NHERI SimCenter

Center for Computational Modeling & Simulation

WE-UQ Tutorial

Characterizing ABL flows using large-eddy simulation for wind load evaluation

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About WE-UQ

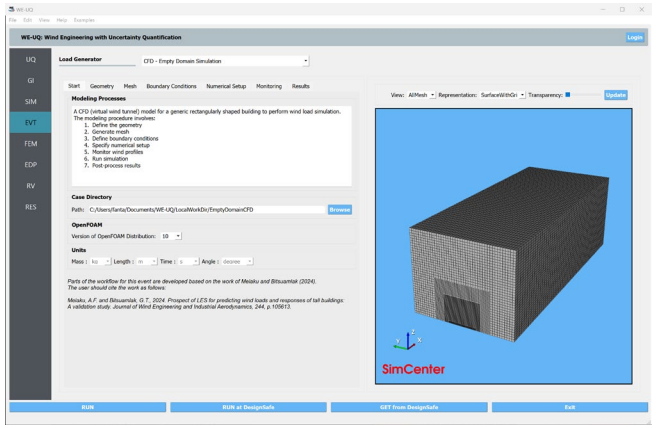
- **Wind Engineering with Uncertainty Quantification** (WE-UQ) is an open-source tool for predicting the response of a building subjected to wind loads while propagating uncertainties present in the wind and structural parameters. The simulations are performed in a workflow application that will run on either the user's local machine or on a high-performance computer at DesignSafe.

- Tool webpage: https://simcenter.designsafe-ci.org/research-tools/we-uq/
- Tool documentation: https://nheri-simcenter.github.io/WE-UQ-Documentation/
- Source code in Github: https://github.com/NHERI-SimCenter/WE-UQ
- User forum: https://github.com/orgs/NHERI-SimCenter/discussions/categories/we-uq
- DesignSafe account: https://www.designsafe-ci.org/

Outline

- **Introduction**
  - ✓ CFD-based workflow in WE-UQ
- **Tutorial description**
  - ✓ Setup files
  - ✓ Target experimental measurement
- **CFD Setup in WE-UQ**
  - ✓ Geometry & domain setup
  - ✓ Mesh generation
  - ✓ Boundary conditions
  - ✓ Numerical setup
  - ✓ Monitoring results
  - ✓ Running on HPC
- **Results and post-processing**
  - ✓ Display results in WE-UQ
  - ✓ Flow visualization using Paraview

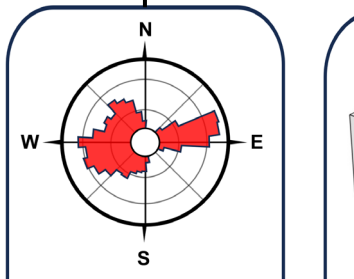
Modeling of wind effects on buildings in WE-UQ



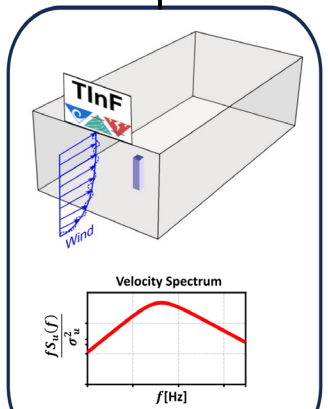
CLOUD | UQ | SAM | FEM | Earthquake | **Wind** | Tsunami | EDP | DL

EVENT

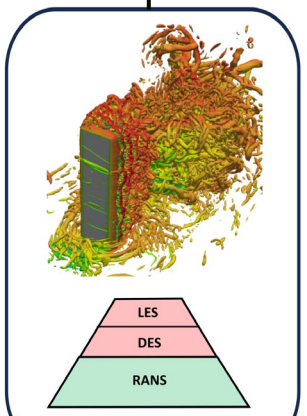
Wind Climate → **Terrain Effect** → **Aerodynamic Effect** → **Dynamic Effect** → **EDP**



