Notes for a FAFMIP experiment with MOM

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Abstract

These notes are intended to be a guide for the FAFMIP test case. FAFMIP includes three main experiments: FAF-HEAT, FAF-WATER and FAF-STRESS. Only the first experiment requires some code changes, that we introduce here. Both FAF-WATER and FAF-STRESS are trivial and can be performed with the standard MOM5 code.

Key words: MOM5, FAFMIP, Surface flux perturbations, ocean tracers

1. Introduction

The perturbation experiments use the Flux-Anomaly-Forced Model Intercomparison Project (FAFMIP) surface flux perturbations (Gregory et al., 2016). FAFMIP anomalies are the results of CMIP5 atmosphere-ocean general circulation models (AOGCM) under the scenario called 1pctCO2. In 1pctCO2, CO_2 concentrations increase at a rate of 1%/yr and double their preindustrial concentration at year 70. FAFMIP flux perturbations are obtained from the time mean during years 61-80 of CMIP5 1pctCO2 experiments, with a seasonal cycle retained.

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Gregory et al. (2016) proposes three options for performing FAF-HEAT. Method A does not require any code changes, using the standard potential temperature tracer to compute the ocean surface heat flux. Method B introduces two new tracers: added heat, T^A, and redistributed heat, T^R. Method C uses climatological monthly-mean SSTs, instead of the prognostic temperature field, to compute the ocean surface heat flux.

These notes detail the code changes and necessary steps to perform FAF-HEAT Method B.

For a detailed introduction and derivation we refer the reader to Gregory et al. (2016) and the FAFMIP website `http://www.fafmip.org/`.

2. Control Experiment

In order to perform any ocean/sea-ice FAFMIP experiment, the global ocean-sea ice model MOM5 is first forced by the CORE-I atmospheric dataset, or any other atmospheric forcing providing a *repeated year* climatological state.

Within the CORE-I protocol, multi-centennial simulations are forced by a repeated *normal year* forcing, which contains synoptic variability and has been derived from 43 years of atmospheric data to represent one normal year, representative of El Niño Southern Oscillation neutral conditions, with no major anomalies associated with other modes of climate variability (Griffies et al., 2009).

We will refer to this experiment as our Control. The Control experiment should be ideally spun-up for thousands of model years.

3. FAF-HEAT experiment

3.1. FAFMIP heat tracers

We here document the three heat related tracers considered in the FAF-HEAT experiment using Method B.

3.1.1. Potential or Conservative temperature

The potential or Conservative temperature field, θ, affects the seawater density. It satisfies the following equation for a surface ocean grid cell

$$\frac{\partial(\theta\,\rho\,\mathrm{dz})}{\partial t} = \mathrm{ADV}(\mathbf{v},\theta) + \mathrm{SGS}(\kappa,\theta) + Q^{\theta}_{\text{advect}} + Q^{\theta}_{\text{frazil}} + Q^{T^R}_{\text{non-advect}} + Q_{\text{FAF}}. \tag{1}$$

We now detail the terms appearing in (1).

- ADVECTION of θ is represented by $\mathrm{ADV}(\mathbf{v},\theta)$, where $\mathbf{v}$ is the three-dimensional current vector.
- SUBGRID SCALE PROCESSES are represented by $\mathrm{SGS}(\kappa,\theta)$, with κ symbolizing any number of diffusivites or non-local processes associated with the parameterized subgrid scale.
- ADVECTIVE HEAT FLUX Q^{θ}_{advect} arises from the transfer of water across the ocean boundary through precipitation, evaporation, and runoff. Note that $Q^{\theta}_{advect} = 0$ in an ocean model that does not transfer mass across its boundary, such as a rigid lid or linear free surface ocean model. However, for real water flux models, it is important to note how Q^{θ}_{advect} is computed.
- FRAZIL HEAT FLUX Q^{θ}_{frazil} is used to keep the potential temperature no lower than the freezing point of seawater. In a non-FAFMIP simulation, this heat is extracted from the sea ice model to produce sea ice. But for FAFMIP, it is the frazil term Q^{TR}_{frazil} that is exchanged with sea ice, whereas the frazil heat flux Q^{θ}_{frazil} is ignored by the sea ice model.
- NON-ADVECTIVE HEAT FLUX $Q^{\theta}_{non-advect}$ includes latent, sensible, longwave, and shortwave contributions. Importantly, this flux in FAFMIP is determined by the redistributed heat tracer, T^R, discussed in Section 3.1.2.

3.1.2. Redistributed heat tracer

The redistribued heat tracer, T^R, does not affect ocean density, yet it does affect the surface fluxes. It is initialized to θ at the start of the simulation and it satisfies the following equation

$$\frac{\partial(T^R\,\rho\,\mathrm{dz})}{\partial t} = \mathrm{ADV}(\mathbf{v},T^R) + \mathrm{SGS}(\kappa,T^R) + Q^{TR}_{\text{advect}} + Q^{TR}_{\text{frazil}} + Q^{TR}_{\text{non-advect}}. \tag{2}$$

As defined, T^R does not feel the perturbation heat flux, Q_{FAF}. However, T^R is used to compute the non-advective heat flux, $Q^{TR}_{\text{non-advect}}$, which also impacts the potential temperature θ in (1). Additionally, the frazil heat, Q^{TR}_{frazil}, is extracted from the sea-ice model to produce ice. Finally, the advective heat flux, Q^{TR}_{advect}, uses T^R for its precipitation and evaporation temperature.

