Research on terrain grids generation in CFD software

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Abstract: Traditional research of environmental impact of Natural Draft Cooling Tower in Nuclear Power Plant is based on Diffusion model or Tunnel experiment, and with the development of modern Mainframe computers and turbulence models, it is possible to use Computational Fluid Dynamics (CFD) method to simulate plume drift. CFD software, due to its powerful computing ability, can simulate and display the plume drift more accurately. This paper presents an effective way of generating terrain grids which can be used in StarCD, a CFD software. SRTM terrain data is obtained from Internet and IDW Interpolation method is used in the coordinates translation process. A powerful program named GridInter is developed using Fortran90 to convert terrain data to StarCD vertex file, terrain grids generation process in StarCD including Nuclear Power Plant building grids combination is also introduced, this model can be directly used in the numerical simulation of plume dispersion.

Keywords: Terrain grids; CFD; IDW; Fortran 90

1. Introduction

With the rapid development of the national economy and the nuclear power industry, the construction of nuclear power plants has become a very important planning objective for China. Due to the limitations of water sources, inland nuclear power plants are often built in a relatively flat area in mountainous terrain, and at present, domestic inland megawatt nuclear power projects basically use a secondary cooling system of large natural ventilation cooling towers. If a one-tower solution is adopted, eight very large natural ventilation cooling towers with a shower area of approximately 12,000m^2 (preliminary estimate based on meteorological conditions in central China) will be required. The condensation mist formed by the towers will have an impact on the local climate, forming fog plumes, salt deposits, fogging and icing, which will affect the local environment as well as road safety, recreational activities, transport activities, airports, housing, etc. How to quantify these impacts has become an urgent issue for the EIA of inland nuclear power. The National Nuclear Safety Administration's "Format and Content of Environmental Impact Reports for Nuclear Power Plants" (NEPA-RG1) also specifies that the environmental impact of cooling towers must be evaluated.

Strongly influenced by the undulating mountainous terrain and uneven subsurface, which makes the near-surface flow field extremely irregular, the dispersion pattern of cooling tower plumes is also often highly uncertain. The steam and flue gas plume from nuclear power plant cooling towers and nuclear island stacks is a major form of gaseous pollutant dispersion, which involves the release of air containing pollutants from a point source into the atmosphere. The heat transfer (heat diffusion) and mass transfer (concentration diffusion) of the source flow at large Reynolds numbers results in complex temperature and concentration fields downwind. The shape of the fields is made more variable by complex topographic boundaries and meteorological conditions [1,2].

The diffusion state of the plume in the atmosphere depends on meteorological and topographical conditions such as wind direction, wind speed, atmospheric turbulence, vertical gradients in air temperature, and the thermodynamic stability of the atmosphere. At present, simple diffusion models are commonly used in engineering to project the concentration of exhaust smoke [3-6], such as Gaussian models, or the use of wind tunnels and other to carry out fluid model tests and field tracer tests, etc. [7-11]. However, in mountainous areas due to the influence of undulating terrain, the airflow is not flat in both horizontal and vertical directions, and the spatial distribution of the flow field is also very uncertain, the concentration distribution does not completely follow the normal law, turbulent diffusion rate is much more complex than the plain area. The traditional Gaussian formula has been unable to meet the accuracy of the calculation needs. With the development of computer technology, the numerical solution of diffusion differential equations has gradually increased [12-14]. Although the wind tunnel test can be more ideal to simulate the wind field and concentration field change law, but the wind tunnel test needs to spend a lot of human, material and financial resources, and the wind tunnel test needs to spend a long time. The current development of large scale computers and the continuous improvement of various turbulence models have made it possible to simulate the wind and concentration fields in close proximity using Computational Fluid Dynamics (CFD) software with meshing technology.

The use of CFD software to simulate cooling tower plume dispersion was proposed by foreign scholars as early as the 1970s, for example, England et al. used a three-dimensional CFD code in 1973 to calculate the dispersion pattern of wet and dry cooling tower plumes in the downwind direction at the Keystone power plant in western Pennsylvania [15]. Bergstorm et al. used two-dimensional The CFD software was used to simulate the diffusion pattern of the ideal cooling tower model plume at different wind speeds and directions [16]. The results showed that the CFD numerical wind tunnel can better simulate the disturbance pattern of airflow in the cooling tower [17].

An important prerequisite for CFD software calculations is the quality of the mesh generation, traditional mesh modelling is basically the use of common CAD-aided design software to draw a completed three-dimensional model into CFD software, and then mesh division, because the plume simulation needs to consider the complex terrain around the pollution source of about 5 ~ 10km, it is impossible to use CAD software to build the terrain mode, so the effective meshing of complex terrain is a key factor in the accuracy of CFD software. The paper discusses in detail the process of terrain mesh generation in CFD software, and concludes with an example of an inland nuclear power plant in China to illustrate the results of the terrain mesh model in CFD software to simulate the diffusion pattern of a large naturally ventilated cooling tower plume.

The basic framework of this paper is shown in Figure 1.

The setting of the program parameters, the operation and the post-processing part are relatively simple and the research examples in this paper will give some of the results of the post-processing of the fog plume.