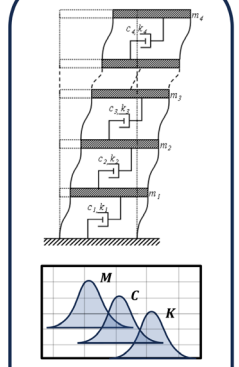
Wind speed & direction



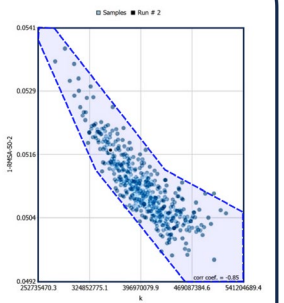
Boundary Conditions



Turbulence Modeling

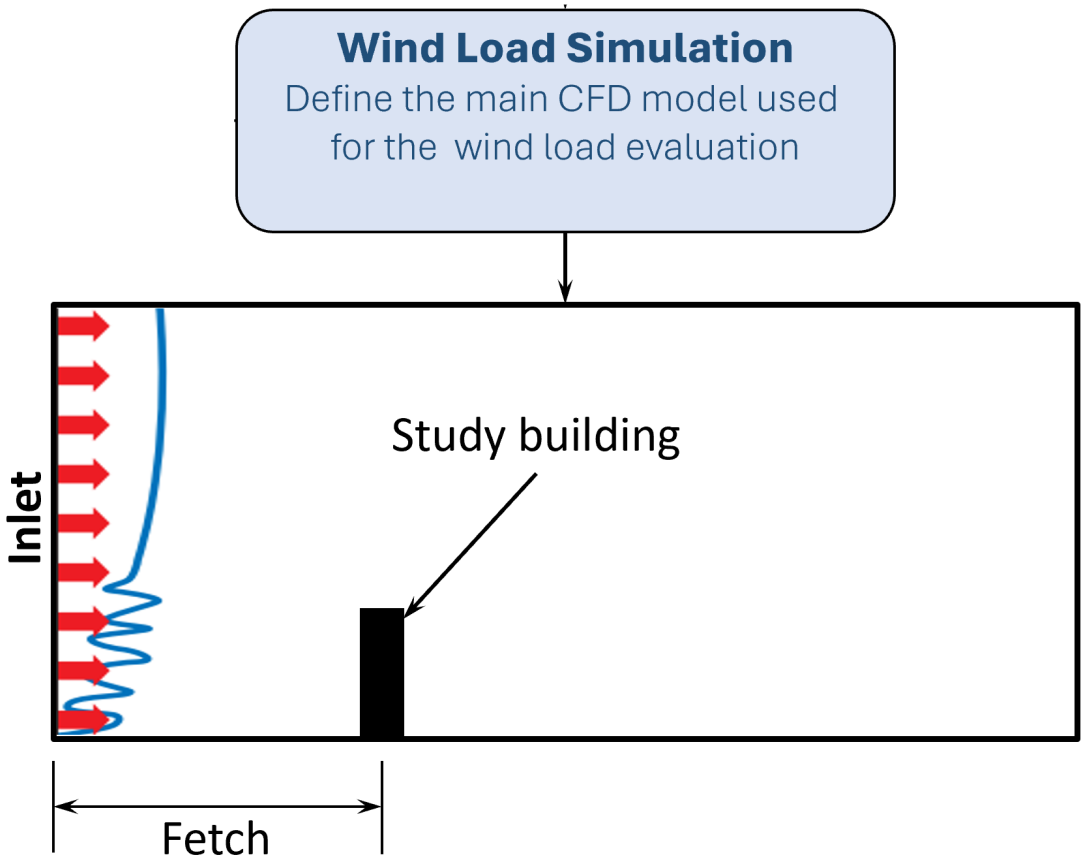


Structural Model



EDPs with UQ

Computational Wind Load Evaluation: empty domain simulation



Step-by-step procedure to create CFD model in WE-UQ

Geometry Definition
- Computational domain
- Building
- Surroundings

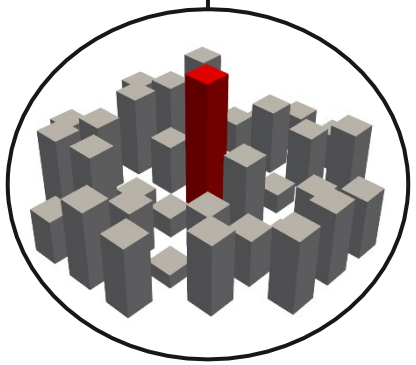
Mesh Generation
- Base mesh
- Refinements

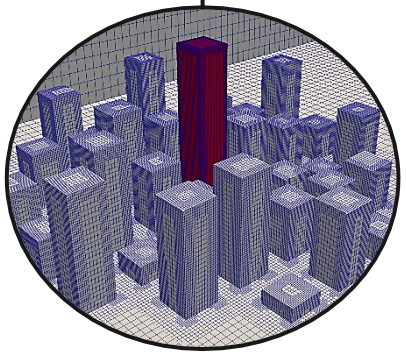
Boundary Conditions
- Inflow
- Surface roughness

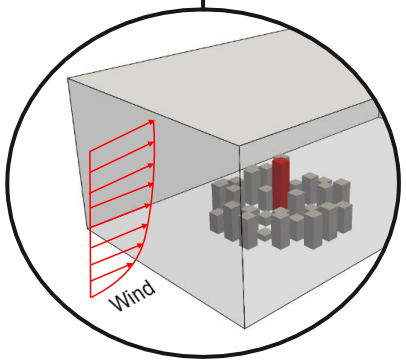
Numerical Setup
- Turbulence model
- Solver

Result Monitoring
- Wind profiles
- Local loads
- Integrated loads

Result Analysis
- Wind loads
- Wind profiles
- Flow field

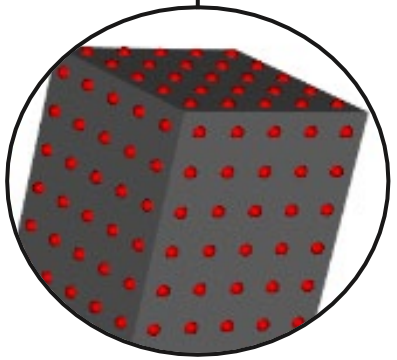


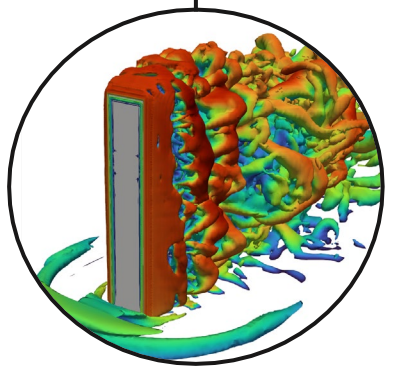




OpenFOAM

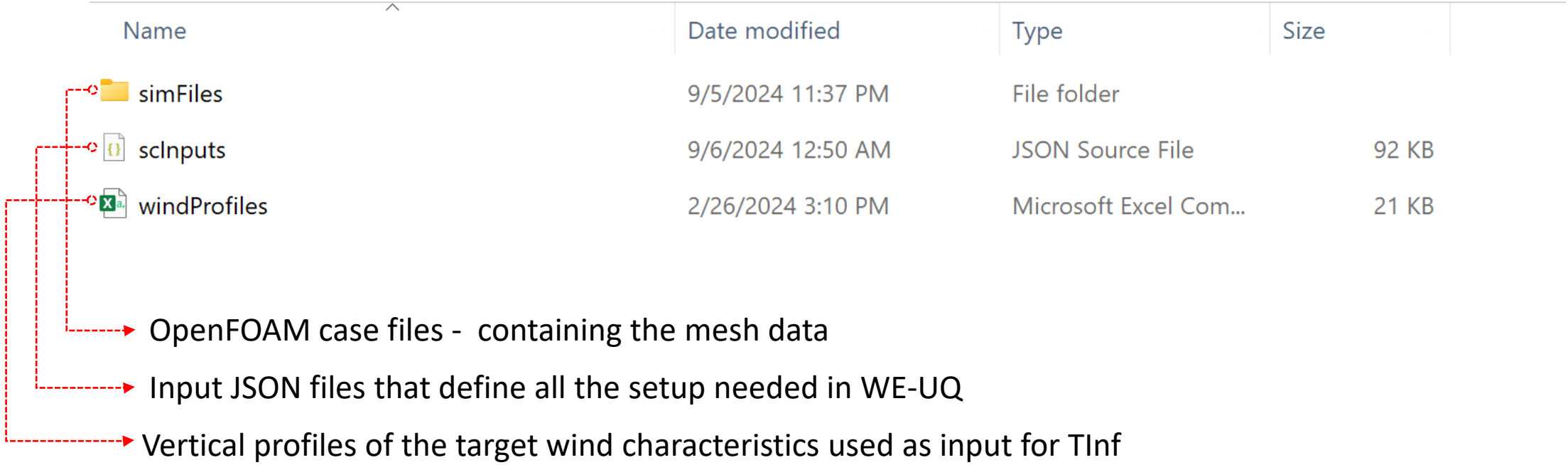
```
>Turbulence model
>Solver
>Time step
```



