地球系统数值模拟装置项目
(地球系统模式数值模拟系统)
大陆冰盖模式分系统培训

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02 模式原理

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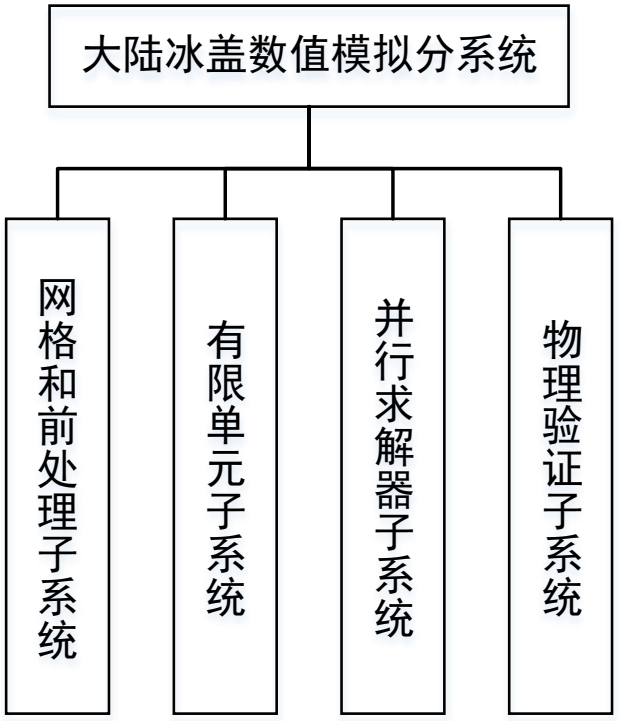
01 分系统介绍

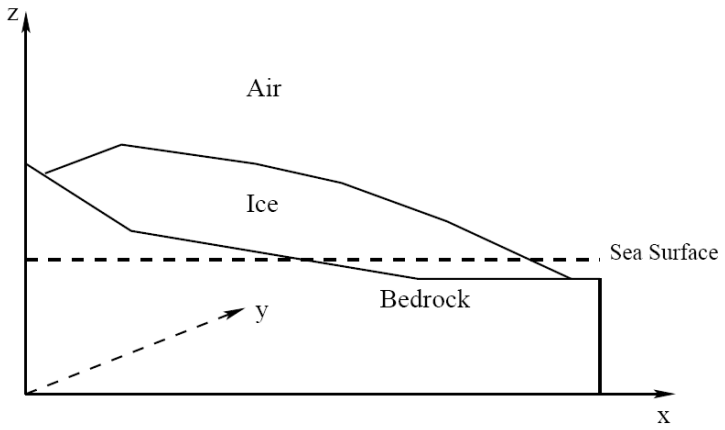


大陆冰盖模式分系统组成图

大陆冰盖模式分系统主要基于冰盖的动量、能量和质量守恒偏微分方程组，以及冰盖表面融化剥蚀过程的控制方程，利用最新的卫星观测数据（包括冰层厚度分布数据、年平均，月平均冰层温度分布数据、冰层底部基岩高程分布数据等）以及最新的实验室模拟结果数据等等，以国际上较为成熟的冰盖模型为基础，建立高分辨率的大陆冰盖数值模拟软件系统，可以对大陆冰盖在数百年内的发展趋势做出可靠的预测，为全球大气和海洋相关的科学研究提供有价值的参考。

02 模式原理

三维Full Stokes方程



$$\begin{cases} \nabla \cdot \boldsymbol{\sigma} + \rho \boldsymbol{g} = 0 \\ \nabla \cdot \boldsymbol{u} = 0 \end{cases}$$

$$\boldsymbol{\sigma} = \boldsymbol{\tau} - p\mathbf{I}$$

$$-\nabla \cdot \boldsymbol{\tau} + \nabla p = \rho \boldsymbol{g}$$

$$\boldsymbol{\tau} = 2\eta \dot{\boldsymbol{\varepsilon}}$$

$$\dot{\boldsymbol{\varepsilon}} = \frac{1}{2}(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T)$$

$$\eta = \frac{1}{2} A^{1/n} \dot{\varepsilon}_e^{(1-n)/n}$$

$$\dot{\varepsilon}_e = \sqrt{\frac{1}{2} \dot{\boldsymbol{\varepsilon}}_u : \dot{\boldsymbol{\varepsilon}}_u}$$

$$A = A(T) = a \exp(-Q/RT)$$

热传导对流扩散方程

$$\rho c \frac{\partial T}{\partial t} + \rho c \boldsymbol{u} \cdot \nabla T = \nabla \cdot (\kappa \nabla T) + 2\eta \dot{\varepsilon} : \dot{\varepsilon} + q$$

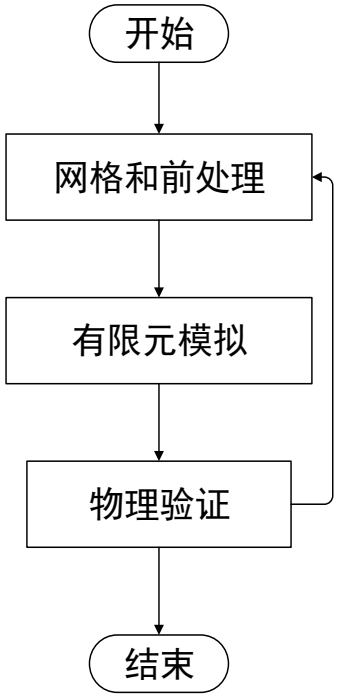
冰盖顶部自由表面方程

$$\frac{\partial h}{\partial t} + u_x \frac{\partial h}{\partial x} + u_y \frac{\partial h}{\partial y} - u_z = h_{flux}$$

