

Perturbation Tool (V4r4)

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Introduction

This document describes steps to set up and run programs and scripts to compute the ECCO ocean model's (V4r4) response to perturbations in its control ("Perturbation Tool"); i.e., forward sensitivity. The tool is useful for studying the ocean's response to changes in the controls and to assess the accuracy of adjoint gradients. Available perturbations are, at present, those listed in steps 15) & 16) below.

The ocean model is the flux-forced version of ECCO's Version 4 release 4 (V4r4) ocean state estimate described in Wang et al. [2021]. The output of the Perturbation Tool consists of differences in time-series of model state (sea level, ocean bottom pressure, temperature, salinity, velocity) between model integrations with and without the perturbation, normalized by dividing the results by the amplitude of the perturbation. Perturbation to the control is at a particular model grid point at a particular time defined weekly, starting from 12Z January 01, 1992, which is the starting instant of V4r4. The model time-step is 1-hour and the perturbation is interpolated linearly in time.

A. Steps to set up the tool

User commands/input are given in **red**. (Steps 1-4 in *italic* are the same as those for setting up the bulk-formula version of the model described in Wang et al. [2020].) **pfe25>** denotes Unix prompt.

1) *Create and cd to a work directory*

```
pfe25>mkdir WORKDIR
```

```
pfe25>cd WORKDIR
```

2) *Download MITgcm "checkpoint 66g"*

```
pfe25>git clone https://github.com/MITgcm/MITgcm.git -b checkpoint66g
```

3) *Create and cd to subdirectory*

```
pfe25>cd MITgcm
```

```
pfe25>mkdir -p ECCOV4/release4
```

```
pfe25>cd ECCOV4/release4
```

- 4) Download V4 configurations

```
pfe25>git clone https://github.com/ECCO-GROUP/ECCO-v4-Configurations
```

- 5) Extract flux-forced configuration of the model

```
pfe25>mv ECCO-v4-Configurations/ECCOV4\ Release\ 4/flux-forced .
```

```
pfe25>rm -rf ECCO-v4-Configurations
```

```
pfe25>cd flux-forced
```

```
pfe25>set basedir=`pwd`
```

```
pfe25>mkdir forcing
```

- 6) Download forcing from ECCO Drive. (Substitute username “*fukumori*” below with your own username and use your WebDAV password, **NOT** your Earthdata account password.) The second wget will take a while to complete.

```
pfe25>wget -P forcing -r --no-parent --user fukumori --ask-password -nH --cut-dirs=4  
https://ecco.jpl.nasa.gov/drive/files/Version4/Release4/input_init
```

```
pfe25>wget -P forcing -r --no-parent --user fukumori --ask-password -nH --cut-dirs=4  
https://ecco.jpl.nasa.gov/drive/files/Version4/Release4/other/flux-forced
```

- 7) Load module for compilation.

```
pfe25>module purge
```

```
pfe25>module load comp-intel/2020.4.304
```

```
pfe25>module load mpi-hpe/mpt.2.25
```

```
pfe25>module load hdf4/4.2.12
```

```
pfe25>module load hdf5/1.8.18_mpt
```

```
pfe25>module load netcdf/4.4.1.1_mpt
```

```
pfe25>module list
```

- 8) Compile MITgcm program (generates executable “mitgcmuv”)

```
pfe25>mkdir build
```

```
pfe25>cd build
```

```
pfe25>../../../../tools/genmake2 -mods=../code  
-optfile=../../../../tools/build_options/linux_amd64_ifort+mpi_ice_nas -mpi
```

```
pfe25>make depend
```

```
pfe25>make all
```

```
pfe25>cd ..
```

- 9) Download scripts, programs, and data files for the Perturbation Tool and compile. (Substitute username “*fukumori*” below with your own username and use your WebDAV password, **NOT** your Earthdata account password.)

```
pfe25>git clone https://github.com/ECCO-GROUP/ECCO-EIS.git
```

```
pfe25>mv ECCO-EIS/tool_pert .
```

```
pfe25>rm -rf ECCO-EIS
```

```
pfe25>wget -P tool_pert -r --no-parent --user fukumori --ask-password -nH --cut-  
dirs=7 https://ecco.jpl.nasa.gov/drive/files/Version4/Release4/other/flux-  
forced/tool_pert_data
```

```
pfe25>cd tool_pert
```

```
pfe25>make all
```

- 10) Copy files that will be modified, just in case. (optional)

```
pfe25>cp -p gen_pert_ref.csh gen_pert_ref.csh_orig
```

```
pfe25>cp -p tool_pert.csh tool_pert.csh_orig
```

```
pfe25>cp -p setup.csh setup.csh_orig
```

```
pfe25>cp -p README_pert README_pert_orig
```

- 11) **Modify** MITgcm’s namelist file “*data*”. (Can be skipped for initial testing.)

In the `tool_pert` directory in step 9) above, there are three data* files that control the behavior of MITgcm suitable for the Perturbation Tool. In particular, the namelist file “`data`” is configured for test purposes and should be changed for production runs as below.