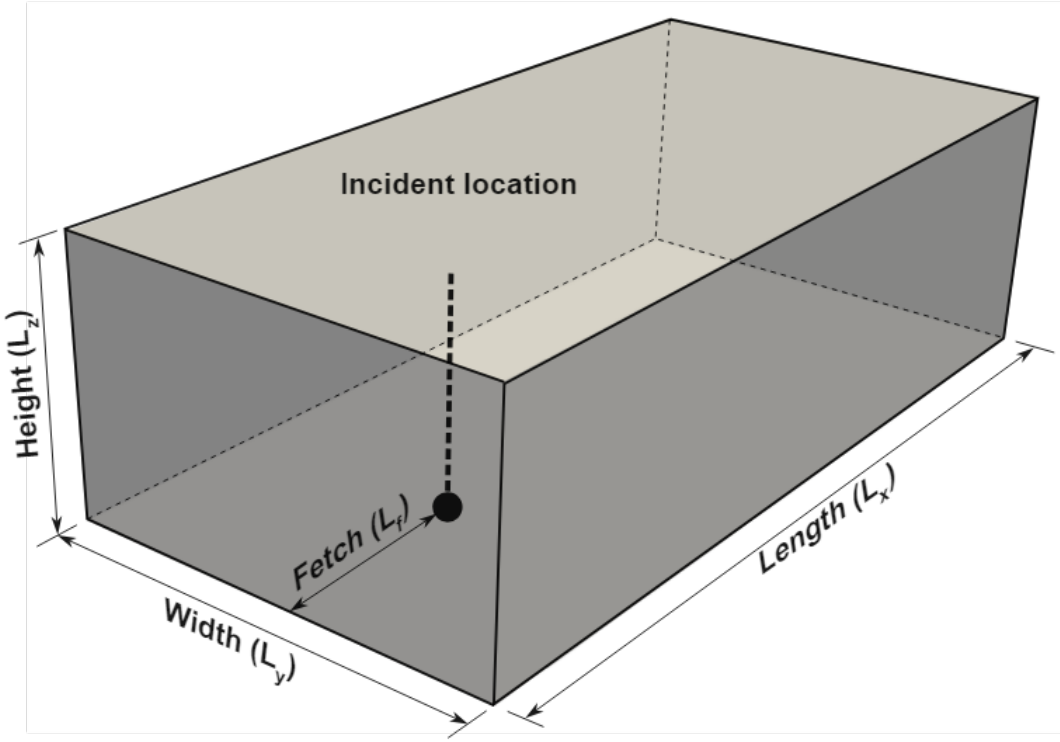


ParaView

Tutorial-1: Simulation input and case files



Tutorial-1: Target experimental measurement



Description	Value	Unit
Tunnel/domain width	2.2	m
Tunnel/domain height	1.8	m
Domain length	5.2	m
Wind fetch distance	2.1	m
Geometric scale	1:400	
Velocity scale	1:4	
Time scale	1:100	
Reference wind speed	10.69	m/s
Reference height	0.3	m
Duration of the simulation	34	s
Aerodynamic roughness length in full scale	0.5	m
Air density	1.225	kg/m^3
Kinematic viscosity of air	1.5e−5	m^2/s
Sampling frequency (rate)	500	Hz

Taken from TPU[1] database

[1]Tokyo Polytechnic University: http://www.wind.arch.t-kougei.ac.jp/info_center/windpressure/highrise/Homepage/homepageHDF.htm

Tutorial-1: Computational domain

Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results

WE-UQ

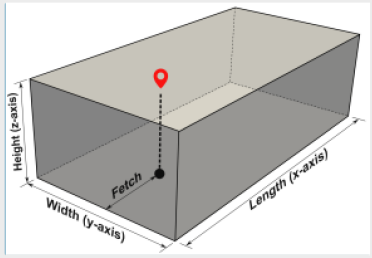
Start | Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | Results

Import Domain Setup

Geometric Scale: 400

Main Domain JSON Setup File: Import JSON

Domain Dimensions



Domain Length (X-axis): 5.2

Domain Width (Y-axis): 2.2

Domain Height (Z-axis): 1.8

Fetch Length (X-axis): 2.1

COST Recommendation:

Coordinate System

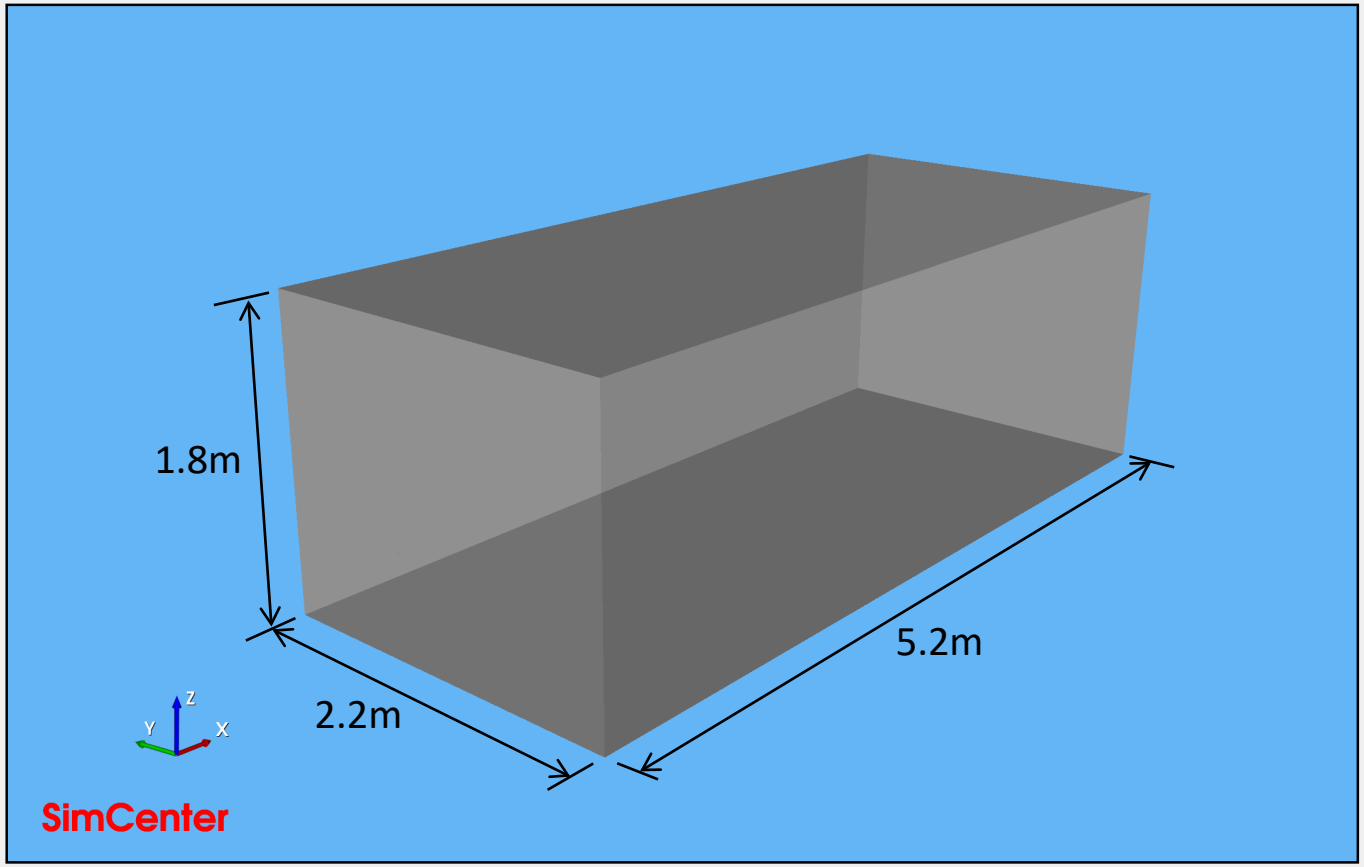
Absolute Origin: End of Fetch Center

Coordinate: X_o: 0 Y_o: 0 Z_o: 0

Save Mesh

Save Case Files

View: AllMesh Representation: Surface Transparency: Update



LOAD File | SAVE File | RUN at DesignSafe | GET from DesignSafe | Close

Tutorial-1: Generate computational grid

Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results

Start | Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | Results

Background Mesh | Regional Refinements

	Name	Level	X-min	Y-min	Z-min	X-max	Y-max	Z-max	Mesh Size
1	Box1	1	-2.1	-0.6	0	2.1	0.6	0.9	0.031498
2	Box2	2	-2.1	-0.4	0	1.8	0.4	0.6	0.015749
3	Box3	3	-2.1	-0.3	0	1.5	0.3	0.05	0....