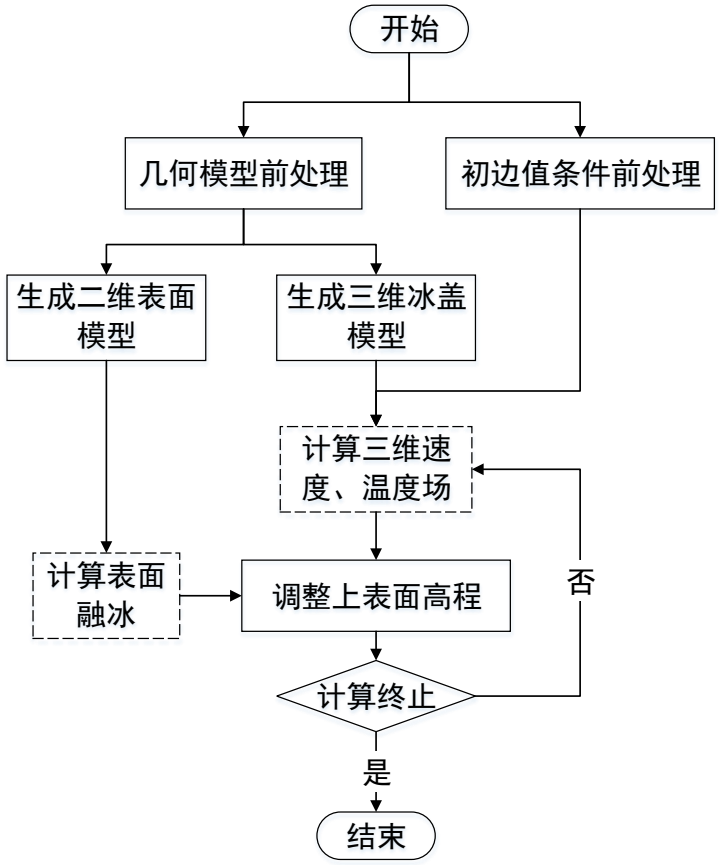
Rayleigh摩擦边界

$$\boldsymbol{n} \times (\boldsymbol{\tau} \cdot \boldsymbol{n}) \times \boldsymbol{n} = \begin{cases} -\beta^2 \boldsymbol{n} \times \boldsymbol{u} \times \boldsymbol{n} & if \ |\boldsymbol{\sigma} \cdot \boldsymbol{n}| = |(-p\mathbf{I} + \boldsymbol{\tau}) \cdot \boldsymbol{n}| > \tau_c \\ 0 \text{ 且 } \boldsymbol{u} = 0 & if \ |\boldsymbol{\sigma} \cdot \boldsymbol{n}| = |(-p\mathbf{I} + \boldsymbol{\tau}) \cdot \boldsymbol{n}| > \tau_c \end{cases}$$

03 程序代码结构



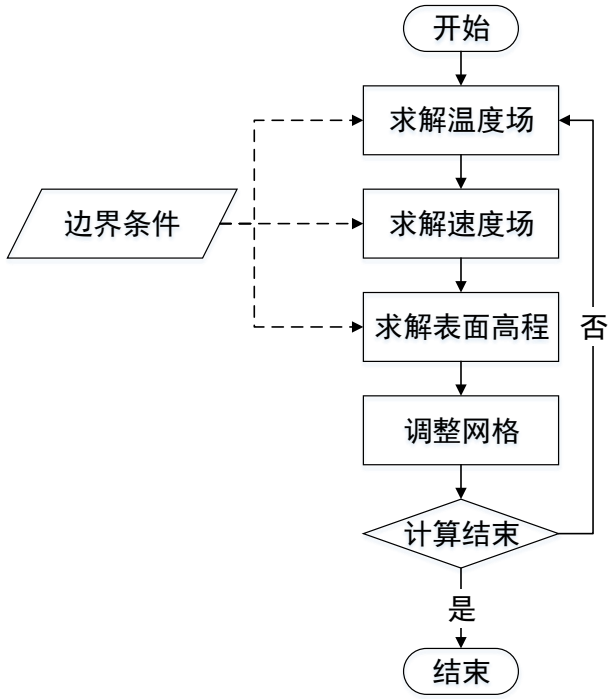
大陆冰盖模式代码结构



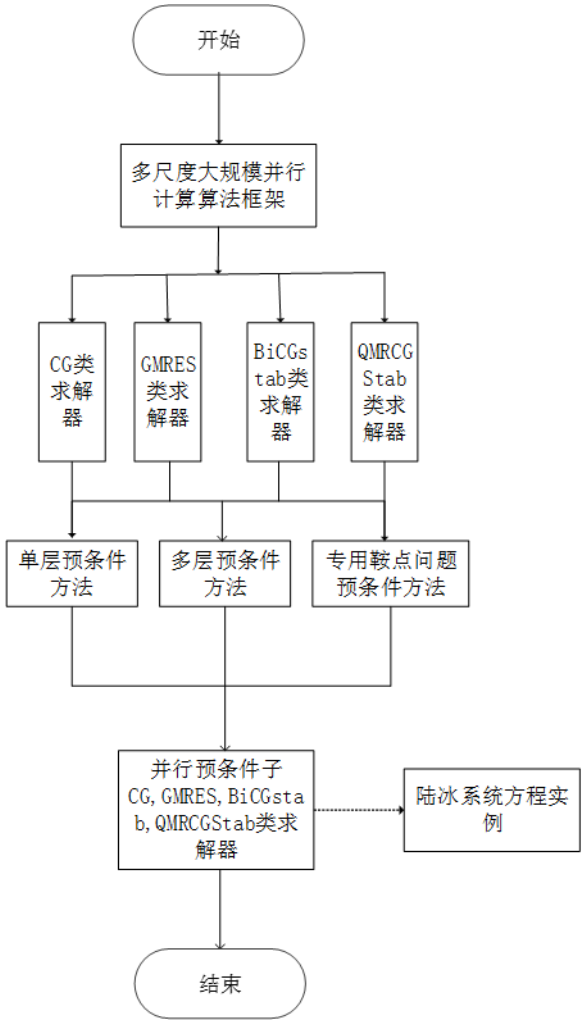
网格和前处理子系统流程图

（1）首先，网格和前处理子系统读取NSIDC（美国国家冰雪中心）提供的全球大陆冰盖几何模型，建立三维网格，并且将卫星提供的水平速度场和大气温度场插值到网格结点，作为数值模拟的初始条件和边界条件。

03 程序代码结构



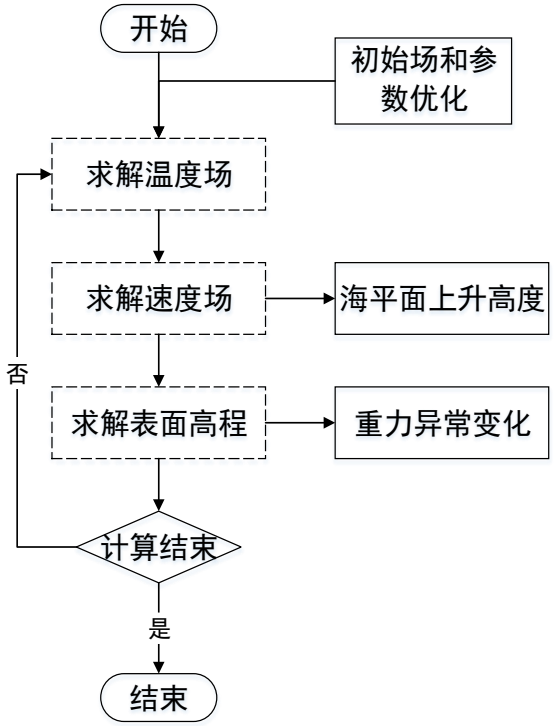
有限元模拟子系统流程图



并行求解器子系统流程图

（2）有限单元子系统和并行求解器子系统根据网格建立线性系统，并读取前处理模块给出的初始条件和边界条件，对冰盖的速度场、温度场和表面水文随时间的演化进行数值模拟。模拟结果传递给后处理子系统和物理验证子系统进行分析和可视化。

03 程序代码结构



物理验证子系统流程图

（3）物理验证子系统使用统计学方法对数值模拟结果和实际观测得到的历史数据进行比对，优化模型初始条件和模型参数，同时计算冰盖变化引起的区域重力异常和海平面变化，分析大陆冰盖对岩石圈和海洋的影响。