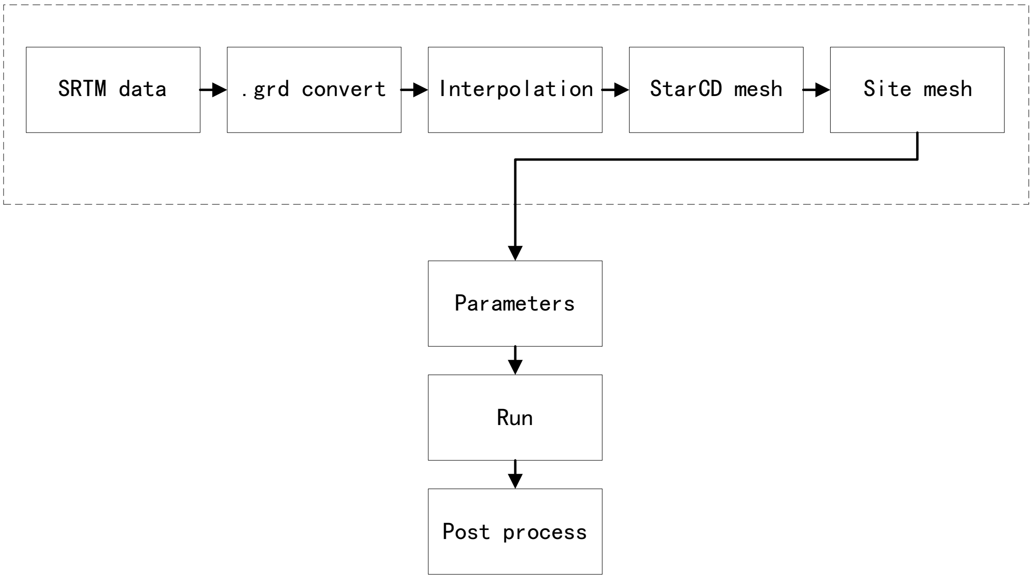

Figure 1 Article framework diagram

2 Methodology

In order to apply the above .grd topographic data to the CFD software, the topographic grid needs to be converted from latitude and longitude to a Cartesian coordinate grid and the accuracy of the grid needs to be redefined according to the calculation needs. The coordinates of the point source in this paper are located at latitude 30.0354 N and longitude 116.713 E. The resolution of the grid is 100m and the range is 20km, and the terrain grid is re-defined using the formula for calculating latitude and longitude distances. Grid delineation in the case of discrete point data only, interpolation is used to obtain a valuation without data points. If the results calculated under an unstructured grid are considered as known discrete point data, the values of the structured grid nodes under a curved coordinate system need to be obtained by interpolation. In general, commonly used interpolation methods are: kriging interpolation, linear interpolation triangular mesh and inverse distance weighted interpolation [18].

The basic principle of the IDW method is to assume that the spatial points to be interpolated are $O(x_0, y_0, z_0)$, O points with known scatter in the neighborhood $Q(x_i, y_i, z_i), i = 1, 2, \ldots, n$, Using the inverse distance weighting method for O attribute values for points Z_p interpolation. The interpolation principle is that the attribute value of the point to be interpolated is a weighted average of the attribute values of the known scatter points in the neighborhood of the point to be interpolated, and the magnitude of the weight is related to the distance between the point to be interpolated and the scatter points in the neighborhood, and is the reciprocal of the power of the distance ($0 \le p \le 2$) [19].

$$z_0=\sum_{i=1}^{n}\frac{1}{(D_i)^p}z_i\left[\sum_{i=1}^{n}\frac{1}{(D_i)^p}\right]^{-1} \tag{1}$$

$$D_i=\sqrt{(x_0-x_i)^2+(y_0-y_i)^2} \tag{2}$$

Where,

z_0 is the estimated value.

z_i is the $i\,(i=1,2,\ldots,\mathrm{n})$ sample.

p is the power of the distance, which significantly affects the results of interpolation, and it is selected on the basis of the minimum mean absolute error.

D_i is the distance. The literature [20] shows that the higher the power p, the smoother the interpolation result, often chosen p=2.

In this paper, the technical steps used are shown in Figure 2.

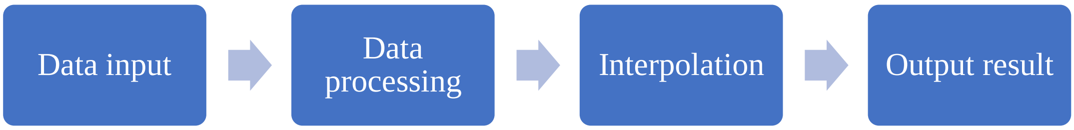

Figure 2 Technological steps

3 Pre-processing of topographic data

This paper uses an inland Chinese nuclear power plant as an example to illustrate the terrain grid generation method. Firstly, down load terrain data from http://srtm.csi.cgiar.org, SRTM data is mainly measured jointly by NASA and the National Mapping Agency (NIMA) of the Department of Defense, the full name of SRTM is Shuttle Radar Topography Mission. The topographic data in this paper ranges from 29.85539 to 30.21539 N and 116.51300 to 116.91300 E. The topographic data was then converted to a common .grd (Surfer) data format using GlobalMapper software.

3.1 Data format

Table 1 lists the basic forms of composition of .grd data.

Table 1 .grd data format

Line number	Data values
1	DSAA
2	481 433
3	116.513 116.913
4	29.855 30.215
5	5.65348 831.554
6	13.5285 13.436 13.6424……
……	……
……	……
2226	16.4007 15.7123 16.0953……

The first part of the data has only one line, the data header, which describes the identification of the file.

The second part of the data runs from the second to the fifth row, where the two numbers in the second row represent the x and y array sizes of the data, the third and fourth rows represent the maximum and minimum values of the x and y coordinates respectively, and the fifth row represents the minimum and maximum values of the elevation data.

The third part of the data represents the elevation values of the grid and the number of data is the same as in the second row.