Add Region | Remove Region | Check Regions

Advanced Options

Number of Cells Between Levels: 5 | Run Mesh in Parallel: ☐

Feature Resolution Angle: 30 | Number of Processors: 4

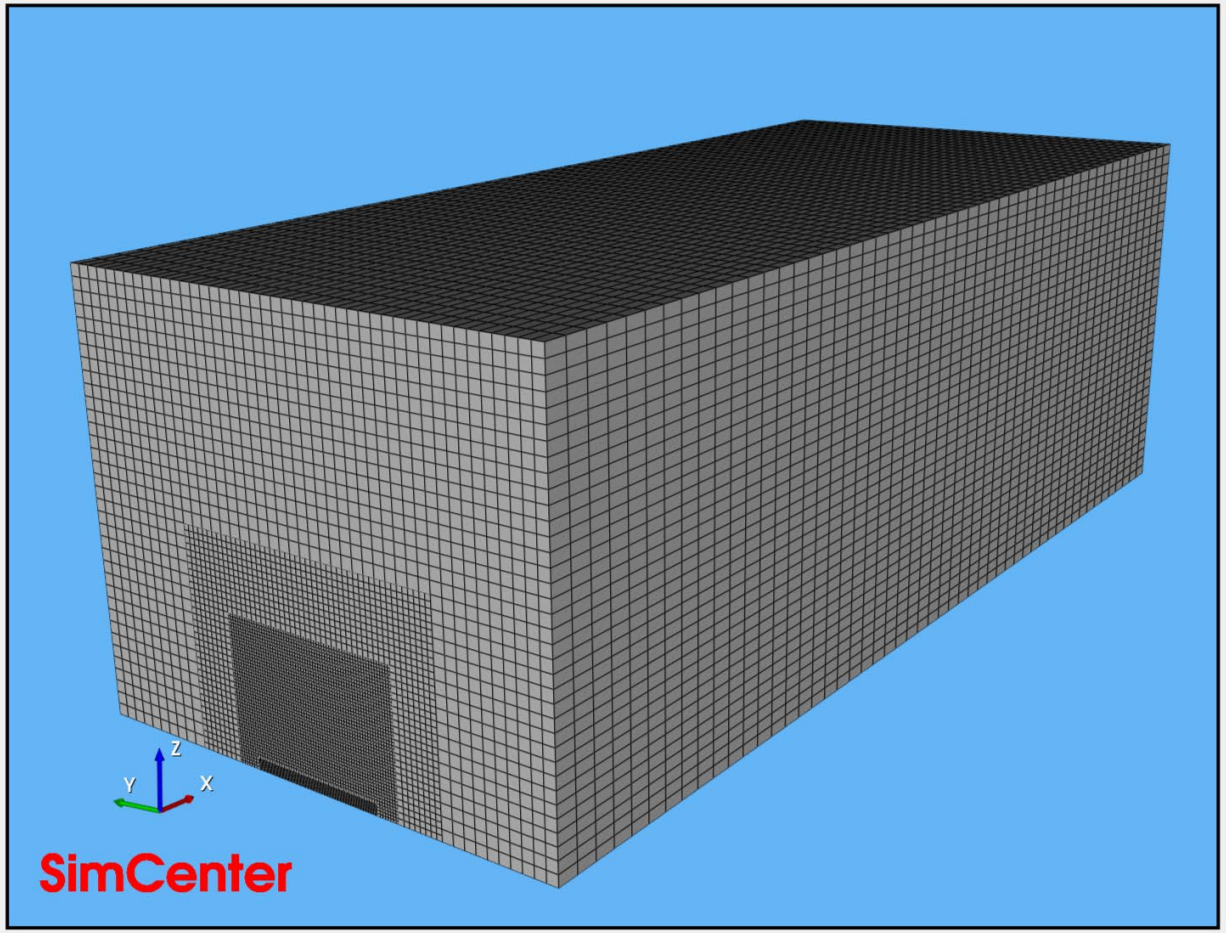
Run Mesh

Run Background Mesh | Run Final Mesh | Check Mesh

Save Mesh

Save OpenFOAM Files

View: AllMesh | Representation: SurfaceWithGri | Transparency: | Update



Tutorial-1: Define boundary conditions

Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results

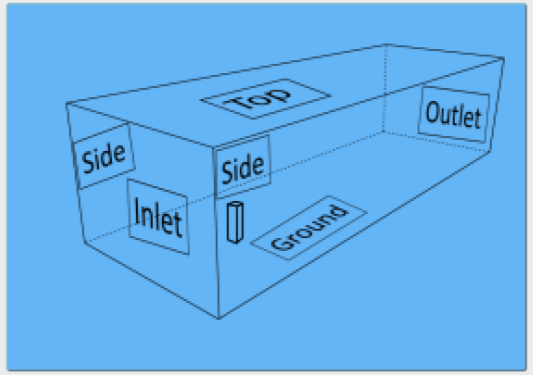
Start | Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | Results

Wind Characteristics

Velocity Scale:	4	Time Scale:	100
Reference Wind Speed:	10.69	Air Density:	1.225
Reference Height:	0.3	Kinematic Viscosity:	1.5e-05
Roughness Length:	0.5	Reynolds Number:	213800

Calculate

Boundary Conditions



Face Name	Boundary Condition
Inlet:	TInf
Outlet:	zeroPressureOutlet
Sides:	symmetry
Top:	slip
Ground:	roughWallFunction