04 数据制备

greenland.data_orig

在ice-sheet-meshgen\geomesh\GL 目录下，为格陵兰冰盖地形原始数据，该数据用于生成冰盖三角形网格，一般不做修改。数据格式如下图所示，第一行为网格数，如nx = 301，ny=561；第二行开始为冰盖数据，第一列和第二列为标号，第三列为冰盖厚度，第五列为mask，第四列为密度等（不做读取）。

301	561			
1	1	0.0000000000E+00	0.0000000000E+00	1
1	2	0.0000000000E+00	0.0000000000E+00	1
1	3	0.0000000000E+00	0.0000000000E+00	1
1	4	0.0000000000E+00	0.0000000000E+00	1
1	5	0.0000000000E+00	0.0000000000E+00	1
1	6	0.0000000000E+00	0.0000000000E+00	1
1	7	0.0000000000E+00	0.0000000000E+00	1
1	8	0.0000000000E+00	0.0000000000E+00	1
1	9	0.0000000000E+00	0.0000000000E+00	1
1	10	0.0000000000E+00	0.0000000000E+00	1
1	11	0.0000000000E+00	0.0000000000E+00	1
1	12	0.0000000000E+00	0.0000000000E+00	1
1	13	0.0000000000E+00	0.0000000000E+00	1
1	14	0.0000000000E+00	0.0000000000E+00	1
1	15	0.0000000000E+00	0.0000000000E+00	1
1	16	0.0000000000E+00	0.0000000000E+00	1
1	17	0.0000000000E+00	0.0000000000E+00	1
1	18	0.0000000000E+00	0.0000000000E+00	1
1	19	0.0000000000E+00	0.0000000000E+00	1
1	20	0.0000000000E+00	0.0000000000E+00	1

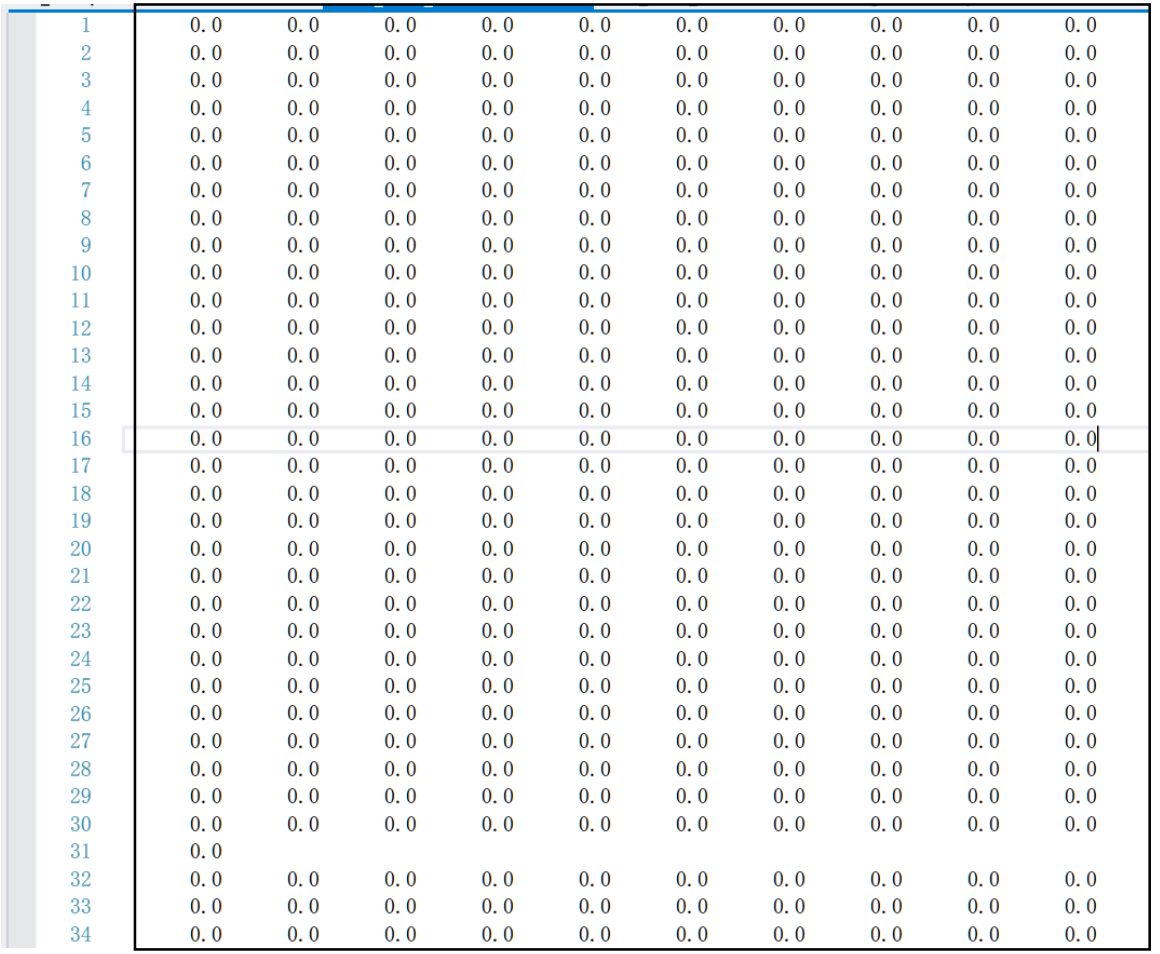
greenland.data_orig 数据文件截图

04 数据制备

thick_5km_corrected

在 ice-sheet-prediction\mesh.greenland.couple.t 目 录 和 ice-sheet-prediction\mesh.greenland.couple.v目录下，该数据为格陵兰冰盖5km分辨率的冰层厚度，用于冰盖有限元网格插值生成三维网格及计算初值等。

数据格式如图方框所示，每31行计301个数据为一组，每行为10列，共计561组，即301*561个格点数据。



thick_5km_corrected 数据文件截图

04 数据制备

bed_5km_corrected

在 ice-sheet-prediction\mesh.greenland.couple.t 目 录 和 ice-sheet-prediction\mesh.greenland.couple.v目录下，该数据为格陵兰冰盖5km分辨率的冰层基岩地形，用于冰盖有限元网格插值生成三维网格及计算初值等。

数据格式如图方框所示，每31行计301个数据为一组，每行为10列，共计561组，即301*561个格点数据。

2016	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2017	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2018	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2019	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2020	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	118.5	275.9
2021	-0.1	310.6	438.5	567.2	727.6	815.1	712.5	739.3	820.4	926.3
2022	1150.2	1143.8	1141.6	1163.4	1165.2	1165.1	1109.7	1051.7	1010.1	967.0
2023	914.9	852.6	793.7	772.4	788.7	822.3	865.3	927.1	1001.2	1072.9
2024	1124.0	1121.5	1082.6	1011.1	923.5	850.9	841.6	901.7	969.9	1027.7
2025	1068.1	1092.4	1097.5	1076.5	998.5	949.8	1068.0	1100.4	1080.6	1047.2
2026	1002.8	973.9	954.7	970.7	989.3	984.6	973.3	919.5	826.9	755.7
2027	837.3	956.9	1065.7	1136.9	1162.2	1187.8	1230.5	1269.7	1205.3	1059.1
2028	918.6	765.7	648.0	666.2	602.4	249.7	-0.1	-0.1	-0.1	-0.1
2029	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2030	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2031	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2032	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2033	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2034	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2035	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2036	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2037	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2038	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2039	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2040	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2041	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2042	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2043	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2044	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2045	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2046	-0.1									
2047	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2048	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
2049	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1

bed_5km_corrected 数据文件截图

04 数据制备

GL_Temperature5KM.dat

在 ice-sheet-prediction\mesh.greenland.couple.t 目 录 和 ice-sheet-prediction\mesh.greenland.couple.v目录下，该数据为格陵兰冰盖5km分辨率的冰层温度，用于冰盖有限元网格插值生成三维网格及计算初值等。

