

# 高性能数值计算大作业

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(1) 整个区域可以分为  $N_x * N_y$  个单元，一共有  $(N_x+1) * (N_y+1)$  个点需要计算，令  $h_x=1/n$ ,  $h_y=1/m$  为步长。采用均匀网格做离散得：

$$\begin{aligned}
& \frac{2u_{i,j} - u_{i+1,j} - u_{i-1,j}}{h_x^2} + \frac{2u_{i,j} - u_{i,j+1} - u_{i,j-1}}{h_y^2} - \frac{\omega_{i,j+1} - \omega_{i,j-1}}{2h_y} = 0 \\
& \frac{2v_{i,j} - v_{i+1,j} - v_{i-1,j}}{h_x^2} + \frac{2v_{i,j} - v_{i,j+1} - v_{i,j-1}}{h_y^2} - \frac{\omega_{i+1,j} - \omega_{i-1,j}}{2h_x} = 0 \\
& \frac{2\omega_{i,j} - \omega_{i+1,j} - \omega_{i-1,j}}{h_x^2} + \frac{2\omega_{i,j} - \omega_{i,j+1} - \omega_{i,j-1}}{h_y^2} + DIW(\omega) - G_r \frac{T_{i+1,j} - T_{i-1,j}}{2h_x} = 0 \\
& \frac{2T_{i,j} - T_{i+1,j} - T_{i-1,j}}{h_x^2} + \frac{2T_{i,j} - T_{i,j+1} - T_{i,j-1}}{h_y^2} + P_r * DIV(T) = 0 \\
& DIV(C) = u_{i,j} * \frac{(C_{i+1,j} - C_{i-1,j})}{2h_x} + v_{i,j} * \frac{(C_{i,j+1} - C_{i,j-1})}{2h_y} \\
& C = \omega, T \\
& h_x = \frac{1}{n}, \quad h_y = \frac{1}{m} \quad l, j=0,1,\dots,n; \\
& n=N_x \\
& m=N_y
\end{aligned}$$

$X = (u, v, \omega, T)$ , 写成向量的形式可得:  $F(X) = 0$

(2) 编译程序 ex19.c:

```
make PETSC_DIR=~/code/petsc ex19
```

运行程序：

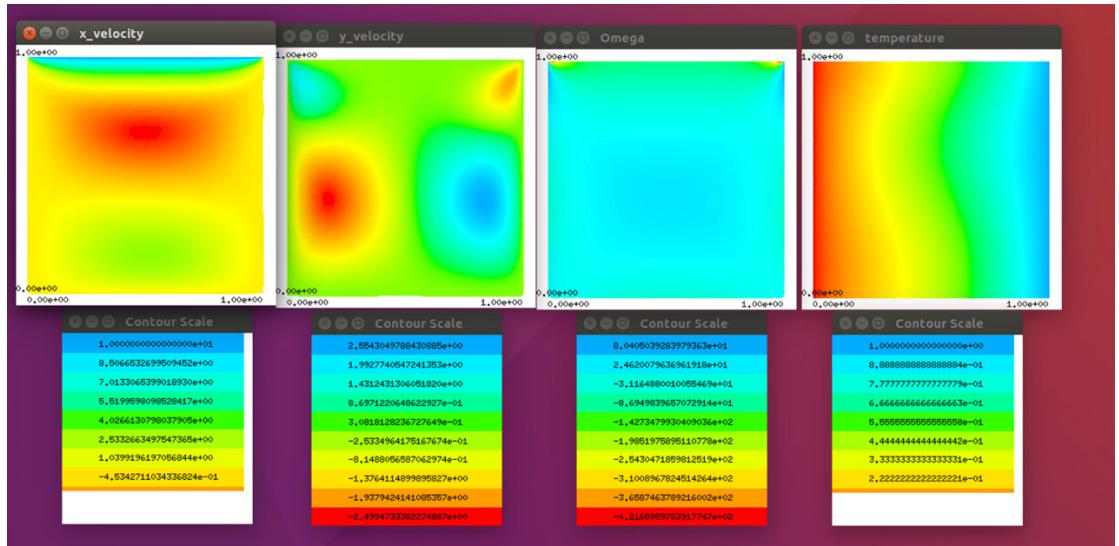
```
mpirun -np 4 ./ex19 -da_grid_x 64 -da_grid_y 64 -snes_monitor -  
snes_converged_reason -lidvelocity 10. -prandtl 1. -grashof 1000. -contours 1 -  
draw_pause -2
```