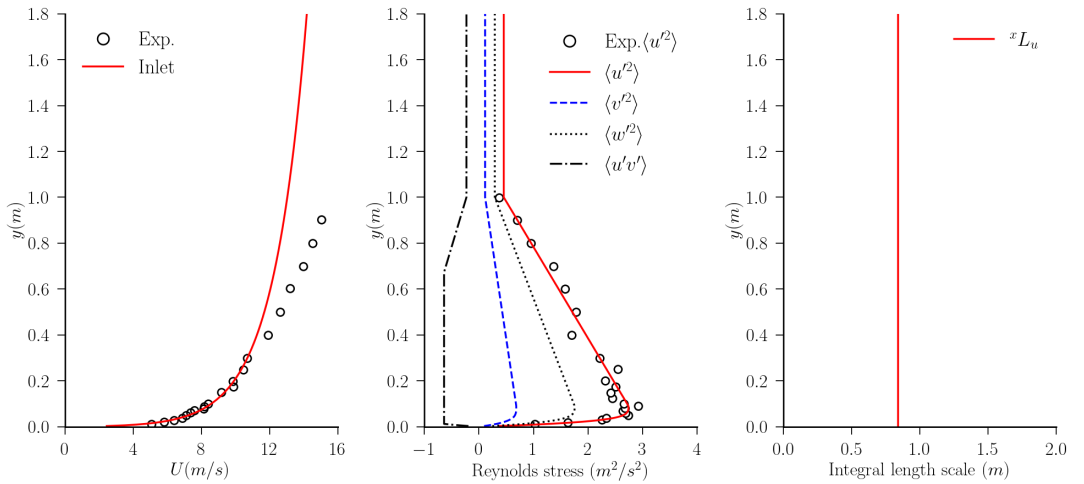
Inflow Generation

Generation Method: ○ DFSR ◉ DFM ○ SEM ○ DFSEM ○ TSM

Inflow Time Step: 0.005

Max. Frequency: 100

Wind Profile: Table | Import(*.csv) | Show Wind Profiles

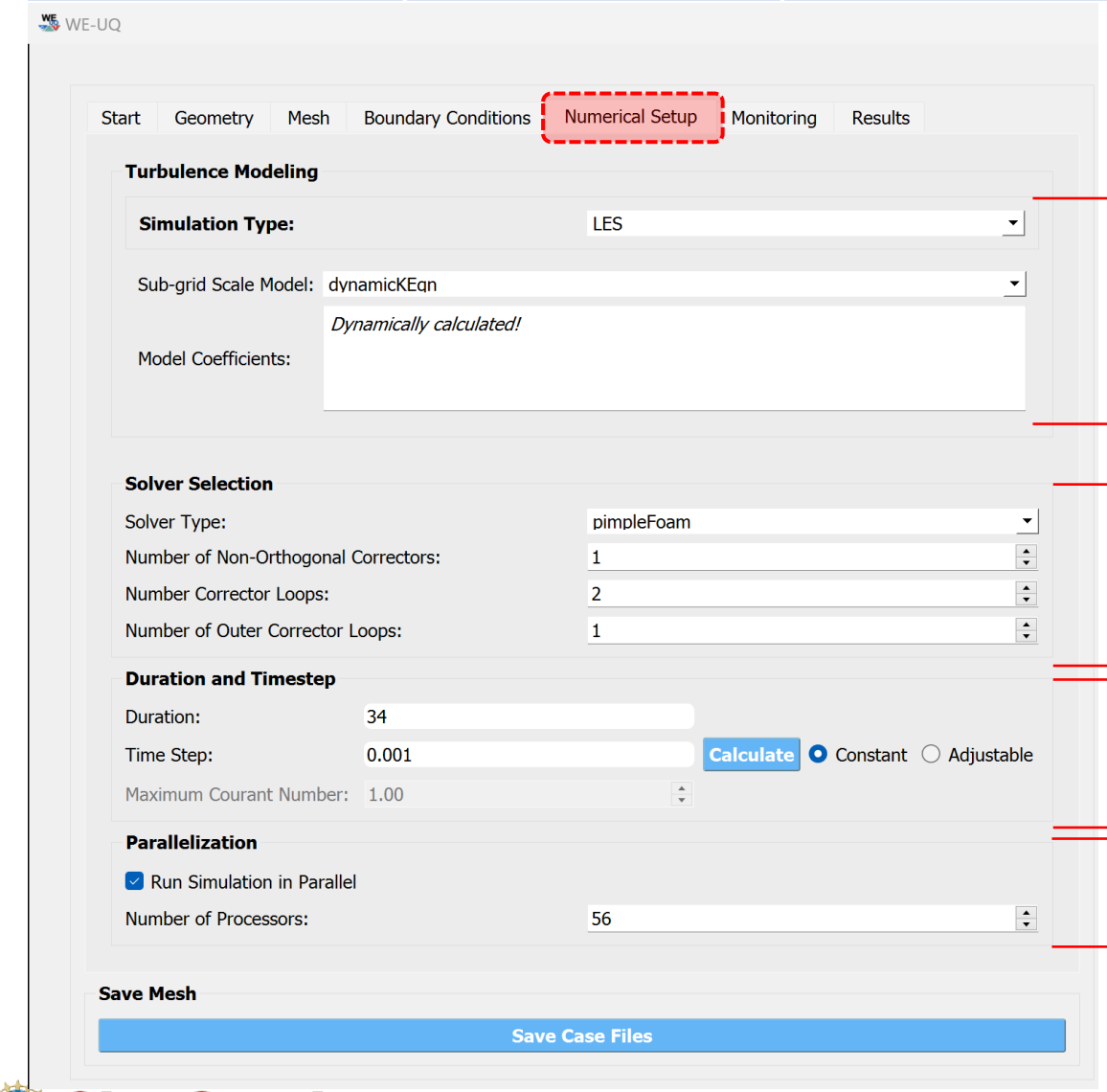


Wind Profiles

	z[m]	Uav[m/s]	R11[m2/s2]	R12[m2/s2]	R13[m2/s2]	R22[m2/s2]	R23[m2/s2]	R33[m2/s2]	xLu[m]	yLu[m]	zLu[m]	xLv[m]	yLv[m]	zLv[m]	xLw[m]	yLw[m]	zLw[m]
1	0.003125	2.44221	0.381923	0	-0.171865	0.244431	0	0.095481	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
2	0.00625	3.49297	0.72061	0	-0.324274	0.46119	0	0.180152	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
3	0.009375	4.17198	1.02055	0	-0.459248	0.653155	0	0.255139	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
4	0.0125	4.6746	1.28491	0	-0.5742	0.822345	0	0.321228	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
5	0.015625	5.07384	1.51671	0	-0.5742	0.970693	0	0.379177	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
6	0.01875	5.40505	1.71882	0	-0.5742	1.10004	0	0.429705	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
7	0.021875	5.68808	1.89399	0	-0.5742	1.21215	0	0.473497	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
8	0.025	5.93518	2.04482	0	-0.5742	1.30869	0	0.511206	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
9	0.028125	6.15445	2.17379	0	-0.5742	1.39123	0	0.543447	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
10	0.03125	6.35153	2.28322	0	-0.5742	1.46126	0	0.570805	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
11	0.034375	6.53051	2.3753	0	-0.5742	1.52019	0	0.593825	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
12	0.0375	6.69443	2.45209	0	-0.5742	1.56934	0	0.613022	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
13	0.040625	6.84562	2.5155	0	-0.5742	1.60992	0	0.628874	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
14	0.04375	6.98593	2.56731	0	-0.5742	1.64308	0	0.641827	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
15	0.046875	7.11682	2.60915	0	-0.5742	1.66986	0	0.652289	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
16	0.05	7.23947	2.64254	0	-0.5742	1.69123	0	0.660636	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
17	0.05625	7.46379	2.68926	0	-0.5742	1.72113	0	0.672315	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872
18	0.0625	7.66494	2.7167	0	-0.5742	1.73869	0	0.679176	0.8371	0.226017	0.234388	0.16742	0.050226	0.058597	0.385066	0.117194	0.267872

Tutorial-1: Specify numerical settings

Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results



Select LES with a dynamic one-equation subgrid-scale model (**`dynamicKEqn`**)

Select **`pimpleFoam`** solver with the default configuration

Set the duration of the simulation to 34 sec, with a constant time step of 0.001 sec.

Check the option to run the simulation in parallel and set the number of processors to 56 cores.