数据格式如图方框所示，每行301个数据，共计561行，即301*561个格点数据。

1	0.0000000e+00	0.0000000e+00	0.0000000e+00	0.0000000e+00	0.0000000e+00	0.0000000e+00	0.0000000e+
2	0.0000000e+00	4.1544089e-02	7.8238771e-02	1.1008405e-01	1.3707991e-01	1.5736275e-01	1.7155377e-
3	0.0000000e+00	7.3437744e-02	1.3845758e-01	1.9505950e-01	2.4324351e-01	2.7977135e-01	3.0572245e-
4	0.0000000e+00	9.5680966e-02	1.8065642e-01	2.5492635e-01	3.1849077e-01	3.6722580e-01	4.0250606e-
5	0.0000000e+00	1.0827375e-01	2.0483529e-01	2.8968461e-01	3.6282172e-01	4.1972610e-01	4.6190459e-
6	0.0000000e+00	1.0753277e-01	2.0409304e-01	2.8968080e-01	3.6429605e-01	4.2368840e-01	4.6927464e-
7	0.0000000e+00	9.4685795e-02	1.8073004e-01	2.5813273e-01	3.2689387e-01	3.8364066e-01	4.2949735e-
8	0.0000000e+00	7.7099504e-02	1.4854863e-01	2.1434738e-01	2.7449575e-01	3.2675055e-01	3.7185951e-
9	0.0000000e+00	6.2140577e-02	1.2135115e-01	1.7763171e-01	2.3098227e-01	2.8018577e-01	3.2564790e-
10	0.0000000e+00	5.0382502e-02	1.0027501e-01	1.4967752e-01	1.9859003e-01	2.4671396e-01	2.9414884e-
11	0.0000000e+00	3.8360035e-02	7.8806699e-02	1.2133999e-01	1.6595991e-01	2.1333805e-01	2.6325054e-
12	0.0000000e+00	2.7381763e-02	5.9272164e-02	9.5671204e-02	1.3657888e-01	1.8357863e-01	2.3614264e-
13	0.0000000e+00	1.8756270e-02	4.3997344e-02	7.5723223e-02	1.1393391e-01	1.6095631e-01	2.1601478e-
14	0.0000000e+00	1.2893839e-02	3.3745723e-02	6.2555652e-02	9.9323627e-02	1.4692990e-01	2.0441438e-
15	0.0000000e+00	9.0761168e-03	2.7229056e-02	5.4458817e-02	9.0765400e-02	1.3944842e-01	1.9940800e-
16	0.0000000e+00	6.9187297e-03	2.3695683e-02	5.0330859e-02	8.6824259e-02	1.3676776e-01	1.9896407e-
17	0.0000000e+00	6.0373047e-03	2.2393945e-02	4.9069922e-02	8.6065234e-02	1.3714380e-01	2.0105098e-
18	0.0000000e+00	7.0033612e-03	2.4324811e-02	5.1964350e-02	8.9921978e-02	1.4196009e-01	2.0682457e-
19	0.0000000e+00	9.7972253e-03	2.9488695e-02	5.9074410e-02	9.8554370e-02	1.5153062e-01	2.1680247e-
20	0.0000000e+00	1.3147733e-02	3.5633108e-02	6.7456125e-02	1.0861678e-01	1.6250690e-01	2.2799587e-
21	0.0000000e+00	1.5783722e-02	4.0505562e-02	7.4165519e-02	1.1676359e-01	1.7154048e-01	2.3741594e-
22	0.0000000e+00	1.7423186e-02	4.3606434e-02	7.8549743e-02	1.2225312e-01	1.7788981e-01	2.4440207e-
23	0.0000000e+00	1.8725089e-02	4.6103372e-02	8.2134849e-02	1.2681952e-01	1.8329028e-01	2.5050282e-
24	0.0000000e+00	1.9829719e-02	4.8244787e-02	8.5245205e-02	1.3083097e-01	1.8810881e-01	2.5604315e-
25	0.0000000e+00	2.0877366e-02	5.0279092e-02	8.8205178e-02	1.3465563e-01	1.9271234e-01	2.6134802e-
26	0.0000000e+00	2.1898515e-02	5.2259865e-02	9.1084048e-02	1.3837107e-01	1.9717602e-01	2.6648053e-
27	0.0000000e+00	2.2820655e-02	5.4058841e-02	9.3714559e-02	1.4178781e-01	2.0131170e-01	2.7127521e-
28	0.0000000e+00	2.3629576e-02	5.5651667e-02	9.6066275e-02	1.4487340e-01	2.0509142e-01	2.7571421e-
29	0.0000000e+00	2.4311068e-02	5.7013989e-02	9.8108763e-02	1.4759539e-01	2.0848717e-01	2.7977967e-
30	0.0000000e+00	2.4886093e-02	5.8181546e-02	9.9886358e-02	1.5000053e-01	2.1153824e-01	2.8349477e-
31	0.0000000e+00	2.5353979e-02	5.9153249e-02	1.0139781e-01	1.5208766e-01	2.1424398e-01	2.8685972e-
32	0.0000000e+00	2.5668069e-02	5.9849501e-02	1.0254430e-01	1.5375246e-01	2.1651649e-01	2.8982223e-
33	0.0000000e+00	2.5781703e-02	6.0190708e-02	1.0322702e-01	1.5489062e-01	2.1826788e-01	2.9233001e-
34	0.0000000e+00	2.5695818e-02	6.0178393e-02	1.0344772e-01	1.5550381e-01	2.1949902e-01	2.9438256e-
35	0.0000000e+00	2.5430839e-02	5.9847423e-02	1.0324975e-01	1.5563783e-01	2.2024868e-01	2.9600330e-
36	0.0000000e+00	2.4969342e-02	5.9168221e-02	1.0259664e-01	1.5525459e-01	2.2048583e-01	2.9717578e-
37	0.0000000e+00	2.4293903e-02	5.8111206e-02	1.0145191e-01	1.5431602e-01	2.2017943e-01	2.9788353e-
38	0.0000000e+00	2.3410363e-02	5.6687169e-02	9.9830416e-02	1.5284010e-01	2.1935001e-01	2.9814888e-
39	0.0000000e+00	2.2324521e-02	5.4905658e-02	9.7743412e-02	1.5083778e-01	2.1800452e-01	2.9797170e-
40	0.0000000e+00	2.1018882e-02	5.2735236e-02	9.5149061e-02	1.4826036e-01	2.1609157e-01	2.9730187e-
41	0.0000000e+00	1.9475955e-02	5.0144463e-02	9.2005525e-02	1.4505914e-01	2.1355977e-01	2.9608925e-
42	0.0000000e+00	1.7748287e-02	4.7227207e-02	8.8436760e-02	1.4137695e-01	2.1055721e-01	2.9447441e-

