1.2. Try values for β^{SM} roughly between 0. and 0.5.

You could also adjust α_s, α_i, ϵ, i_o. Even F_w in the worst case scenario, but then you can be criticized because the external forcing you apply is no more identical to what the others are using.

Do the best you can, but use your brain, don't act as a robot. If you see things not moving, then breathe, have a break and get your ideas together.

A final important remark: it is good in this part to make your own choices, to avoid that all models are the same.

3.4 Sharing your experience

The idea is to share your model output with everyone, so that we can compare in the end. To do so we must use common format. Just share the **daily output** of the **last year** of your equilibrium run (365 numbers for surface temperature, thickness, ice thickness, snow depth and water temperature). Store your model output in a text file. Use "CTL_MY_MODEL.txt" (give it your model's name). If using python, you should incorporate the following lines:

```
# Full time series of everything
data = np.column_stack((days,Tsu, h_i, h_s, Tw))
np.savetxt('CTL_MY_MODEL.txt', data, delimiter=" ",
    fmt='%s')
```

4 Climate projections

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Now we are happy with our model's mean state, we will run 3 sea ice projections. Copy "CONTROL_MYMODEL.py" into "PROJECTION_MYMODEL.py" to be able to go back to your control simulation.

In these projections, we will progressively increase downwelling longwave radiation, over the upcoming 100 years, to emulate the effect of the increasing greenhouse effect.

We will run 3 projections, corresponding to weak, mild and strong climate change scenarios, with a maximum longwave perturbation of $\Delta Q^{lw} = 3, 6, 12$ W/m^2 at the end of year 100. The 12 W/m^2 is somehow crazy, but your model is not sensitive enough because of the absence of ice dynamics and atmosphere/ocean feedbacks.

- Set the number of years to 100.

- Take the last value of your four model prognostic variables (h_i, h_s, T_w, T_{su}), at the end of the equilibrium cycle, and use those as initial values for your projections.

- If using python, compute the longwave perturbation as follows, within your model loop:

```
year = np.modf(day/365)[1]
delta_lw = delta_lw_max * year / 100.
```

  where $delta\_lw\_max$ is the imposed longwave perturbation (3,6,12). Add $delta\_lw$ to your surface energy balance (over sea ice and ocean).

- To analyze your projections in an easier way, diagnose the following quantities, to remove the seasonal cycle and see the long-term trend.

```
# Yearly diagnostics
h_i_max  = np.zeros(Ny)     # Annual maximum ice thickness
h_i_min  = np.zeros(Ny)     # Annual minimum ice thickness
h_i_mean = np.zeros(Ny)     # Annual mean thickness
h_s_max  = np.zeros(Ny)     # Annual maximum snow thickness
T_su_min = np.zeros(Ny)
for year in range(0,Ny):
    day00 = year*365
```

```
    day99 = day00+364
    h_i_max[year] = max(h_i[day00:day99])
    h_s_max[year] = max(h_s[day00:day99])
    h_i_min[year] = min(h_i[day00:day99])
    h_i_mean[year] = np.mean(h_i[day00:day99])
    T_su_min[year] = min(Tsu[day00:day99])
```

- Plot it and check that your simulations make sense. Temperature should slightly increase and thickness should decrease. By how much will depend on your model.
- Export your 100 years of diagnostics (100 values) in a text file, using the following lines.

```
data = np.column_stack((years, h_i_min, h_i_mean
    , h_i_max,h_s_max,T_su_min))
np.savetxt('PR03_MY_MODEL.txt', data, delimiter=
    " ", fmt='%s')
```

- Repeat the operation for +6 and +12 W/m^2. In the end, you should get three files: PR03_MY_MODEL.txt, PR06_MY_MODEL.txt and PR12_MY_MODEL.txt.
- Check that your model output is sensible. Make sure ice thickness decreases with time, more so for larger LW perturbation. Check minimum temperature is increasing somehow.
- Once you are satisfied, save the four text files (CTL_MY_MODEL.txt, PR03_MY_MODEL.txt, PR06_MY_MODEL.txt, PR12_MY_MODEL.txt), and send them by email at martin.vancoppenolle@locean.ipsl.fr.

References

Fletcher, J. O. (1965), The heat budget of the arctic basin and its relation to world climate, *Tech. Rep. R-444-PR*, The Rand Corp., Santa Monica, California.

Maykut, G. A., and N. Untersteiner (1971), Some results from a time-dependent thermodynamic model of sea ice, *Journal of Geophysical Research*, *76*, 1550–1575.

Semtner, A. J. (1976), A model for the thermodynamic growth of sea ice in numerical investigations of climate, *Journal of Physical Oceanography*, *6*, 379–389.