REEF2FAST

User Guide (v3.0)

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October 23, 2025

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1 Overview

REEF2FAST is a lightweight command-line application for coupling high-fidelity wavefield data from REEF3D's shock-absorbing non-hydrostatic Navier–Stokes solver (NHFLOW) with the SeaState module of OpenFAST. It enables the direct incorporation of numerically generated hydrodynamic environments into aero-hydro-servo-elastic simulations of floating offshore wind turbines (FOWTs). The software is implemented in modern C++ with a streaming architecture that limits memory usage by retaining only three timesteps simultaneously. REEF2FAST was developed by Aron Vogelsang as part of his Master's thesis at the Department of Marine Civil Engineering, NTNU, and is distributed under the GNU General Public License v3.0 as fully open-source software.

1.1 Key Features

- **File Reader**. Streamingly loads REEF3D::NHFLOW output data from CSV files, supporting both two- and three-dimensional wavefields.
- **Wheeler Projection**. Applies vertical stretching to capture NHFLOW wavefield quantities located outside the vertical SeaState domain.
- **Interpolator**. Applies a k-d tree-based nearest-neighbor scheme to project scattered σ-grid point-cloud data from NHFLOW onto the structured Cartesian SeaState grid used by OpenFAST.
- **Surface Elevation Mapper**. Derives OpenFAST compatible surface elevation arrays, using either NHFLOW's vertical coordinate z or its surface elevation η.
- **Acceleration Estimator**. Computes particle accelerations using finite difference schemes.
- **Exporter**. Writes SeaState-compatible output files, including three-dimensional velocities and accelerations, elevation, and non-hydrostatic pressure arrays. Additionally, generates SeaState input file for efficient and direct implementation into coupled workflow.

For a detailed discussion of the computational theory underlying the algorithms employed in REEF2FAST, as well as evidence of physical consistency based on model-scale validation tests, read the accompanying Master's thesis. The thesis also outlines recommended use cases and further room for improvement. Good luck!

2 System Requirements

- **Operating System**. REEF2FAST is designed to be platform-independent. However, it has been developed on MacOS. Users on MacOS and Windows reported successful installations with current `CMakeLists.txt`.
- **Compiler**: C++17 or newer. Recommended: Homebrew LLVM Clang (MacOS) — tested with Clang `15.0.7`. GCC 10+ or Clang 12+ should also work on Linux.
- **Build**. CMake 3.18+.
- **Libraries**. nanoflann and optional OpenMP for parallelization.
- **RAM**. Recommended: 16+ GB. Proportional to spatial grid size (not timestep dependent); streaming minimizes peak usage.

3 Installation from Source

3.1 Libraries

The header-only library `nanoflann` is already included in the `../external/` folder of the REEF2FAST GitHub repository and does not need to be installed separately. OpenMP support is optional but recommended for improved performance in interpolation and export operations. Most modern compilers provide native OpenMP support; however, on MacOS with Homebrew LLVM, the `libomp` runtime must be installed explicitly via:

```
brew install libomp
```

When building on MacOS, CMake will automatically link `libomp` if it is detected.

3.2 Building REEF2FAST

Once OpenMP is properly configured, clone the repository into your desired working directory:

```
$ git clone https://github.com/aronvogelsang/REEF2FAST.git
```

Navigate into the project folder:

```
$ cd REEF2FAST
```

Create a data directory with:

```
$ cd mkdir data
```

Create a separate build directory and compile:

```
$ mkdir build && cd build
$ cmake ..
$ make -j
```

The REEF2FAST executable will be created in the `build` directory. Run the program from there, some paths are hard-coded.

4 Running NHFLOW

To use wave kinematic data from NHFLOW within the REEF2FAST coupled framework, certain prerequisites must be met when setting up and running the NHFLOW simulation. REEF2FAST reads the `ctrl.txt` and `control.txt` configuration files from REEF3D and DiveMesh, respectively. This section outlines the relevant options in these files that must be configured to ensure compatibility with REEF2FAST.