运行结果及图像如下：

```

ldvelocity = 10., prandtl # = 1, grashof # = 1000.
ldvelocity = 10., prandtl # = 1, grashof # = 1000.
ldvelocity = 10., prandtl # = 1, grashof # = 1000.
SNES Function norm 8.027463868964e+01
0 SNES Function norm 8.027463868964e+01
ldvelocity = 10., prandtl # = 1, grashof # = 1000.
SNES Function norm 8.027463868964e+01
0 SNES Function norm 8.027463868964e+01
1 SNES Function norm 1.78839671599e+01
SNES Function norm 1.78839671599e+01
SNES Function norm 1.78839671599e+01
SNES Function norm 1.78839671599e+01
2 SNES Function norm 4.743612598174e-03
SNES Function norm 4.743612598174e-03
2 SNES Function norm 4.743612598174e-03
SNES Function norm 4.743612598174e-03
3 SNES Function norm 1.595522140204e-06
SNES Function norm 1.595522140204e-06
3 SNES Function norm 1.595522140204e-06
4 SNES Function norm 5.064026281545e-12
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
Number of SNES iterations = 4
4 SNES Function norm 5.064026281545e-12
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
Number of SNES iterations = 4
4 SNES Function norm 5.064026281545e-12
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
Number of SNES iterations = 4
4 SNES Function norm 5.064026281545e-12
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
Number of SNES iterations = 4

```



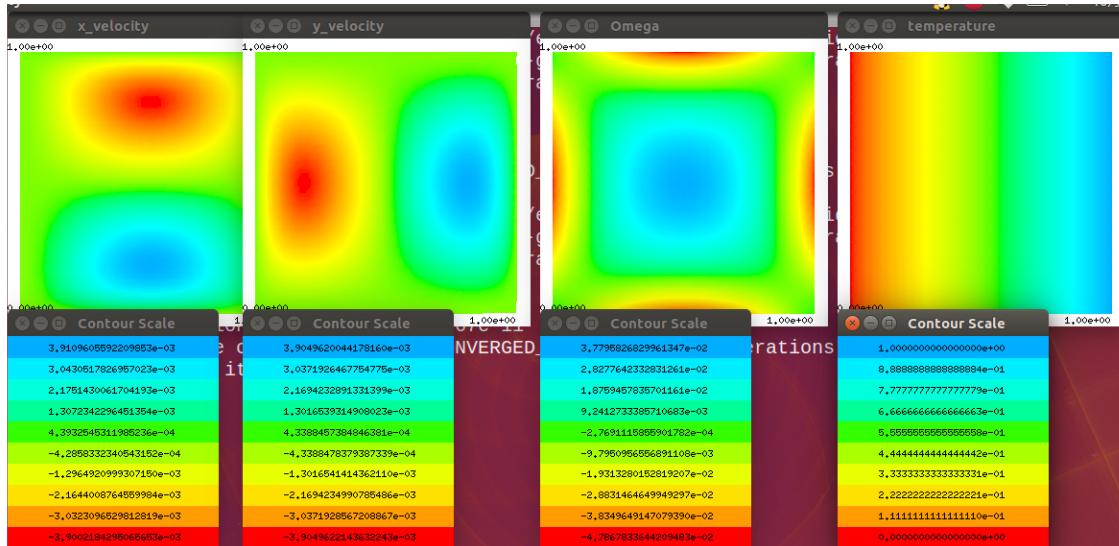
- (3) 基于  $64 \times 64$  的网络，通过 -lidvelocity, -prandtl 和 -grashof 三个选项改变参数的值，研究三个无量纲参数对于计算的影响。建议选择 lid velocity  $V_{lid}=10^{-4}, 0, 0.1, 1, 10$ ;  $Pr=0, 0.1, 1, 10$ ;  $Gr=1, 100, 1000$ ，选定参数后，配合下面的选项运行程序