GL_Temperature5KM.dat 数据文件截图

05 新建case、编译、运行

二维非结构化有限元网格生成

- 目录：ice-sheet/ice-sheet-meshgen/geomesh/GL/
- ./run
- vi runmesh 根据需要修改-a和-i 后面的数值
- ./runmesh

```
[hzhang01@login01 GL]$ ./run
 Open orginal file
 Image size:         301 x         561
 Write mask file
 Write thickness file
 Image size:         301 x         561
 Mask information:           0           1       65725

 Finding all loops ...
 Total Loops:           96
 Write all loops information into "loops.out.orig"
 Removing noises ...
 Remaining loops:           96
 Deleting intermidiate boundary points ...
 Write the maixmal loop into "loopsmax.out"
 Write other loops into "loopsoth.out"
 Number of boundary nodes:        1628
```

./run运行结果

```
[hzhang01@login01 GL]$ vi runmesh
#!/bin/sh
make
./mesh_init -f loopsmax.poly -q 1 -a 1.5
./mesh_opti -s 1 -i 100
./mesh_refi -u 1
./mesh_opti -s 1 -i 40
```

修改runmesh文件参数

```
# of Nodes      =     137177
# of Triangles =     269384
----------- Quality of Input mesh ------------
  h_max = 2.842781e+00   h_min = 2.403664e-01
  h_dif =      11.8269
are_max = 2.378902e+00 are_min = 1.660890e-02
are_dif =     143.2306
ang_max =    128.45511 ang_min =     14.48730
  q_max =     0.999999   q_min =     0.341331
  q_avg =     0.933499   q_dev =     0.060777
eng_max = 9.534067e+03 eng_min = 2.533793e+02
eng_avg = 1.269074e+03 eng_dev =     1.063562
-----------------------------------------------
******Lloyd's Iterations******
N_Iter =    40  T_Move = 0.4637290395
******Ouput Mesh******
# of Nodes      =     137177
# of Triangles =     269193
----------- Quality of Output Mesh -----------
  h_max = 2.955996e+00   h_min = 2.466512e-01
  h_dif =      11.9845
are_max = 2.575621e+00 are_min = 1.916082e-02
are_dif =     134.4212
ang_max =    119.35365 ang_min =     16.90060
  q_max =     1.000000   q_min =     0.471954
  q_avg =     0.947993   q_dev =     0.048924
eng_max = 9.221565e+03 eng_min = 2.640427e+02
eng_avg = 1.254290e+03 eng_dev =     1.035240
-----------------------------------------------
Program stops after maximal iterations ...
```

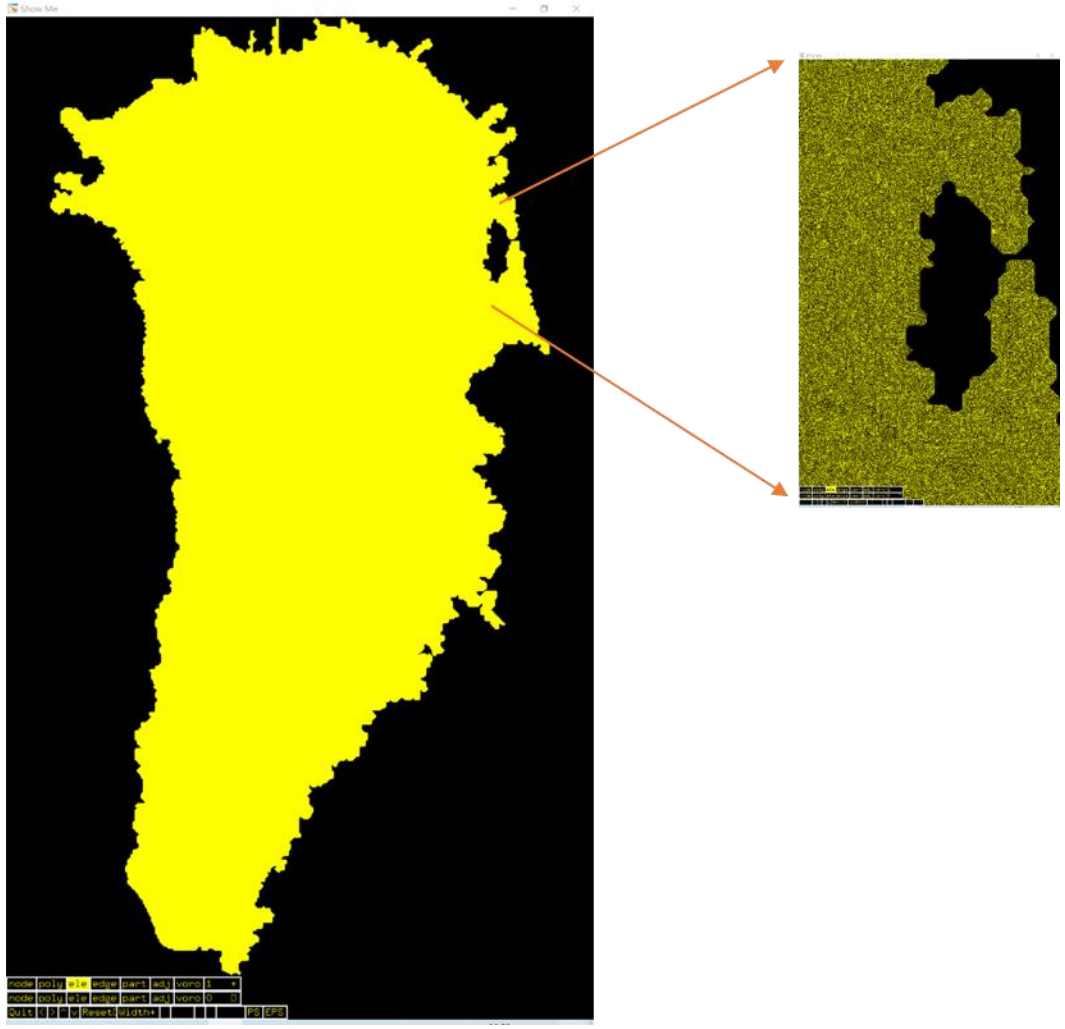
./runmesh运行结果

05 新建case、编译、运行

二维非结构化有限元网格生成

- 目录：ice-sheet/ice-sheet-meshgen/geomesh/GL/
- ./run
- vi runmesh 根据需要修改-a和-i 后面的数值
- ./runmesh

程序运行成功后，会生成网格节点文件nodes.dat和三角形网格文件trigs.dat，并会生成可视化二维非结构化三角形网格输出结果，即output.1系列文件，用 showme output.1 命令即可查看