Tutorial-1: Monitor simulation data

Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results

WE-UQ

Start | Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | Results

Line Probes

Record Wind Profiles | Add Profile | Remove Profile | Show Profiles

	Name	start-X	start-Y	start-Z	end-X	end-Y	end-Z	No. Points	Field
1	Profile1	-2.1	0	0.01	-2.1	0.01	1.8	50	Velocity
2	Profile2	0	0	0.01	0	0.01	1.8	50	Velocity
3	Profile3	-2.1	0	0	3.1	0	0	50	Pressur

Field Write Interval: 2 Write Start Time: 1

VTK Planes

Sample Flow Field | Add Plane | Remove Plane | Show Plane

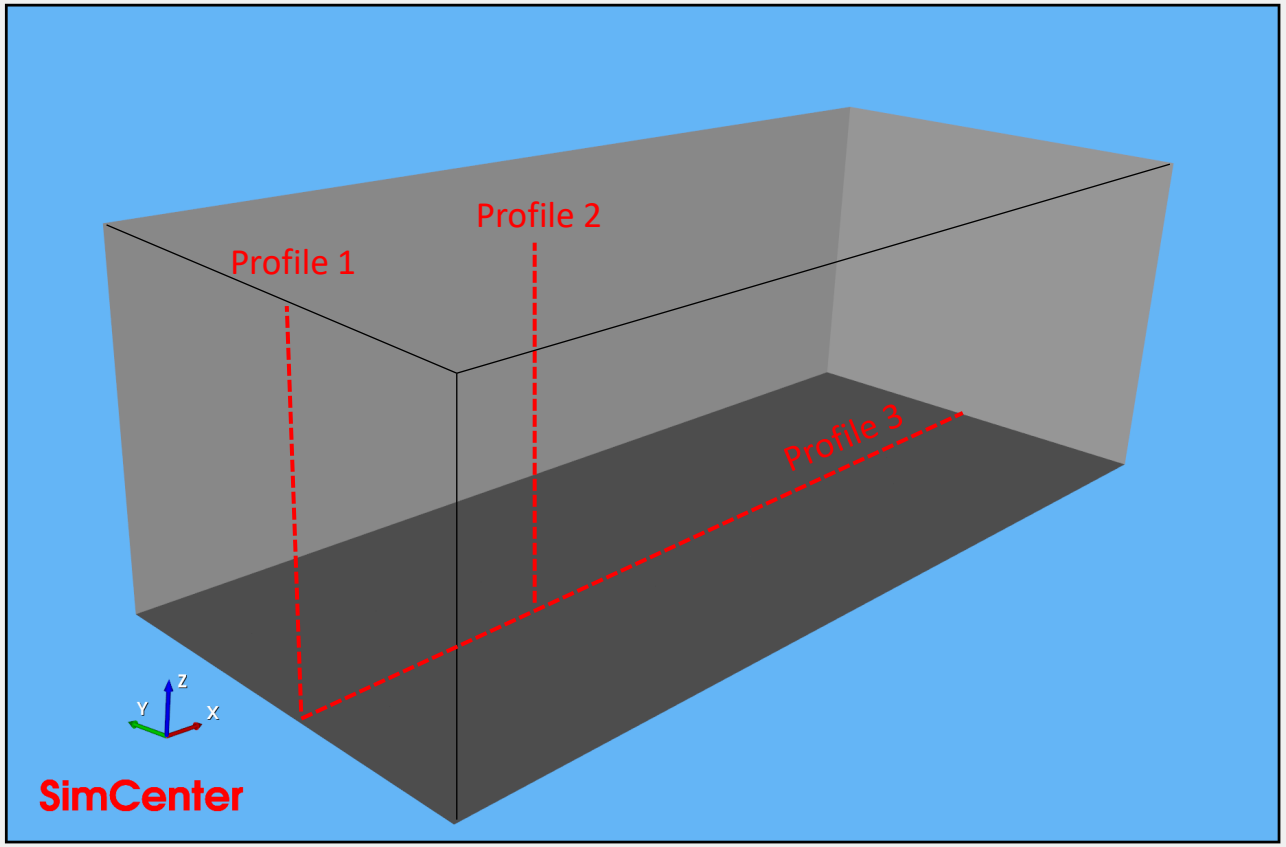
	Name	Normal	point-X	point-Y	point-Z	Start Time	End Time	Field
1	Plane1	Y	0	0	0.3	1	3	Velocity
2	Plane2	Z	0	0	0.3	1	3	Velocity

Flow Write Interval: 20

Save Mesh

Save Case Files

View: Breakou Representation: Surface Transparency: Update



LOAD File | SAVE File | RUN at DesignSafe | GET from DesignSafe | Close

Tutorial-1: Monitor simulation data

Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results

WE-UQ

Start | Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | Results

Line Probes

Record Wind Profiles | Add Profile | Remove Profile | Show Profiles

	Name	start-X	start-Y	start-Z	end-X	end-Y	end-Z	No. Points	Field
1	Profile1	-2.1	0	0	0	0.01	1.8	50	Velocity
2	Profile2	0	0	0	0	0.01	1.8	50	Velocity
3	Profile3	-2.1	0	0	3.1	0	0	50	Pressur

Field Write Interval: 2 Write Start Time: 1

VTK Planes

Sample Flow Field | Add Plane | Remove Plane | Show Plane

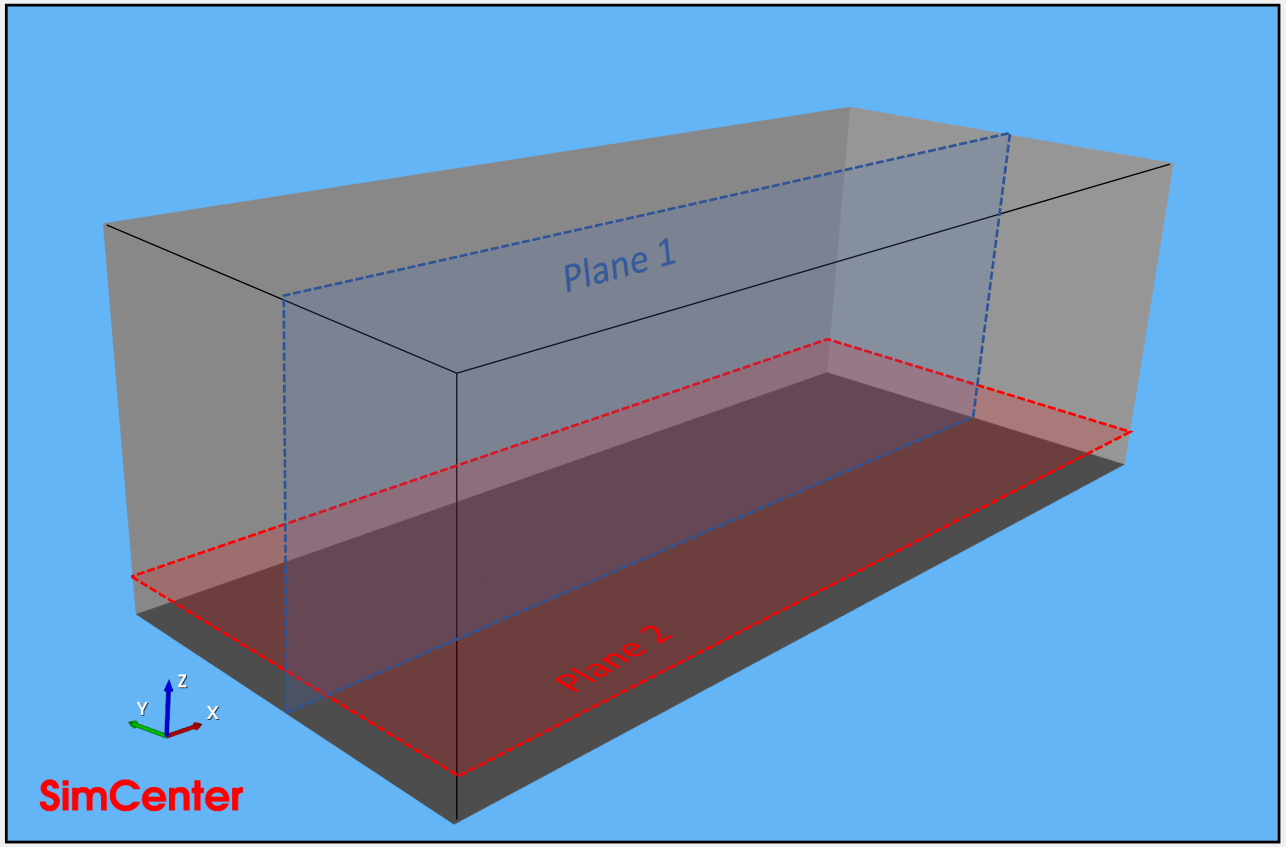
	Name	Normal	point-X	point-Y	point-Z	Start Time	End Time	Field
1	Plane1	Y	0	0	0.3	1	3	Velocity
2	Plane2	Z	0	0	0.3	1	3	Velocity