3.1. lid velocity = 0.0001, prandtl = 0.1, grashof = 1

```
mpirun -np 4 ./ex19 -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason -  
lidvelocity 0.0001 -prandtl 0.1 -grashof 1 -contours 1 -draw_pause -2
```

运行结果及图像如下：

迭代次数为 2 次



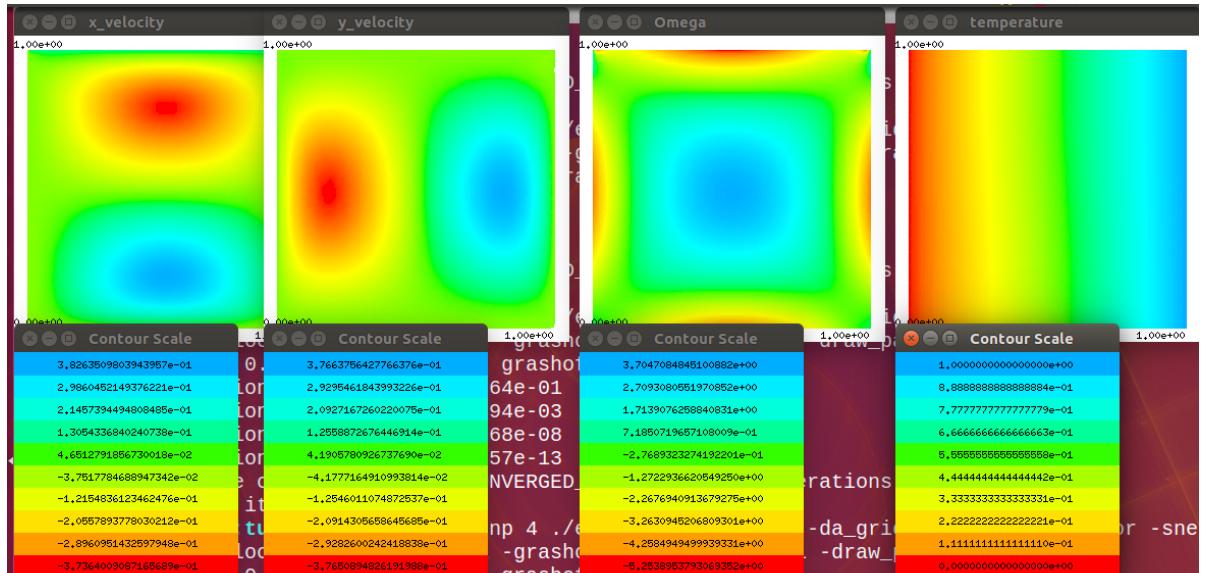
3.2. lid velocity = 0.1, prandtl = 1, grashof = 100

```
mpirun -np 4 ./ex19 -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason -lidvelocity 0.1 -prandtl 1. -grashof 100. -contours 1 -draw_pause -2
```

运行结果及图像如下:

```
su@ssss:/code/petsc/src/snes/examples/tutorials$ mpirun -np 4 ./ex19 -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason -lidvelocity 0.1 -prandtl 1 -grashof 100 -contours 1 -draw_pause -1
lid velocity = 0.1, prandtl # = 1., grashof # = 100.
0 SNES Function norm 1.749335921862e+00
lid velocity = 0.1, prandtl # = 1., grashof # = 100.
0 SNES Function norm 1.749335921862e+00
lid velocity = 0.1, prandtl # = 1., grashof # = 100.
0 SNES Function norm 1.749335921862e+00
lid velocity = 0.1, prandtl # = 1., grashof # = 100.
0 SNES Function norm 1.749335921862e+00
1 SNES Function norm 1.299668799759e-02
2 SNES Function norm 2.88446564615e-07
3 SNES Function norm 2.596772629691e-12
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 3
Number of SNES iterations = 3
3 SNES Function norm 2.596772629691e-12
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 3
Number of SNES iterations = 3
3 SNES Function norm 2.596772629691e-12
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 3
Number of SNES iterations = 3
3 SNES Function norm 2.596772629691e-12
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 3
Number of SNES iterations = 3
```