4.1 DiveMesh file

The `control.txt` file defines the domain specifications:

Domain dimensions

```
B 2 [X, Y, Z]
```

Mesh size

```
B 10 [x, y, z]
```

Note. If $y = 1$, REEF2FAST will automatically run in 2D mode.

4.2 REEF3D file

The `ctrl.txt` file defines the NHFLOW setup:

Select NHFLOW

```
A 10 5
```

Select wave theory and wave parameters

```
B 90 1
B 92 [a]
B 93 [h, d]
```

Note. If you use `B 91` instead of `B 93`, the `REEF2FAST.dat` file must be adapted accordingly.

Set simulation length

```
N 41 [T]
```

Wave kinematic data are transferred using ParaView binary files. At minimum, enable the following printout options:

Print .vtu files

```
P 10 1
```

To define a constant timestep for subsequent OpenFAST simulations and acceleration computations in REEF2FAST:

Set constant timestep for OpenFAST coupling

```
P 30 [dt]
```

Note. For long simulations, you may use `P 35` during the run. Before copying `control.txt` into the REEF2FAST data folder, change `P 35` to `P 30` and remove the start and end time step specifications, leaving only the Δt value.

5 Obtaining wave kinematics

The most straightforward method for making the wavefield simulated by NHFLOW accessible to REEF2FAST is via ParaView. For details on installing and using ParaView, read its official user documentation or consult the REEF3D user guide for more tailored instructions. If ParaView is not available, the Python `vtk` package can be used to process the wave kinematic data.
The objective is to obtain a single, row-wise CSV file sorted by timestep, containing the columns listed below in the specified order. Columns should be separated by commas. The file must not contain any additional data except, a single header row containing column names. The specific names in the header matter, also the *order* of the columns is critical.

REEF2FAST expects row-wise CSV data exported from REEF3D, sorted by `TimeStep`:

Column	Description
`TimeStep`	integer index (monotone, contiguous)
`velocity:0`	u velocity component ($\mathrm{m\,s^{-1}}$)
`velocity:1`	v velocity component ($\mathrm{m\,s^{-1}}$)
`velocity:2`	w velocity component ($\mathrm{m\,s^{-1}}$)
`pressure`	Dynamic pressure (Pa)
`elevation`	Free-surface elevation at point (m)
`Points:0`	x coordinate (m)
`Points:1`	y coordinate (m)
`Points:2`	z coordinate (m)

Note: The `elevation` column is not strictly required, but it is recommended to enable the full range of REEF2FAST features. If no elevation data are available, run REEF2FAST in geometric configuration mode.