二维非结构化网格可视化结果

05 新建case、编译、运行

三维非结构化有限元网格生成

- 目录：ice-sheet/ice-sheet-prediction/mesh.greenland.couple.t/
- 将nodes. dat和trigs.dat复制到本目录
- 修改greenlandprmts文件中垂直网格层数
- ./greendatapre-5m

```
c
c  materials data for computing of western Sichuan area
c
c  solution domain and mesh generation data as following
c
c  Layer's information
   25
c material data for main element
13,3
 6.6e7   2093.d0 0.d0   918.d0   0.d0   7.5e10     0.25  3.0e23  9.8d0   0.d0   2.750d0   (ice)
 6.6e7   2093.d0 0.d0   918.d0   0.d0   2.5e10     0.30  4.0e19  9.8d0   0.d0   2.900d0   (ice)
 6.6e7   2093.d0 0.d0   918.d0   0.d0   1.0e10     0.33  8.0e18  9.8d0   0.d0   3.500d0   (ice)
 6.6e7   2093.d0 0.d0   918.d0   0.d0   5.0e9      0.33  1.0e20  9.8d0   0.d0   4.300d0   (ice)
 6.6e7   2093.d0 0.d0   918.d0   0.d0   1.0e10     0.28  1.0e19  9.8d0   0.d0   4.550d0   (ice)
 6.6e7   2093.d0 0.d0   918.d0   0.d0   1.0e9      0.33  2.0e18  9.8d0   0.d0   4.550d0   (ice)
 6.6e7   2093.d0 0.d0   918.d0   0.d0   1.0e9      0.33  2.0e18  9.8d0   0.d0   4.550d0   (ice)
 6.6e7   2093.d0 0.d0   918.d0   0.d0   1.0e9      0.33  2.0e18  9.8d0   0.d0   4.550d0   (ice)
 6.6e7   2093.d0 0.d0   918.d0   0.d0   1.0e9      0.33  2.0e18  9.8d0   0.d0   4.550d0   (ice)
 6.6e7   432.6d0 0.d0 1000.d0   0.d0   1.0e9      0.33  2.0e18  9.8d0   0.d0   4.550d0  (water)
 6.6e7   432.6d0 0.d0 1000.d0   0.54   1.0e9      0.33  2.0e18  9.8d0   0.d0   4.550d0  (water)
 6.6e7   432.6d0 0.d0 1000.d0   0.54   1.0e9      0.33  2.0e18  9.8d0   0.d0   4.550d0  (water)
 6.6e7   432.6d0 0.d0 1000.d0   0.54   1.0e9      0.33  2.0e18  9.8d0   0.d0   4.550d0  (water)
c material data for boundary surface element - quadrilaterial element
10 2
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
c material data for boundary surface element - triangle element
10 2
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
 0.d0   0.d0   130.d0   0.d0    0.d0   0.d0
c line 47, end of factors file, do not change the colums of this data file.
~
```

修改greenlandprmts文件

```
  Profile data input
  layer information
           100
 material factors for Hex elements
            13           3
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       2093.000000000000       0.0000000000000000
   66000000.000000000       432.60000000000002      0.0000000000000000
   66000000.000000000       432.60000000000002      0.0000000000000000
   66000000.000000000       432.60000000000002      0.0000000000000000
   66000000.000000000       432.60000000000002      0.0000000000000000
 material factors for quadrilaterial elements
            10           2
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
 material factors for triangle elements
            10           2
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000
   0.0000000000000000       0.0000000000000000

 ntri=       669815
 nodde, nr, nnode*(nr+1),ntri,ntri*nr
      339478         100     34287278        669815      66981500
```

三维网格剖分

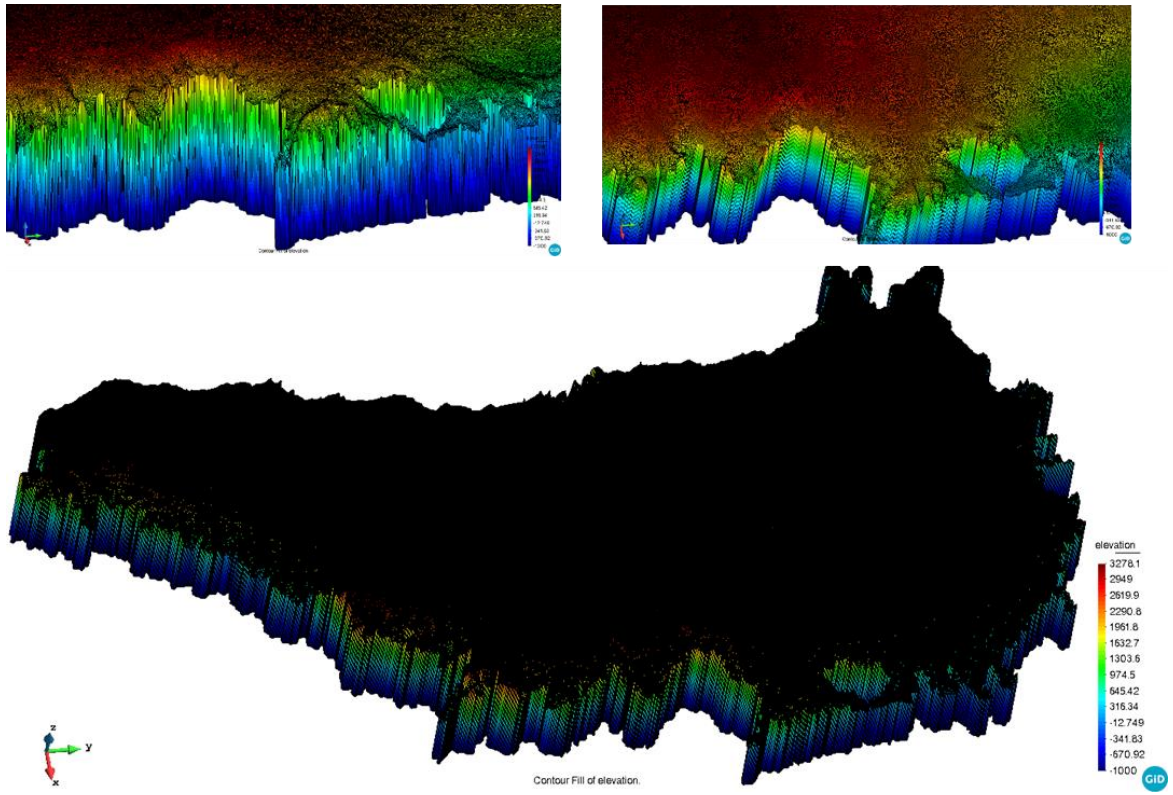
05 新建case、编译、运行

三维非结构化有限元网格生成

- 目录：ice-sheet/ice-sheet-prediction/mesh.greenland.couple.t/
- 将nodes. dat和trigs.dat复制到本目录
- 修改greenlandprmts文件中垂直网格层数
- ./greendatapre-5m

- 程序生成.msh 和.res文件
- 用Gid后处理软件可查看插值过后的三维非结构化网格图像

类似的，进入ice-sheet/ice-sheet-prediction/mesh.greenland. couple.v/目录下，按照以上步骤，也可生成三维网格



三维网格剖分

05 新建case、编译、运行

大陆冰盖温度场和速度场模拟

需确保ice-sheet/ice-sheet-prediction/sourcecode.temperature. couple/和ice-sheet/ice-sheet-prediction/sourcecode.velosity.couple/目录下源程序已通过make编译完成