Specifically, variable `nTimeSteps` in file “`data`” controls the number of time-steps MITgcm will integrate. The `tool_pert` version in 9) uses

`nTimeSteps=13110,`

which amounts to an 18-month integration period used for testing purposes. To run the full 26-year period of V4r4, select

`nTimeSteps=227903,`

On Pleiades, the 18-month and 26-year integrations take 35-min and 10-hours walltime, respectively.

12) **Modify** scripts “`tool_pert.csh`” and “`gen_pert_ref.csh`” as needed.

Script `tool_pert.csh` is a script for users to run the perturbation tool. Script `gen_pert_ref.csh` creates the model’s reference without the perturbation. These files downloaded in step 9) are PBS scripts for running the tool in the devel queue on NAS Pleiades; job controls (`#PBS ...`) and modules should be adapted to the computing platform.

In particular, as in namelist file “`data`” in step 11), the two scripts downloaded are configured for test purposes by limiting the walltime to 2-hours using the “`devel`” queue;

```
#PBS -l walltime=2:00:00
#PBS -q devel
```

Revise/remove these variables/parameters as needed. For reference, 18-month and 26-year integrations take approximately 35-minutes and 10-hours walltime, respectively, in the Tool’s particular configuration on Pleiades.

13) **Modify** scripts.

```
pfe25>sed -i -e "s|SETUPDIR|${basedir}|g" gen_pert_ref.csh
```

```
pfe25>sed -i -e "s|SETUPDIR|${basedir}|g" tool_pert.csh
```

14) Run Perturbation Tool without perturbation to obtain reference results.

This job will produce results under a new directory named `run_pert_ref` in `basedir` (step 5).

```
pfe25>qsub gen_pert_ref.csh
```

15) Copy tools (`tool_csh.csh`, `README_pert`) for user access. Set `FORUSERDIR` below to a full directory path name where you want to install (copy) the tools at.

```

pfe25>set useraccessdir=FORUSERDIR

pfe25>mkdir ${useraccessdir}

pfe25>sed -i -e "s|SETUPDIR|${basedir}|g" setup.csh

pfe25>sed -i -e "s|PUBLICDIR|${useraccessdir}|g" setup.csh

pfe25>sed -i -e "s|PUBLICDIR|${useraccessdir}|g" README_pert

pfe25>cd ${useraccessdir}

pfe25>cp -p ${basedir}/tool_pert/setup.csh .

pfe25>cp -p ${basedir}/tool_pert/README_pert .

```

16) Run Perturbation Tool as a user with user-defined perturbation.

We would like this step to be replaced by a web-based interface, with a feature (e.g., e-mail) to notify users when the computation is complete and where to retrieve the results (step 16).

Here, the perturbation is specified by program *pert_nml.x* and the model result is computed by PBS script *tool_pert.csh*.

Program *pert_nml.x* requires a user's response, specifying what the user wants to perturb. Example below perturbs "empmr" (evaporation minus precipitation minus river runoff) at model grid (85,601) at week 12 with magnitude $-1\text{e-}3$ (kg/m²/s). Program *pert_nml.x* will generate two text files *pert_xx.nml* and *pert_xx.str* that are used in PBS script *tool_pert.csh*.

File *pert_xx.nml* is a namelist file read by program *pert_xx.x* invoked by *tool_pert.csh* that perturbs the model's control. File *pert_xx.str* contains a character string used by *tool_pert.csh* in naming a directory ("*run_directory*") where the computation's output will be placed under *USRDIR* below.

The *run_directory* for the example here will be *run_pert_1_85_601_12_-1.00E-03*, which bears a description of the perturbation in its name. The results to be provided to the user will be placed in sub-directory *pert_result_output* under this *run_directory* (see step 17).

We would like to replace *pert_nml.x* with a web interface, where users fill out the queries and submit the job (equivalent to submitting *tool_pert.csh*) by clicking a button ("submit job").

Create and go to a user directory (USRDIR below, change as needed) to run the tool, separate from where the tool was set up above.

```
pfe25>mkdir USRDIR
```

```
pfe25>cd USRDIR
```

Run setup.csh to set up the perturbation tool in the user directory. (Replace FOREUSERDIR below with what it was specified in step 14.)

```
pfe25>source FORUSERDIR/setup.csh
```

```
pfe25>pert_nml.x
```

Available control variables to perturb ...

- 1) empmr
- 2) pload
- 3) qnet
- 4) qsw
- 5) saltflux
- 6) spflx
- 7) tauu
- 8) tauv

Enter control ... (1- 8) ?

1

..... perturbing empmr

Choose location for perturbation ...

Enter 1 to choose native grid location (i,j),
9 to select by latitude/longitude ... (1 or 9)?

1

Enter native (i,j) grid to perturb ...

i ... (1-90) ?

85

j ... (1-1170) ?

601

..... perturbation at (i,j) = 85 601
which is (long E, lat N) = -151.8 73.5
Depth (m) at this location = 3808.8

Enter week to perturb ... (1-1358) ?