迭代次数为 3 次



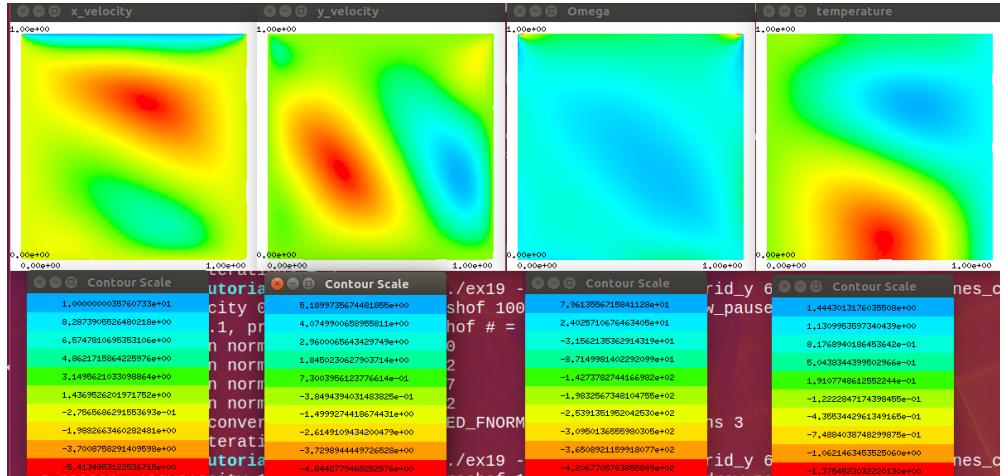
3.3. lid velocity = 10, prandtl = 10, grashof = 1000

```
mpirun -np 4 ./ex19 -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason -lidvelocity 10. -prandtl 10. -grashof 1000. -contours 1 -draw_pause -2
```

运行结果及图像如下:

```
su@ssss:/code/petsc/src/snes/examples/tutorials$ mpirun -np 4 ./ex19 -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason -lidvelocity 10. -prandtl 10. -grashof 1000. -contours 1 -draw_pause
2
lid velocity = 10., prandtl # = 10., grashof # = 1000.
lid velocity = 10., prandtl # = 10., grashof # = 1000.
0 SNES Function norm 8.027463868964e+01
lid velocity = 10., prandtl # = 10., grashof # = 1000.
0 SNES Function norm 8.027463868964e+01
0 SNES Function norm 8.027463868964e+01
0 SNES Function norm 8.027463868964e+01
1 SNES Function norm 1.823282308169e+01
2 SNES Function norm 9.306307526023e-01
3 SNES Function norm 2.481616555556e-01
Nonlinear solve did not converge due to DIVERGED_LINEAR_SOLVE iterations 3
Number of SNES iterations = 3
Nonlinear solve did not converge due to DIVERGED_LINEAR_SOLVE iterations 3
Number of SNES iterations = 3
Nonlinear solve did not converge due to DIVERGED_LINEAR_SOLVE iterations 3
Number of SNES iterations = 3
Nonlinear solve did not converge due to DIVERGED_LINEAR_SOLVE iterations 3
Number of SNES iterations = 3
```

迭代次数为 3 次



(4)

#### 4.1 需要修改的部分:

##### 4.1.1 结构体需要增加 semp、arandtl、brashof，如下图:

```
/*
| User-defined routines and data structures
*/
typedef struct {
    PetscScalar u,v,omega,temp,temp;
} Field;

PetscErrorCode FormFunctionLocal(DMDALocalInfo*,Field**,Field**,void*);

typedef struct {
    PetscReal lidvelocity,prandtl,arandtl,grashof,brashof; /* physical parameters */
    PetscBool draw_contours; /* flag - 1 indicates drawing contours */
} AppCtx;
```