Flow Write Interval: 20

Save Mesh

Save Case Files

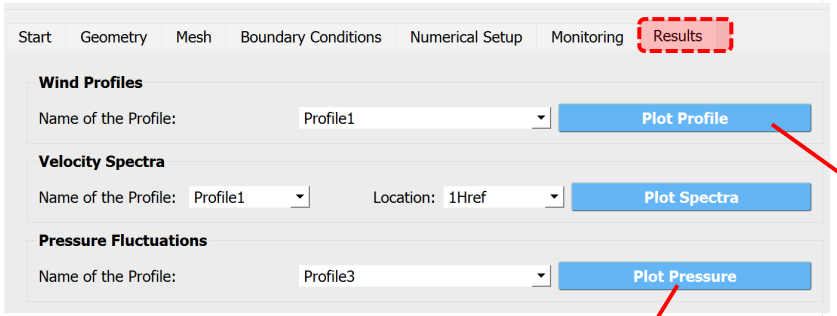
View: Breakou Representation: Surface Transparency: Update

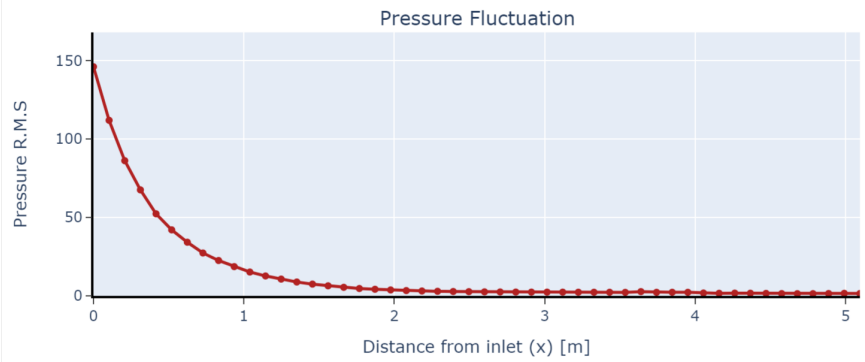


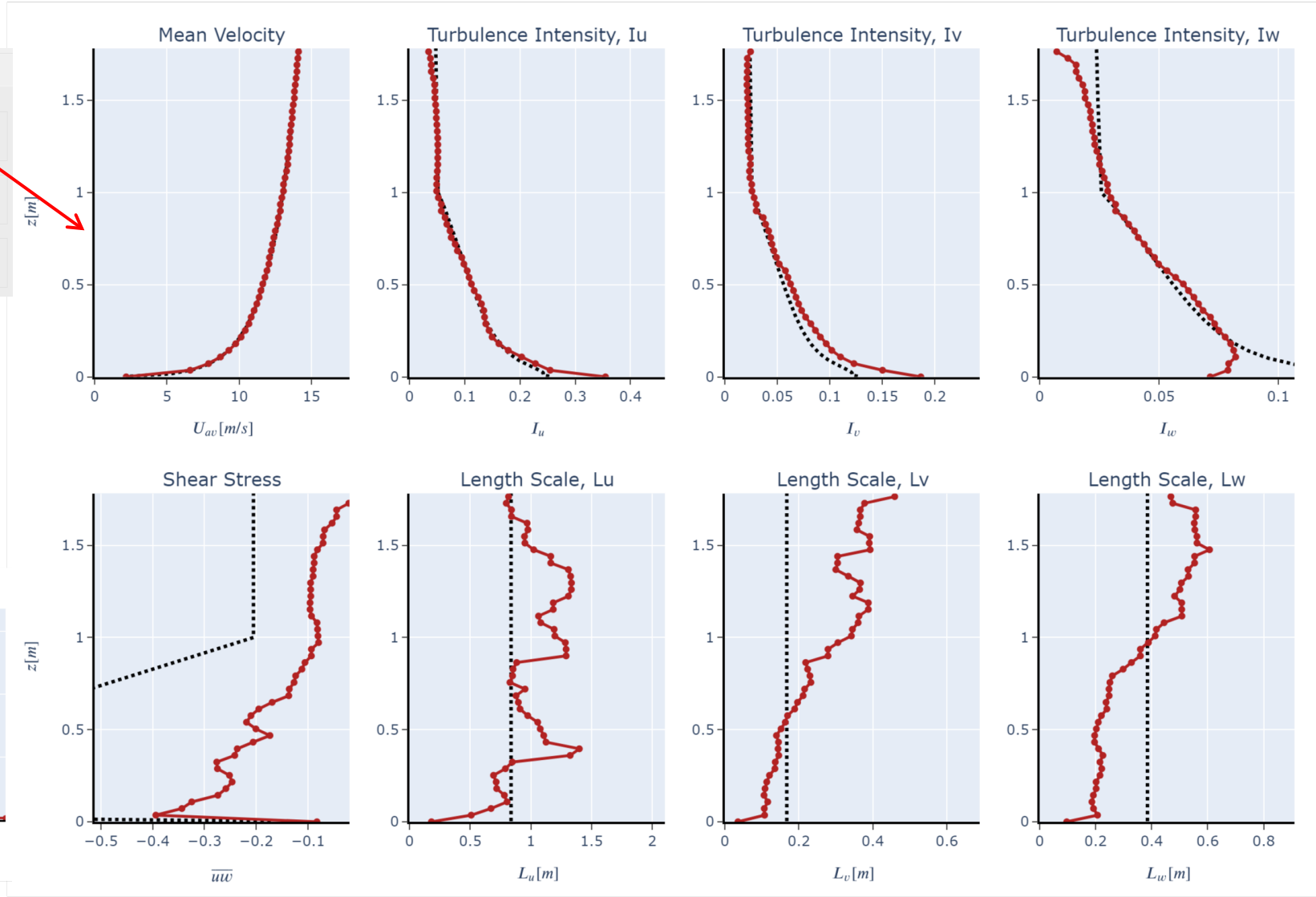
LOAD File | SAVE File | RUN at DesignSafe | GET from DesignSafe | Close