3.1.3. Added heat tracer

The added heat tracer, T^A, does not affect density nor does it impact the surface heat fluxes. It is initialized to 0°C at the start of the simulation, and represents a perturbation temperature arising from the added heat in Q_{FAF}. Consequently, it is not bound to be above the freezing point of seawater, and so does not have a frazil heating term. For the surface ocean, T^A satisfies the following equation

$$\frac{\partial(T^A\,\rho\,\mathrm{dz})}{\partial t} = \mathrm{ADV}(\mathbf{v},T^A) + \mathrm{SGS}(\kappa,T^A) + Q_{\text{FAF}}. \tag{3}$$

T^A thus feels the perturbation heat flux Q_{FAF}, but not the coupled heat flux $Q^{TR}_{\text{non-advect}}$. Additionally, T^A is not altered by mass transport across the ocean surface, since we assume this transport has zero added heat content, $Q^{TA}_{\text{advect}} = 0$.

3.2. *Running a FAF-HEAT Experiment*

Here, we introduce the necessary MOM code changes, forcing and initial files for running FAF-HEAT as in Gregory et al. (2016) Method B. The code, when enabled, uses Method B for the heat flux perturbation and introduces two new tracers: added heat, T^A, and redistributed heat, T^R.

3.3. *Code changes*

Code changes include:

- `/ocean_core/ocean_bbc.F90`
- `/ocean_core/ocean_sbc.F90`
- `/ocean_core/ocean_types.F90`
- `/ocean_core/ocean_model.F90`
- `/ocean_tracers/ocean_frazil.F90`
- `/ocean_tracers/ocean_tpm.F90`
- `/ocean_tracers/ocean_tempsalt.F90`
- `/ocean_tracers/ocean_tracer.F90`
- `/ocean_param/sources/ocean_shortwave.F90`

3.4. *Tables and namelist changes*

The following changes have to be introduced for the new tracers definitions and appropriate flags:
In the `field_table`:

```
"diag_tracers","ocean_mod","frazil_redist"
   restart_file = ocean_frazil_redist.res.nc
   /

"prog_tracers","ocean_mod","added_heat"
   horizontal-advection-scheme = mdppm
   vertical-advection-scheme = mdppm
   restart_file = ocean_added_heat.res.nc
   ppm_hlimiter=2
   ppm_vlimiter=2
   /

"prog_tracers","ocean_mod","redist_heat"
   horizontal-advection-scheme = mdppm
   vertical-advection-scheme = mdppm
   restart_file = ocean_redist_heat.res.nc
   ppm_hlimiter=2
   ppm_vlimiter=2
   /
```

In the `input.nml`:

```
&ocean_sbc_nml
    do_flux_correction = .true.
    tau_x_correction_scale = 1.0
    tau_y_correction_scale = 1.0
    salt_correction_scale = 1.0
    temp_correction_scale = 1.0

&ocean_tempsalt_nml
    do_fafmip_heat = .true.
```

3.5. *Initial and forcing files*

When running FAF-HEAT, both new heat tracers need to be initialized. Added heat is initialized at 0°C, $T^A = 0$, with a file called `ocean_added_heat.res.nc`. Redistributed heat is initialized with the same initial conditions as potential temperature, $T^R = \theta$, with a file called `ocean_redist_heat.res.nc`.

Forcing files include the heat surface flux perturbation `temp_sfc_correction.nc` and the added heat surface flux perturbation `added_heat_sfc_correction.nc`, which have the same 2-D field `sfc_hflux`.

3.6. *A first sanity check: vanishing perturbation heat flux*

The first test that should be done is a check of our code modifications and input files. The following steps will reproduce the results of the Control experiment, using the FAF-HEAT code modifications but setting the heat surface flux perturbation to zero.

1. Prepare to continue running the experiment with CORE-I forcing from a restart file.
2. Include in the `INPUT` directory initial conditions for the two additional tracers (redistributed heat and added heat), as well as the forcing files.
3. In `field_table`, include information on the two additional tracers redistributed heat and added heat, as detailed in Section 3.4.
4. In input_nml, set the following:

```
&ocean_sbc_nml
    do_flux_correction = .true.
    temp_correction_scale = 0.0
    tau_x_correction_scale = 0.0
    tau_y_correction_scale = 0.0
    salt_correction_scale = 0.0

&ocean_tempsalt_nml
    do_fafmip_heat = .true.
```

By setting the above, we will use the FAF-HEAT code modifications but we will also set the surface flux anomalies to zero. In this trivial case of a vanishing perturbation heat flux, $F = 0$, the redistributed heat tracer and the potential temperature satisfy the same equation. Since they are initialized to be the same, they will remain the same throughout the simulation, $\theta = T^R$. This identity offers a useful check that code for the redistributed heat tracer has been properly implemented. Since $F = 0$, added heat will remain equal to zero, $T^A = 0$.

3.7. *A true FAF-HEAT Experiment*

Repeat the experiment as in Section 3.6 and set

```
do_flux_correction = .true.
temp_correction_scale = 1.0
tau_x_correction_scale = 0.0
tau_y_correction_scale = 0.0
salt_correction_scale = 0.0
```

for adding the full heat surface flux perturbation included in the FAFMIP data set.

References

Gregory, J. M., et al., 2016: The Flux-Anomaly-Forced Model Intercomparison Project (FAFMIP) contribution to CMIP6: investigation of sea-level and ocean climate change in response to CO_2 forcing. *Geosci. Model Dev.*, **9**, 3993–4017.

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