data > case1.csv

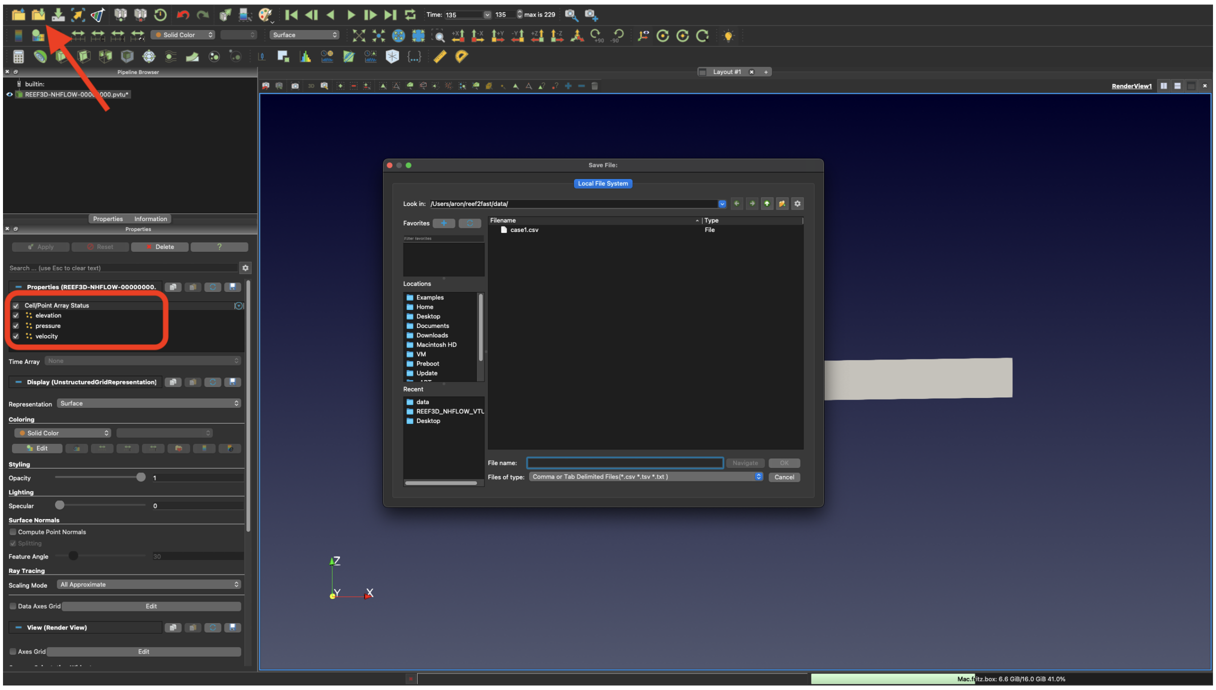
```
"TimeStep","velocity:0","velocity:1","velocity:2","pressure","elevation","Points:0","Points:1","Points:2"
0,2.30356e-05,0.00000e+00,-2.92472e-04,0.00000e+00,0.00000e+00,-7.00000e+02,-5.00000e-01,0.00000e+00
0,8.93010e-05,0.00000e+00,-5.68269e-04,0.00000e+00,0.00000e+00,-6.97500e+02,-5.00000e-01,0.00000e+00
0,1.71294e-04,0.00000e+00,-5.29143e-04,0.00000e+00,0.00000e+00,-6.95000e+02,-5.00000e-01,0.00000e+00
0,2.43682e-04,0.00000e+00,-4.79395e-04,0.00000e+00,0.00000e+00,-6.92500e+02,-5.00000e-01,0.00000e+00
0,3.05289e-04,0.00000e+00,-4.20941e-04,0.00000e+00,0.00000e+00,-6.90000e+02,-5.00000e-01,0.00000e+00
0,3.55278e-04,0.00000e+00,-3.55793e-04,0.00000e+00,0.00000e+00,-6.87500e+02,-5.00000e-01,0.00000e+00
```

Figure 1: Example of a correctly formatted CSV file (Visual Studio Code) compatible with REEF2FAST.

5.1 ParaView

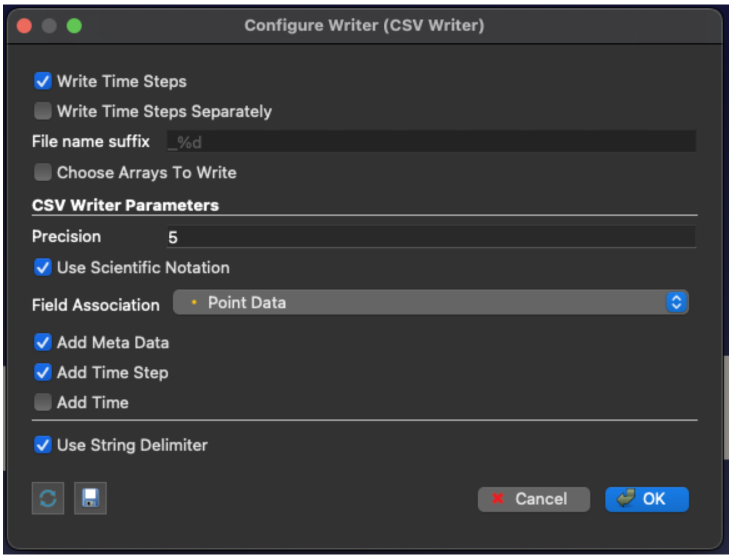
If you export the CSV file with ParaView, you do not need to worry about the file format. As long as you set the export options correctly, ParaView will create the file exactly in the way REEF2FAST requires – no processing needed.
The following sequence of screenshots will guide you step-by-step through the process of exporting the wavefield data correctly in ParaView:

1. Click "Save Data" in the top-left corner (red arrow), before make sure the options "pressure", "velocity", and "elevation" are all ticked within the Cell/Point Array Status on the left side in the menu (red rectangle):



2. In the window that opens, navigate to the `../REEF2FAST/data` folder, choose a file name, and select the option "Comma or Tab Delimited Files (*.csv *.tsv *.txt)". Click "OK". Another window will appear – here, tick the following options: "Write Time Steps", "Use Scientific Notation", "Add Meta Data", "Add Time Step", and "Use String Delimiter". Keep the precision at 5 for a good balance between accuracy and file size. Under "Field Association", select "Point Data". The selected options are shown in the screenshot below. Click "OK" to start the export.

This may take a moment.



Your exported file is now in REEF2FAST's `data` folder and ready for use when you run the program.

6 Running REEF2FAST

Before starting the program, make sure that `control.txt`, `ctrl.txt`, and the `*.csv` file are placed in the `data` folder. The name of the `*.csv` file does not matter. You can either leave the compiled REEF2FAST executable in the `build` folder or create a dedicated simulation folder inside the REEF2FAST directory and run the tool from there.
Open your terminal, navigate to the `build` or `simulation` folder, and start the program with:

```
$ ./reef2fast
```

When the program starts, you will be prompted to choose whether to use geometric data (`z`) or hydrodynamic data (`e`) for the surface elevation interpolation algorithm.
Next, select whether you want to apply the Wheeler stretching method (`y` or `n`).
For debugging purposes, you can also choose to write out an interpolated output CSV file (`y` or `n`).
If you run REEF2FAST in its 2D configuration, you must duplicate the wavefield along the transverse (y) direction to make it compatible with OpenFAST. REEF2FAST will then prompt you to specify the desired y-domain width and the number of cells in the y-direction.
Once all user flags have been set, the program will begin iterating. The console output will look similar to the example shown below.

Figure 2: Example REEF2FAST console output during execution.

7 Using REEF2FAST-generated Wavefields

After a successful run of the program, the generated files will be located in the `output` folder. You can now use them in any OpenFAST simulation. In addition to the eight wave kinematic fields, you will find a `REEF2FAST.dat` file in this folder. This file can be used directly as the `SeaState` input file in OpenFAST, already containing the correct domain configuration.
Since the OpenFAST grid and the REEF3D grid will not match exactly, this is particularly helpful—especially when you are still getting familiar with OpenFAST. Furthermore, the `WaveMod 6` option is already activated for fully externally generated wavefields, and the simulation length

is set according to the `N 41` option you specified earlier in your NHFLOW case.
Note: In the current OpenFAST version, fully external wavefields can only be run with strip theory, not with potential theory. Set the `HydroDyn` file accordingly.

7.1 File Naming Conventions

- Elevation: `REEF2FAST.Elev`
- Velocities: `REEF2FAST.Vxi`, `REEF2FAST.Vyi`, `REEF2FAST.Vzi`
- Accelerations: `REEF2FAST.Axi`, `REEF2FAST.Ayi`, `REEF2FAST.Azi`
- Dynamic pressure: `REEF2FAST.Dynp`
- SeaState file: `REEF2FAST.dat`

8 Tutorials

You can find three ready-to-run benchmark cases in REEF2FAST's `benchmark` folder:

- Regular wave case
- Second-order Stokes wave case
- Irregular JONSWAP spectrum

These cases are already correctly set up. Run them to familiarise yourself with the software.