Tutorial-1: Check simulation results (wind profiles)

Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results

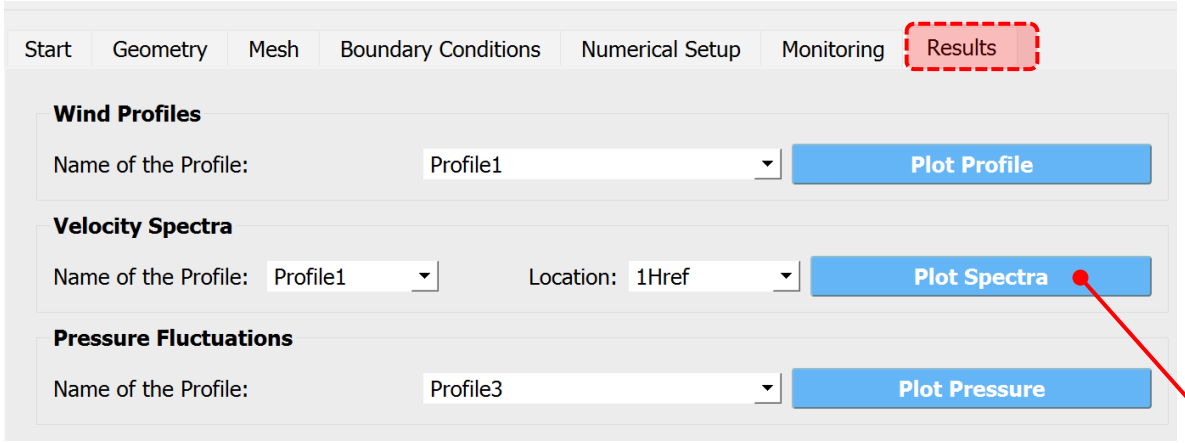


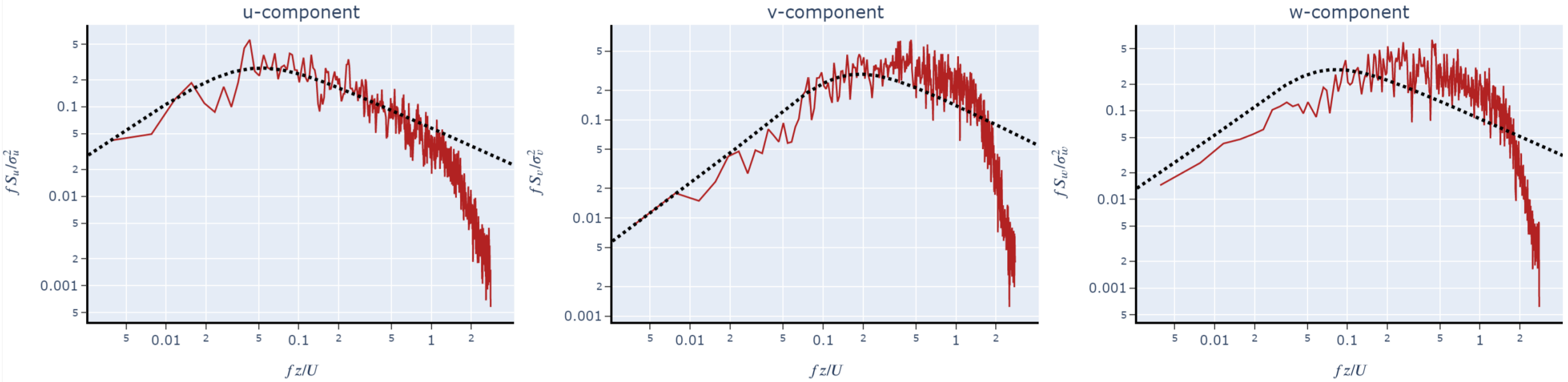




Tutorial-1: Check simulation results(velocity spectra)

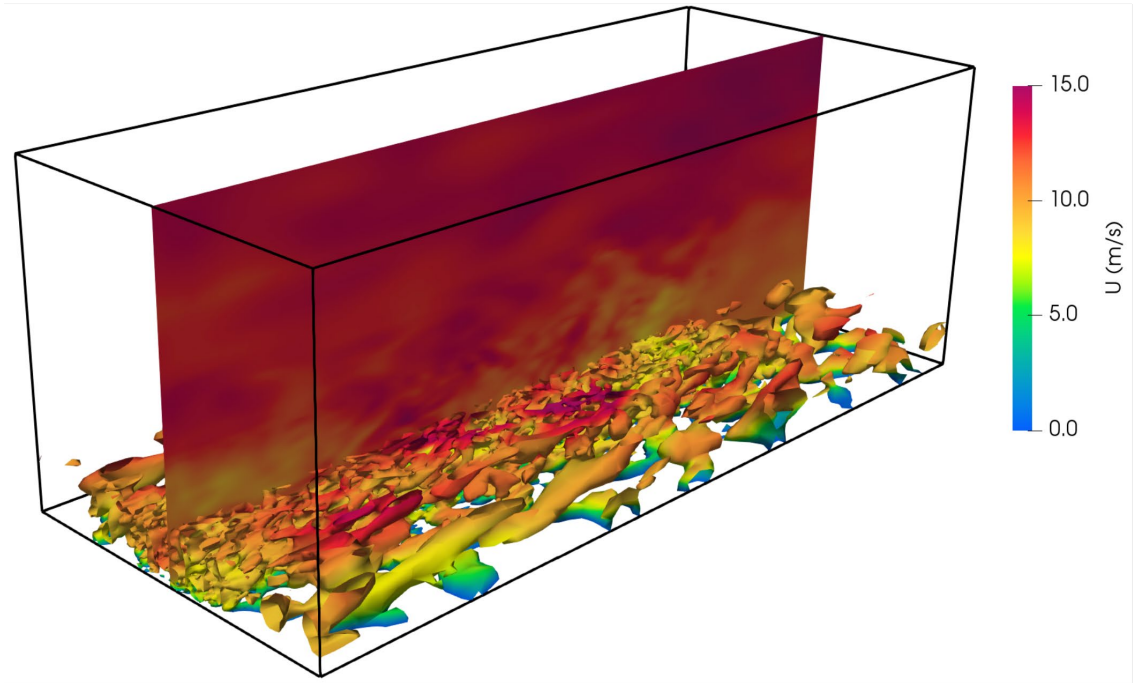
Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results





Tutorial-1: Check simulation results (flow field)

Geometry | Mesh | Boundary Conditions | Numerical Setup | Monitoring | CFD-Results



ParaView