温度场模拟

- 目录：ice-sheet/ice-sheet-prediction/mesh.greenland.couple.t/
- ./cpdata.sh 将网格及数据信息复制到计算部分中
- 修改partition.dat中的参数，确定分区数目
- 运行USCazpartition-ih-vtc进行数据分区
- 用sbatch提交ddmrunTemperature.slurm作业并行计算，求解冰盖温度场

```
filename === elem0.elm\0 ^C
*************************************************************************
Partitioning Dual Graph... ------------------------------------------
 Begin          1   subdomain data partition...
nod_iblk,ncoor,num_iblk,nnode,nne,knode==
      61880          3      111125          7          6     3566602
partition:iblk,nblk,nnode,nodall matall=          1      111225          7      778575         39
partition:iblk,nblk,nnode,nodall matall=          1           0          5      778575         59
partition:iblk,nblk,nnode,nodall matall=          1           0          4      778575         79
 Begin          2   subdomain data partition...
nod_iblk,ncoor,num_iblk,nnode,nne,knode==
      63102          3      115350          7          6     3566602
partition:iblk,nblk,nnode,nodall matall=          2      115500          7      808500         39
partition:iblk,nblk,nnode,nodall matall=          2           0          5      808500         59
partition:iblk,nblk,nnode,nodall matall=          2           0          4      808500         79
 Begin          3   subdomain data partition...
nod_iblk,ncoor,num_iblk,nnode,nne,knode==
      61776          3      113875          7          6     3566602
partition:iblk,nblk,nnode,nodall matall=          3      113975          7      797825         39
partition:iblk,nblk,nnode,nodall matall=          3           0          5      797825         59
partition:iblk,nblk,nnode,nodall matall=          3           0          4      797825         79
 Begin          4   subdomain data partition...
nod_iblk,ncoor,num_iblk,nnode,nne,knode==
      62270          3      114650          7          6     3566602
partition:iblk,nblk,nnode,nodall matall=          4      114775          7      803425         39
partition:iblk,nblk,nnode,nodall matall=          4           0          5      803425         59
partition:iblk,nblk,nnode,nodall matall=          4           0          4      803425         79
 Begin          5   subdomain data partition...
nod_iblk,ncoor,num_iblk,nnode,nne,knode==
      65832          3      119925          7          6     3566602
partition:iblk,nblk,nnode,nodall matall=          5      120125          7      840875         39
partition:iblk,nblk,nnode,nodall matall=          5           0          5      840875         59
partition:iblk,nblk,nnode,nodall matall=          5           0          4      840875         79
 Begin          6   subdomain data partition...
nod_iblk,ncoor,num_iblk,nnode,nne,knode==
      64402          3      117450          7          6     3566602
partition:iblk,nblk,nnode,nodall matall=          6      117575          7      823025         39
partition:iblk,nblk,nnode,nodall matall=          6           0          5      823025         59
partition:iblk,nblk,nnode,nodall matall=          6           0          4      823025         79
 Begin          7   subdomain data partition...
nod_iblk,ncoor,num_iblk,nnode,nne,knode==
      64584          3      117350          7          6     3566602
partition:iblk,nblk,nnode,nodall matall=          7      117425          7      821975         39
```

数据分区

05 新建case、编译、运行

大陆冰盖温度场和速度场模拟

温度场模拟

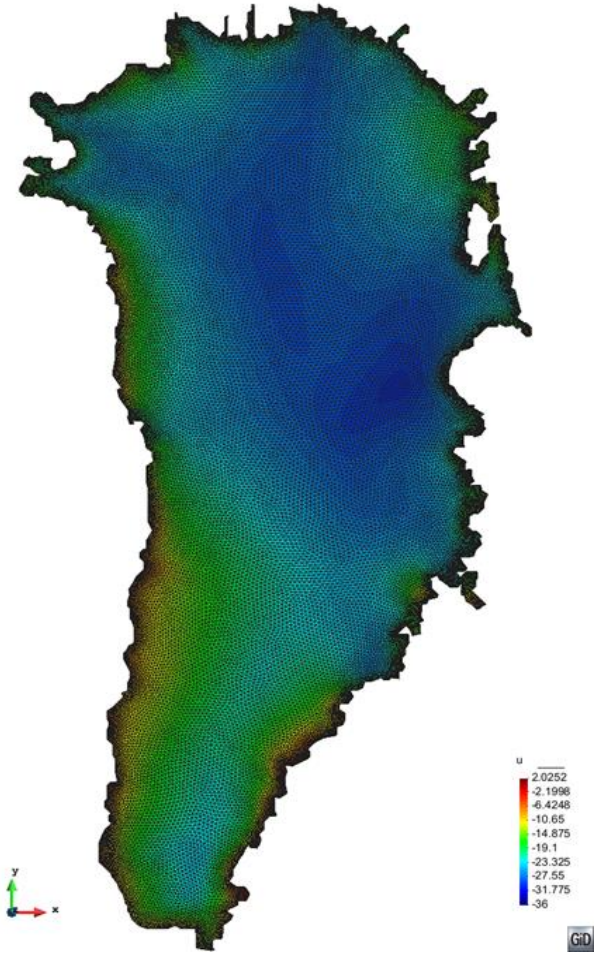
- 目录：ice-sheet/ice-sheet-prediction/mesh.greenland.couple.t/
- ./cpdata.sh 将网格及数据信息复制到计算部分中
- 修改partition.dat中的参数，确定分区数目
- 运行USCazpartition-ih-vtc进行数据分区
- 用sbatch提交ddmrunTemperature.slurm作业并行计算，求解冰盖温度场

- 程序生成results.flavia.res和results.flavia.msh等文件，将其导入Gid软件中，即可可视化模拟结果

速度场模拟

- 目录：ice-sheet/ice-sheet-prediction/mesh.greenland.couple.v/
- ./cpdata.sh 将将温度场模拟信息复制到速度场的计算程序中
- 运行USCazpartition-ih-vtc进行数据分区
- 用sbatch命令提交ddmrunVelocity.slurm作业，进行速度场的并行计算