3.2 Data interpolation

In this paper, a GridInter terrain dot matrix interpolation program has been developed using Fortran 90 as the programming language and the basic framework of the program is shown in Figure 3.

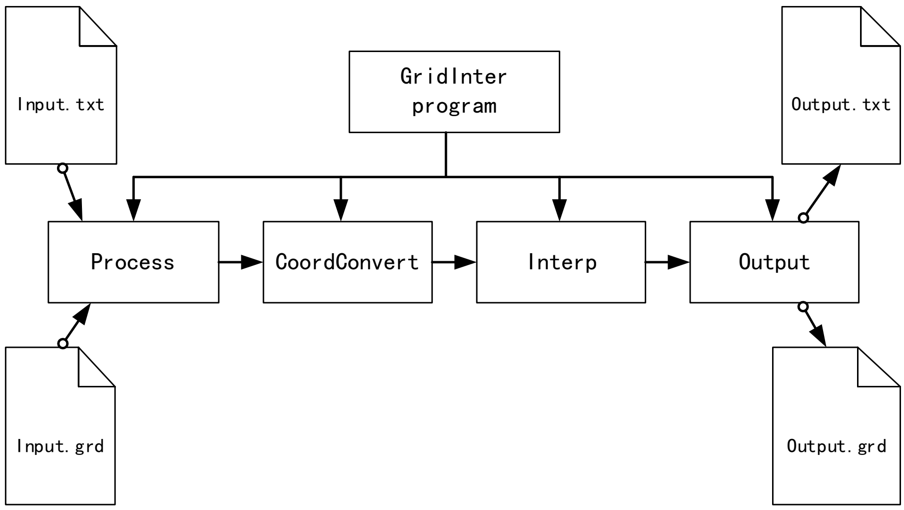

Figure 3 Diagram of the GridInter terrain grid program

The GridInter program is divided into four basic modules.

(1) Process module

This module is mainly used for the pre-processing of the program files. The input files of the program are input.txt and input.grd, where the basic structure of the input.txt file is shown in Table 2.

Table 2 Description of input.txt file

Rows number	Field Meaning	Field accuracy	Remarks
1	Point source coordinates	F10.3	Latitude and longitude coordinates
2	Mesh number	I10	Number of meshes xy direction
3	Mesh grid,m	F10.1	Individual grid size

The basic format of the Input.grd file has already been described in detail, so we will not repeat it here.

(2) CoordConvert module

The module converts the point coordinates expressed in latitude and longitude in the input.grd file into a Cartesian Cartesian coordinate system, the origin of which is the source coordinates of the point determined by the user, and re-transforms the original coordinate system using the method of calculating the distance between two points in latitude and longitude, where the code for calculating the distance in latitude and longitude is as follows.

```
! Function to calculate the distance in latitude and longitude dis
real function dis(x1,y1,x2,y2)
    real y1,x1,y2,x2
      real a,b,s
    a=x1-x2
    b=y1-y2
    s=2.0*asin(sqrt((sin(a/2.0))**2.0+cos(x1)*cos(x2)*(sin(b/2.0))**2.0))
    s=s*6378.137
    dis=s
    return
    end function
……
```

(3) Interp module

This module re-interpolates the input.grd file according to the grid size defined by the user in the input.txt file, the interpolated results are temporarily stored in a dynamic array, the interpolation part of the code is as follows.

```
……
do i=1,cols_output
   do j=1,rows_output
……
        x1=lat_old(inter_x(1))
        x2=lat_old(inter_x(2))
        y1=lon_old(inter_y(1))
        y2=lon_old(inter_y(2))
        z1=grids_input(inter_x(1),inter_y(1))
        z2=grids_input(inter_x(2),inter_y(2))
        z3=grids_input(inter_x(1),inter_y(2))
        z4=grids_input(inter_x(2),inter_y(1))

        H1=sqrt((x_old(i)-x1)**2.0+(y_old(j)-y1)**2.0)
        H2=sqrt((x_old(i)-x2)**2.0+(y_old(j)-y2)**2.0)
        H3=sqrt((x_old(i)-x1)**2.0+(y_old(j)-y2)**2.0)
        H4=sqrt((x_old(i)-x2)**2.0+(y_old(j)-y1)**2.0)

        H1_sum=H1**(-2.0)+H2**(-2.0)+H3**(-2.0)+H4**(-2.0)
        w1=H1**(-2.0)/H1_sum
        w2=H2**(-2.0)/H1_sum
```

```
            w3=H3**(-2.0)/H1_sum
            w4=H4**(-2.0)/H1_sum
            grids_output(i,j)=z1*w1+z2*w2+z3*w3+z4*w4
        end do
      end do
      ……
```

(4) Output module

The first part is output.grd, which can be read directly by Surfer software and is mainly used for the calibration of the terrain interpolation; the second part is output.txt, which is in the StarCD dot matrix file format.

The surface topography data after interpolation is shown in Fig.5, and compared with the original topography map 3, it can be seen that the two maps differ slightly in small local parts due to the difference in grid resolution, but are basically the same overall, indicating that the inverse distance weighted interpolation method used in this paper achieves better interpolation results.