12

..... perturbing week = 12

Default perturbation = -1.00000005E-03
in unit kg/m2/s (upward freshwater flux)

Enter 1 to keep, 9 to change ... ?

1

Wrote pert_xx.nml

Wrote pert_xx.str

pfe25>qsub tool_pert.csh

- 17) Results of the Perturbation Tool will be in sub-directory **pert_result_output** under the *run_directory* described in step 16).

Users only need files in this sub-directory, once the computation of step 16) is complete.

pert_xx.nml:

Namelist file with specifics of the perturbation saved for reference. Created by pert_nml.xx and used by pert_xx.x to perturb controls of MITgcm.

pert_result.obp_day

pert_result.ssh_day

Daily mean output of ocean bottom pressure (obp) and sea level (ssh). Units are meters in equivalent sea level for both. Files are direct access binary. Each record is for a particular day and consists of a time-step index and a 2-dimensional array (90-by-1170) of the daily mean quantity on the model's native grid. The time-step index (1-hour time-step from 12Z January 01, 1992) is an integer*8 (64-bit integer) variable. The 2d array is real*4 (single precision) and is normalized as the model's response to a unit perturbation of the control (control's unit noted by pert_nml.x in step 13). For reference, the units of all the controls are;

- control (1) = 'empmr' 'kg/m2/s (upward freshwater flux)'
- control (2) = 'pload' 'N/m2 (downward surface pressure loading)'
- control (3) = 'qnet' 'W/m2 (net upward heat flux)'
- control (4) = 'qsw' 'W/m2 (net upward shortwave radiation)'
- control (5) = 'saltflux' 'g/m2/s (net upward salt flux)'
- control (6) = 'spflx' 'g/m2/s (net downward salt plume flux)'
- control (7) = 'tauu' 'N/m2 (westward wind stress)'
- control (8) = 'tauv' 'N/m2 (southward wind stress)'

pert_result.obp_mon

pert_result.salt_mon

pert_result.ssh_mon

pert_result.theta_mon

pert_result.uvelmass_mon

pert_result.vvelmass_mon

Monthly mean output of ocean bottom pressure (obp), salinity (salt), sea level (ssh), potential temperature (theta), zonal velocity (uvelmass), and meridional velocity (vvelmass). Units are PSU for salt, degrees centigrade for theta, and m/s for velocity. Units for obp and ssh are meters in equivalent sea level for both. Files are direct access binary. Each record is for a particular month and consists of a time-step index and an

array of the model's field on its native grid, which is 90-by-1170-by-50 for 3-dimensional fields of salt, theta, and velocity and 90-by-1170 for 2-dimensional obp and ssh. The time-step index (1-hour time-step from 12Z January 01, 1992) is an integer*8 (64-bit integer) variable. The array is real*4 (single precision) and is normalized as the model's response to a unit perturbation of the control as in the daily fields above.

Example code to read a particular record (irec) of [pert_result.theta_mon](#)

FORTRAN

```
integer nx, ny, nr
parameter (nx=90, ny=1170, nr=50)
integer irec
integer*8 itime
real*4 fld(nx,ny,nr)
character*256 f_in

f_in = 'pert_result.theta_mon'
open(60, file=f_in, access='direct',
$  recl=nx*ny*nr*4+8, form='unformatted')
read(60,rec=irec) itime, fld
```

IDL

```
nx = 90
ny = 1170
nr = 50

f_in = 'pert_result.theta_mon'
close,1 & openr,1,f_in,/swap_if_little_endian
d_rec = {itime:long64(0), fld:fltarr(nx,ny,nr)}
d_file = assoc(1,d_rec)
d_theta = d_file(irec)
```

B. [Perturbation Tool on Pleiades](#)

The perturbation tool has been set up on Pleiades and can be run by the following steps.

- 1) Create and cd to a work directory. Results and pertinent files will be created under this directory.

```
pfe25>mkdir USRDIR
```

```
pfe25>cd USRDIR
```

- 2) Set up perturbation tool.


```
pfe25>source /nobackup/ifukumor/ECCO_tools/pert/setup.csh
```

For demonstration purpose, and to avoid unintentionally long computations, this step sets up a namelist file “**data**” that limits the model’s duration of integration to 18-months (variable “**nTimeSteps**”; see A-11). Similarly, the PBS script “**tool_pert.csh**” limits the walltime to 2-hours using the “devel” queue;

```
#PBS -l walltime=2:00:00
```

```
#PBS -q devel
```

Revise/remove these variables/parameters as needed; See A-12).

- 3) Specify perturbation (follow the prompt; see step A-16).

```
pfe25>pert_nml.x
```

- 4) Submit PBS job to run the Perturbation Tool's computation (see step A-16).

```
pfe25>qsub tool_pert.csh
```

- 5) Results of the computation will be generated in sub-directory **pert_result_output** under the “**run_directory**” (run_pert_*****) that will be created under USRDIR of step B-1). (See steps A-16 & A-17.)

References