- 程序生成results.flavia.res和results1.flavia.msh等文件，将其导入gid软件，即可查看模拟结果



温度场模拟结果

05 新建case、编译、运行

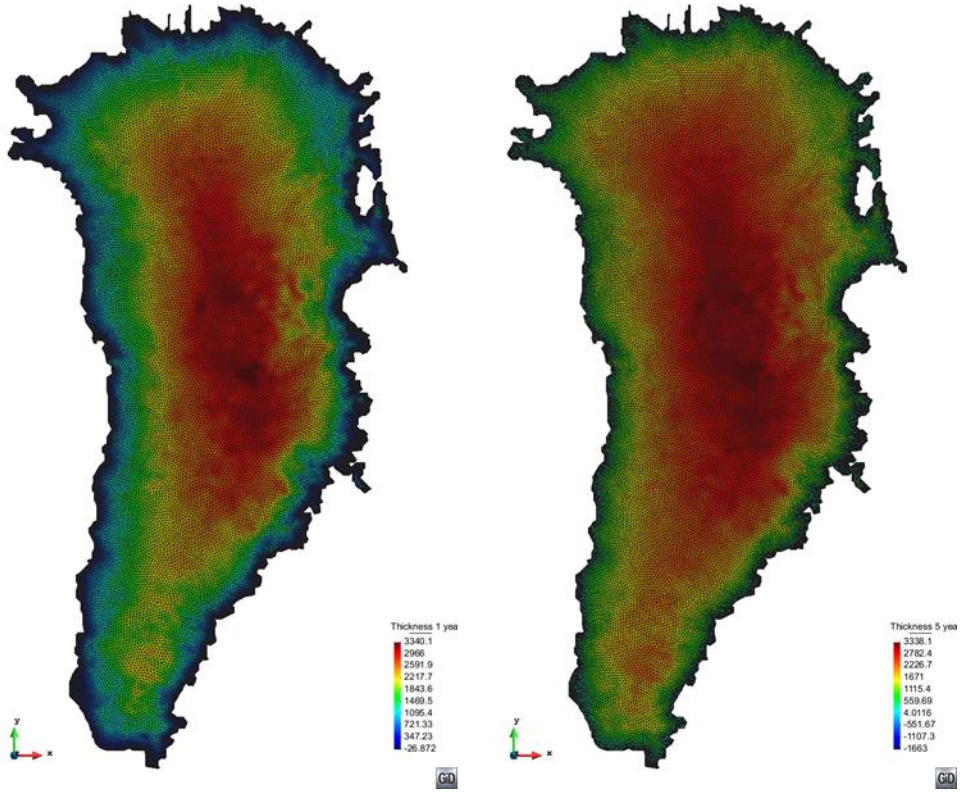
大陆冰盖厚度及高度变化模拟

- 目录：/ice-sheet/diff.prediction/
- ./cpdata.sh　复制所需文件到本目录
- make　　生成diff和ThickPrediction可执行程序
- ThichickPrediction　预测冰盖厚度及高度的变化情况

- 程序生成.msh 和.res文件
- 用Gid后处理软件可查看预测结果

```
[hzhang01@login01 diff.prediction]$ make
ifort -O2 -L../lib -c diff.f
ifort -O2 -o diff diff.o
ifort -O2 -L../lib -c ThickPrediction.f
ifort -O2 -o ThickPrediction ThickPrediction.o
```

源程序编译



大陆冰盖厚度预测结果

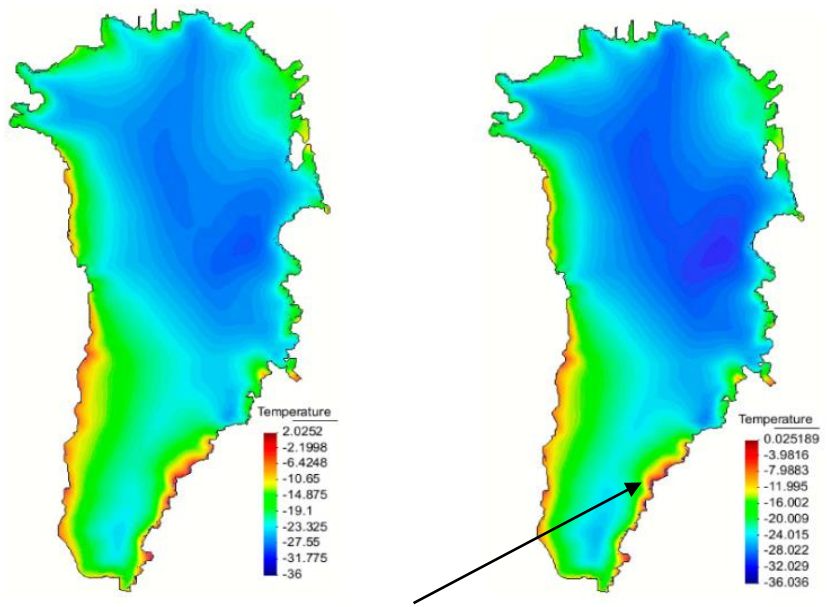
06 结果诊断分析与应用案例

以格陵兰大陆冰盖为例，对大陆冰盖模式分系统进行各项指标的测试工作，测试结果显示：

网格前处理阶段分辨率	水平分辨率	<350M
	垂直分辨率	>100层
整体非结构化网格数		5000万-1亿
网格自适应加密和进程间通讯	用时占比	<10%
	使用内存占比	<30%
组建刚度矩阵和右端项用时占比		<40%
相对残差		<10e-7
模拟冰盖表面高程值与观测值平均相差		<50M

模拟得到的冰盖表面高程值能够对冰盖消融引起的海平面上升和重力异常变化做出有意义的估算

06 结果诊断分析与应用案例



在一些格陵兰冰盖的边缘地区的温度已经超过了融点

图1：格陵兰冰盖一年后的温度演化模拟结果。左：经过纯扩散过程稳定后的初始表面温度场；右：模拟演化一年后的表面温度场

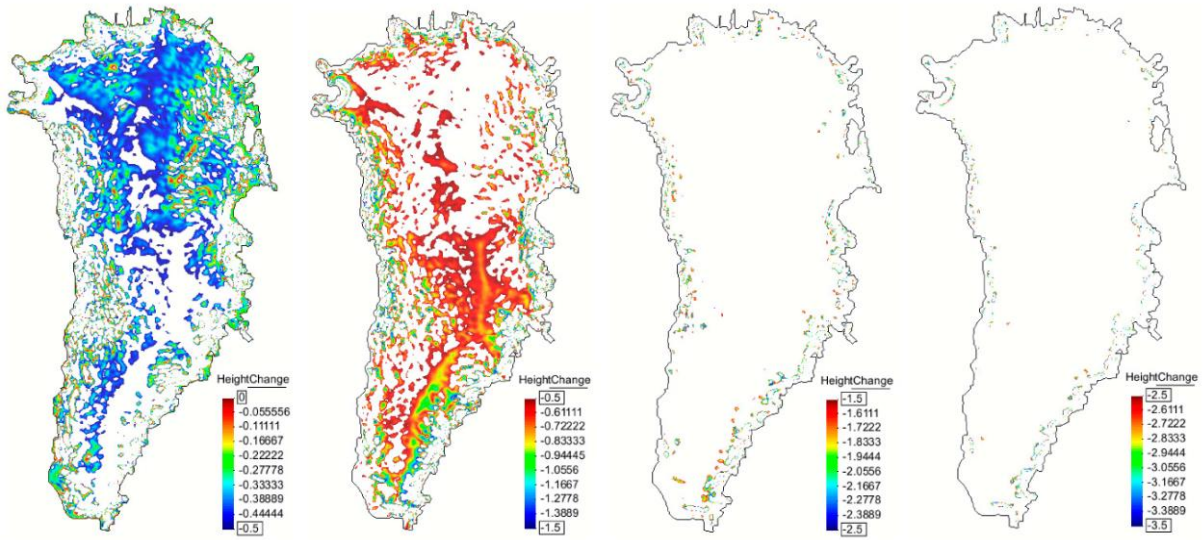


图2：模拟格陵兰冰盖一年后冰厚度的变化；为了更好的可视化和解释，绘制的值被限制在不同的范围

谢　谢