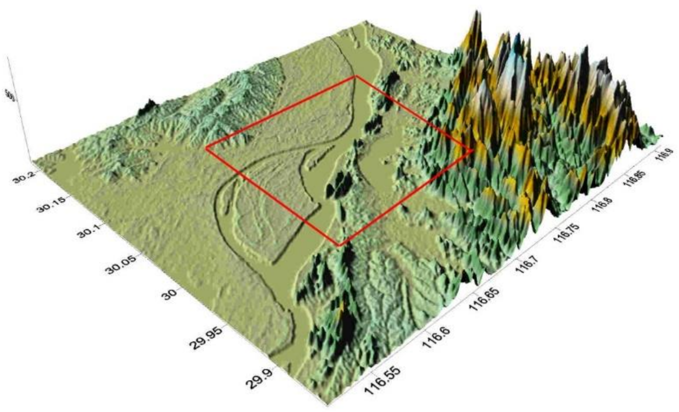

Figure 4 Original topographic map

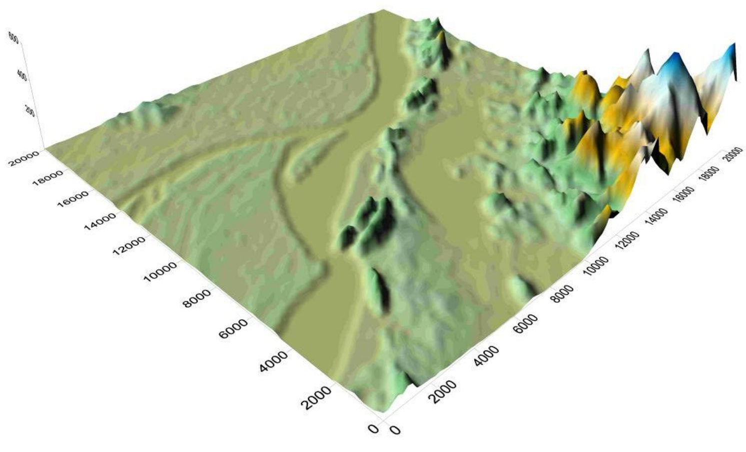

Figure 5 Interpolated topographic map

4 Example of terrain mesh generation

When studying hydrodynamic problems such as atmospheric plume dispersion using numerical methods, it is necessary to be able to generate grids from complex topographic data that can be used in hydrodynamic calculation software in order to take into account the effect of complex topographic conditions on the dispersion of scalar fields.

Some of the more mature commercial CFD software on the market today are CFD2000, CFX-4, CFX-5, CFD Taskflow, FLOW-3D, FLUENT, PHOENICS, STAR-CD, etc. [21]. This paper focuses on STAR-CD as an example to illustrate the method of generating terrain meshes in CFD software.

STAR-CD was originally developed by professor Gosman, an expert in the field of computational fluid dynamics at Imperial College of Science and Technology in the UK, who collaborated to develop an unstructured mesh calculation program based on the traditional fundamental theory of heat transfer, based on the finite volume algorithm. With key technologies such as fully discontinuous meshes, slip meshes and mesh repair, STAR-CD has been supplemented and refined by over 200 renowned academics from more than 10 countries worldwide, making it the best software of its kind in terms of mesh adaptability, computational stability and convergence. The introduction of the latest turbulence model has led to significant improvements in computational stability, convergence and reliability of results.

4.1 Data reading and grid generation methods

StarCD can generate and handle structured or unstructured meshes and allows the use of four basic types of mesh cells, i.e. hexahedral, trigonal, tetrahedral and tetrahedral cells, as well as six types of clipping meshes and some deformation meshes. Three basic grid layouts can be formed from these cells, namely a hexahedral grid layout, a tetrahedral grid layout and a hybrid grid layout including hexahedral cells and tetrahedral cells. In this paper, hexahedral mesh is used to generate the terrain mesh.

This paper takes a domestic nuclear power plant as an example, where the site elevation is generally between 64-174m. The geomorphology of the site area is mainly low hills and valleys, with the lowest valley elevation at 53.3m and the highest peak in the southern mountain range at 263.9m. The grid resolution is 200m x 200m, the number of grids is 100 x 100 and the coordinate system is Cartesian Cartesian Coordinates. The first step was to use Fortran programming to implement the conversion of the already generated .grd file into a point file (vertex.txt) that can be imported in bulk in pro-Star. Using the Ifile “vertex.txt” command, all the Vertex points can be imported into the pro-Star program on StarCD at once.

For example to create 4 points, v1 v2 v3 v4:

```
v   1   -10000   -10000   44
v   2   -10000   -9800    34
v   3   -10000   -9600    20
v   4   -10000   -9400    18
```

v is the abbreviation for vertex, 1 is the node number, which is unique in StarCD, followed by the x,y,z coordinates of the node.

The generated nodes are shown in the following figure.

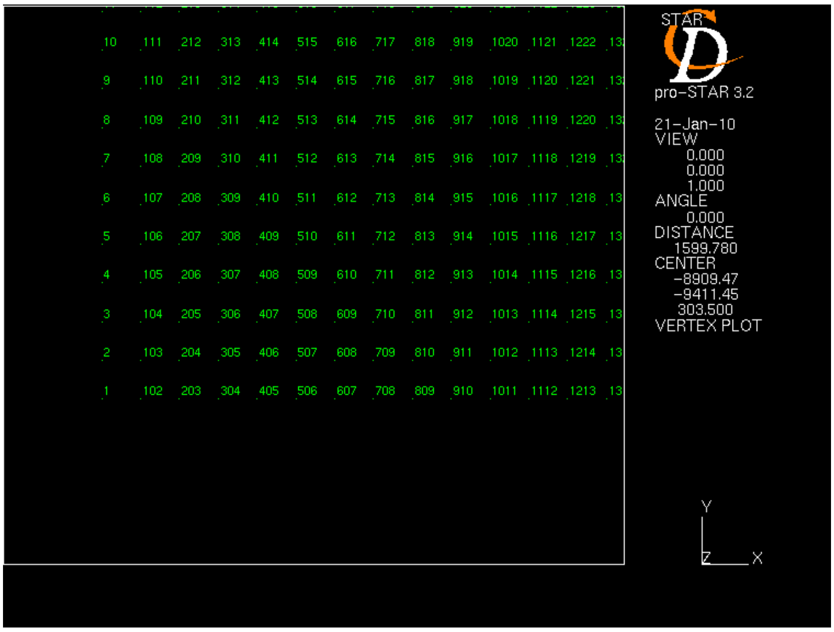

Figure 6 Node diagram

Use ctab 11 shell to define the type of cell table No. 11 as shell, and activate it as the current cell table, type the command C 1 2 103 102, according to the law, create a cell of shell type with vertex No. 1, 2, 103, 102, type the command cset news type 11, select all the type 11 cell created, put it into the current cset, and generate the effect as shown in Figure 7.

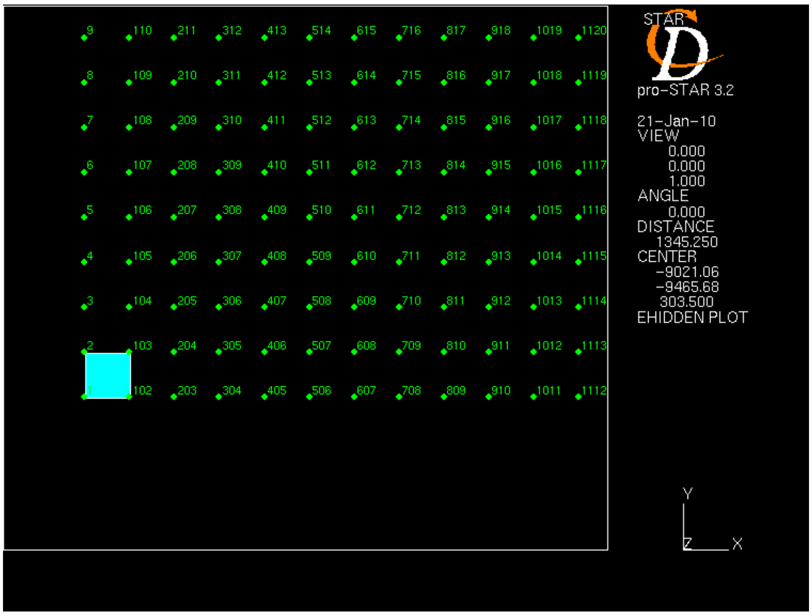

Figure 7 Single Cell effect

A quick method of generating Cell meshes is provided in StarCD, using the following commands to make offset copies on top of existing meshes.

Cgen 100 1 cset,,,

Cset news type 11

Cplo

Generate a single column of Cell grid faces, as shown in Figure 8.

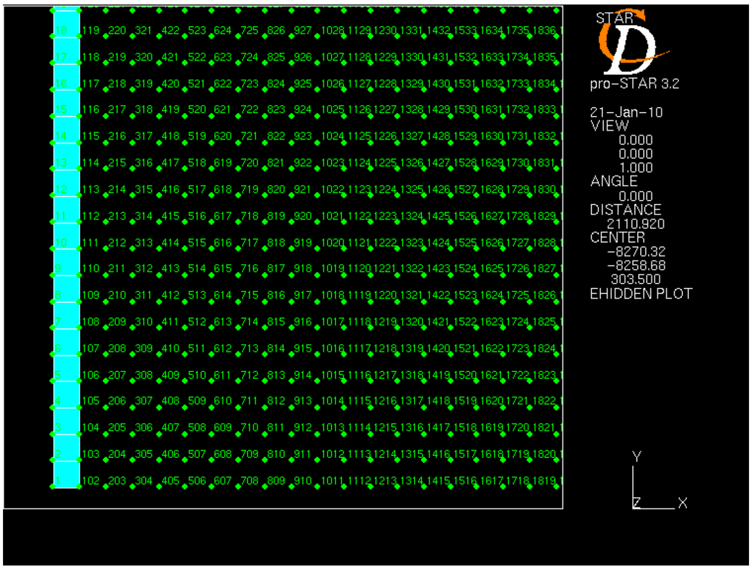

Figure 8 Single-column Cell grid surface

Use the command again to copy the Cell grid face by offsetting it to the right.

Cgen 50 51 cset,,,

Cset news type 11

Cplo

The generated results are shown in Figure 9.

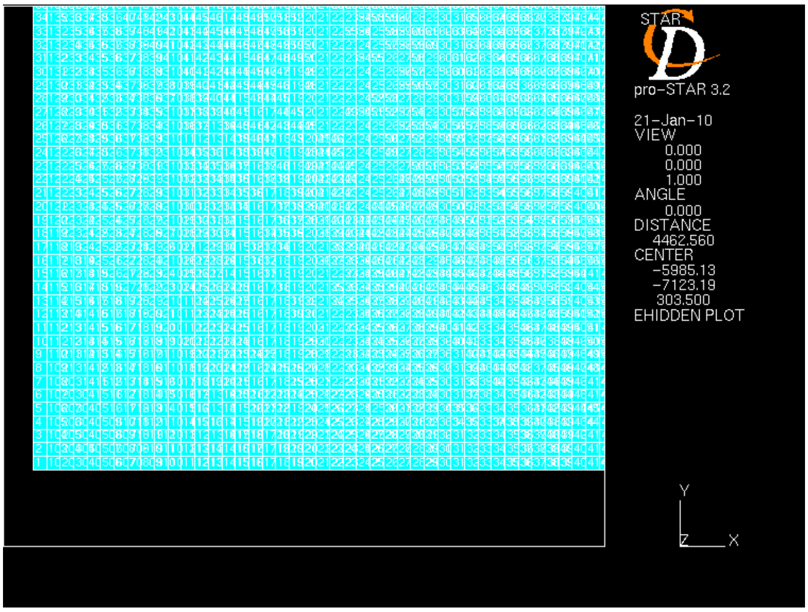

Figure 9 Cell grid surface

As the terrain in which the nuclear power plant area is located is generally filled manually, this paper fills in a 2km radius grid of the nuclear power plant area, which is achieved in StarCD using the following macro commands.

*set X0 -2000

*set Y0 -2000

*set X1 2000

*set Y1 2000

*set H 2.5

vset,news,gran,X0,X1,Y0,Y1,,,,

csys,1

vmod,vset,f,f,H

cdis,on,vert

vsty,3,6,1

replot

Select the Hidden Surface display mode in StarCD and the filled display will appear as shown in Figure 10.

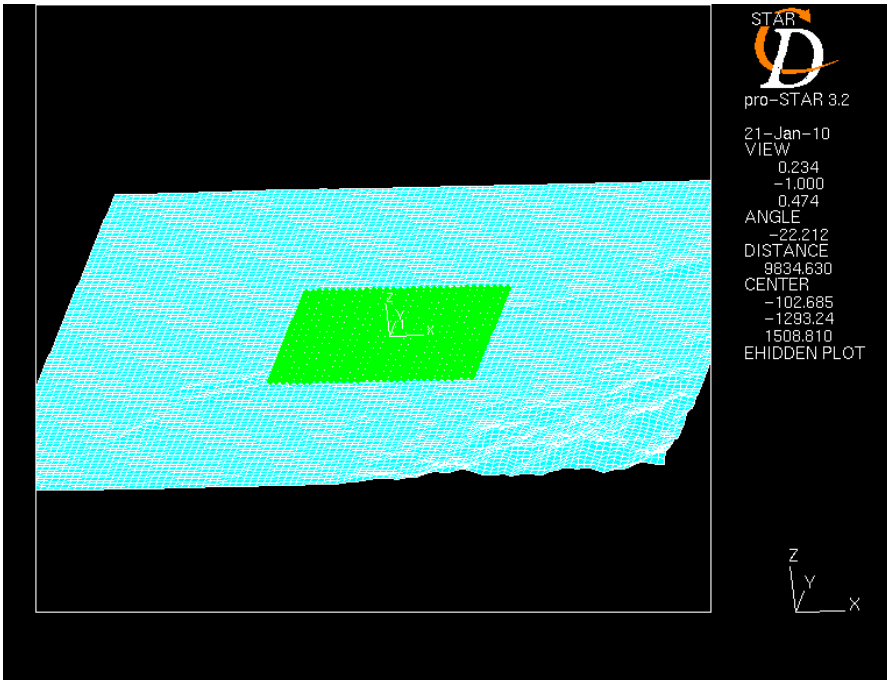

Figure 10 Cell grid filling

At this point the Cell mesh faces have been generated and the mesh is stretched to a flui body mesh using the following command.

Cset all

Vset all

vcex,30,,cset,,,loca,,,1.25,both,nonu,3000

cset news flui

cplo

In this paper, the body mesh is stretched to a height of 3000m, the number of stretched layers is 30, and the mesh growth ratio is 1.25. The effect of generating the body mesh is shown in Figure 11.

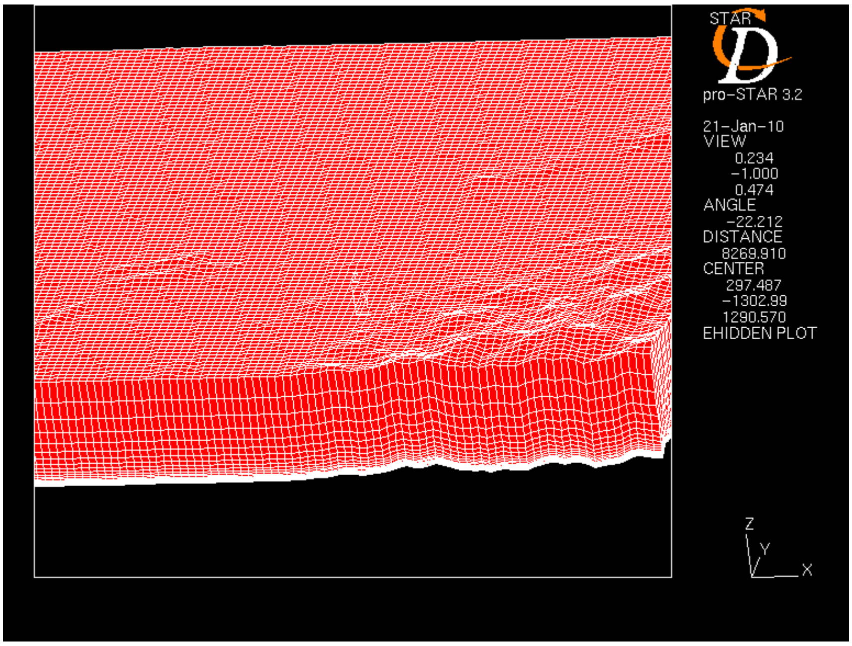

Figure 11 flui body mesh

Comparing Figure 11 and Figure 5, the terrain undulations are basically known in both figures, indicating that the terrain mesh generated by StarCD is a more realistic reflection of the terrain, and the side view of the Flui body mesh is shown in Figure 12.

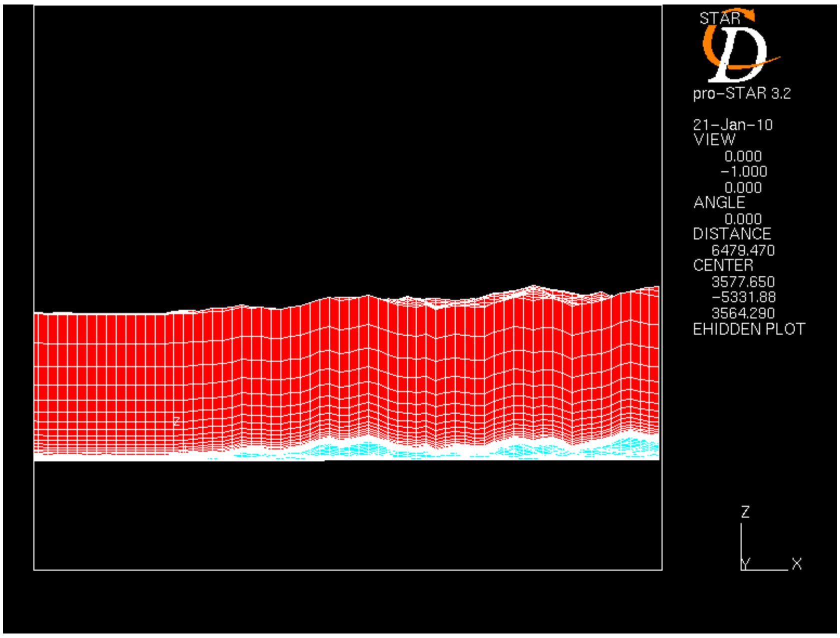

Figure 12 Side view of flui body mesh

Once the Flui body mesh has been generated, the terrain mesh needs to be merged with the building model of the nuclear power plant area (e.g. cooling towers), and the part of the terrain mesh in the nuclear power plant area needs to be hollowed out before merging.

```
*set,X0,-2000
*set,Y0,-2000
*set,X1,2000
```

```
*set,Y1,2000
*set,Z0,1000
cset,news,gran,X0,X1,Y0,Y1,,Z0,,,
vset,news,cset
cdel,cset
cset,all
cplo
```

Where X0, Y0, X1, Y1 correspond to the coordinates of the previous grid fill, Z0 is the depth of the dredge, taken as 1000m in this paper, the dredged flui body grid is shown in Figure 13.

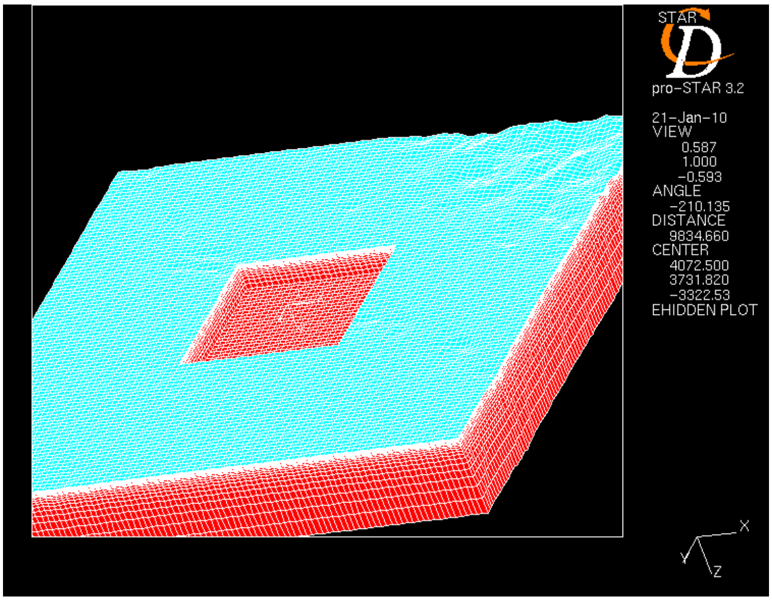

Figure 13 Flui body mesh after hollowing out

At this point, the entire terrain mesh has been created and four large natural ventilation cooling tower mesh models have been imported in this paper, see Figure 14 and Figure 15.

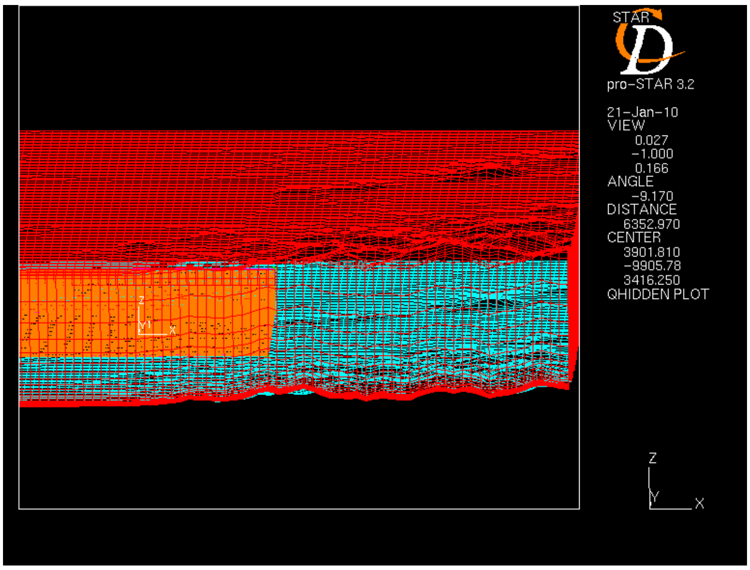

Figure 14 Merging with the nuclear power plant zone grid

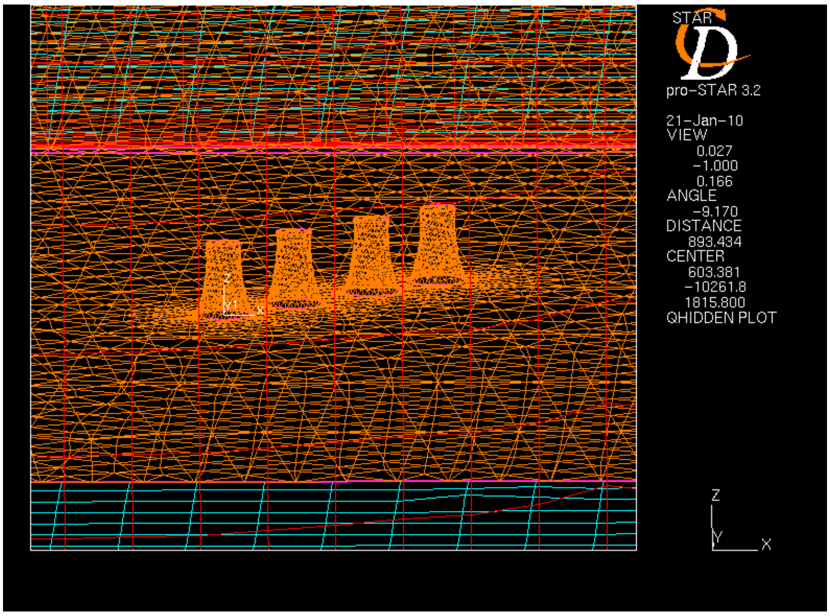

Figure 15 Large naturally ventilated cooling tower

After the terrain grid model is established, various boundary conditions are determined using different meteorological conditions, and the model can be directly used for numerical simulation calculations. The research results of this paper have now been applied to the environmental impact assessment of the Taohwajiang Nuclear Power Plant and Jiangxi Pengze Nuclear Power Plant. Figure 16 shows the plume concentration distribution of a single cooling tower in the Taohwajiang nuclear power using StarCD.

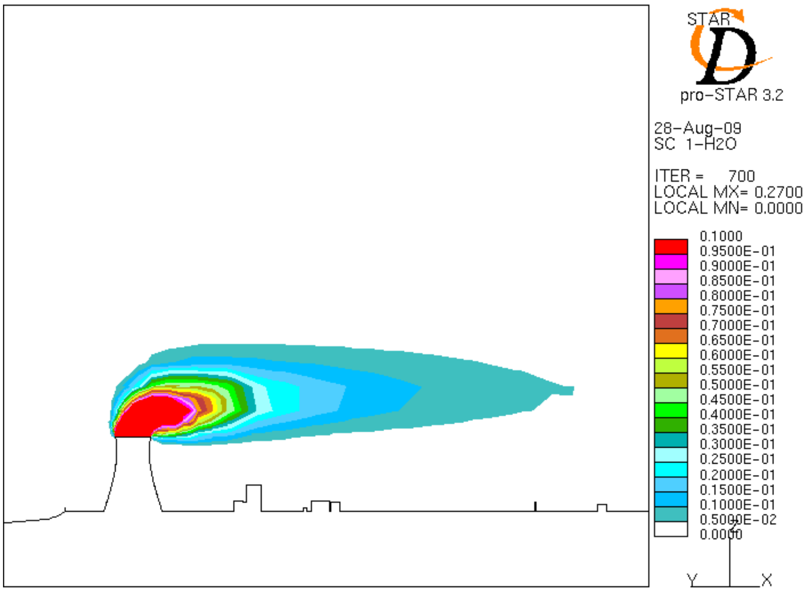

Figure 16 NNW wind direction cooling tower heat plume cross-sectional concentration distribution

5 Conclusion

In this paper, we use the inverse distance weighted interpolation method to generate terrain data files in .grd format based on SRTM terrain data in the process of simulating plume dispersion under complex terrain conditions, and at the same time use the Fortran90 programming language to write the GridInter terrain grid program to convert the .grd file format to a dotted file format that can be recognised in StarCD. The article discusses in detail the generation method of StarCD terrain grids, and the results show that the terrain grids in StarCD can reflect the terrain changes more accurately.

In this paper, the structures in the nuclear power plant area (four large natural ventilation cooling towers as an example) are synthesised with the terrain grid, and the generated grid model can be directly used for numerical calculations. The terrain mesh generation method proposed in this paper operates with high efficiency.

The results of this paper can be used in numerical simulations to study the dispersion of atmospheric pollutants in inland nuclear power plants, and the approach is also applicable to other models that require loading of topographic data, such as the simulation of noise from large naturally ventilated cooling towers in inland nuclear power plants.

Acknowledgments

This research work has been funded by the study on the mechanism of the effect of cooling tower on particle nuclide retention at offshore nuclear power plant site and the evaluation modeling (JZ-202211001) and the particle size spectrum analysis of the effect of cooling tower on nuclide particle dispersion (20221094), Prof. Shuhuan Liu gave a lot of support during the implementation of the project, and we would like to express our sincere thanks.

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Submitted: 20.06.2023.
Revised: 15.07.2023.
Accept: 18.08.2023.