##### 4.1.2 参数 4, 1, 0, 0 改为 5, 1, 0, 0, 给 user.arandtl、user.brashof 赋值

```
/*
| Create distributed array object to manage parallel grid and vectors
| for principal unknowns (x) and governing residuals (f)
*/
ierr = DMDACreate2d(PETSC_COMM_WORLD,
                     DM_BOUNDARY_NONE,
                     DM_BOUNDARY_NONE,
                     DMDA_STENCIL_STAR,4,4,
                     PETSC_DECIDE,PETSC_DECIDE,
                     5,1,0,0,
                     &da);
CHKERRQ(ierr);

/*
| Problem parameters (velocity of lid, prandtl, and grashof numbers)
*/
user.lidvelocity = 1.0/(mx*my);
user.prandtl = 1.0;
user.grashof = 1.0;
user.arandtl = 1.0;
user.brashof = 1.0;

ierr = PetscOptionsGetReal(NULL,NULL,"-lidvelocity",&user.lidvelocity,NULL);CHKERRQ(ierr);
ierr = PetscOptionsGetReal(NULL,NULL,"-prandtl",&user.prandtl,NULL);CHKERRQ(ierr);
ierr = PetscOptionsGetReal(NULL,NULL,"-grashof",&user.grashof,NULL);CHKERRQ(ierr);
ierr = PetscOptionsGetReal(NULL,NULL,"-arandtl",&user.arandtl,NULL);CHKERRQ(ierr);
ierr = PetscOptionsGetReal(NULL,NULL,"-brashof",&user.brashof,NULL);CHKERRQ(ierr);
ierr = PetscOptionsHasName(NULL,NULL,"-contours",&user.draw_contours);CHKERRQ(ierr);

ierr = DMDASetFieldName(da,0,"x_velocity");CHKERRQ(ierr);
ierr = DMDASetFieldName(da,1,"y_velocity");CHKERRQ(ierr);
ierr = DMDASetFieldName(da,2,"Omega");CHKERRQ(ierr);
ierr = DMDASetFieldName(da,3,"temperature");CHKERRQ(ierr);
ierr = DMDASetFieldName(da,4,"semperature");CHKERRQ(ierr);
```

#### 4.1.3 修改边界

```

if (yints == 0) {
    j      = 0;
    yints = yints + 1;
    /* bottom edge */
    for (i=info->xs; i<info->xs+info->xm; i++) {
        f[j][i].u      = x[j][i].u;
        f[j][i].v      = x[j][i].v;
        f[j][i].omega = x[j][i].omega + (x[j+1][i].u - x[j][i].u)*dhy;
        f[j][i].temp   = x[j][i].temp-x[j+1][i].temp;
        f[j][i].semp   = x[j][i].semp;
    }
}

/* Test whether we are on the top edge of the global array */
if (yinte == info->my) {
    j      = info->my - 1;
    yinte = yinte - 1;
    /* top edge */
    for (i=info->xs; i<info->xs+info->xm; i++) {
        f[j][i].u      = x[j][i].u - lid;
        f[j][i].v      = x[j][i].v;
        f[j][i].omega = x[j][i].omega + (x[j][i].u - x[j-1][i].u)*dhy;
        f[j][i].temp   = x[j][i].temp-x[j-1][i].temp;
        f[j][i].semp   = x[j][i].semp + 1;
    }
}

/* Test whether we are on the left edge of the global array */
if (xints == 0) {
    i      = 0;
    xints = xints + 1;
    /* left edge */
    for (j=info->ys; j<info->ys+info->ym; j++) {
        f[j][i].u      = x[j][i].u;
        f[j][i].v      = x[j][i].v;
        f[j][i].omega = x[j][i].omega - (x[j][i+1].v - x[j][i].v)*dhx;
        f[j][i].temp   = x[j][i].temp;
        f[j][i].semp   = x[j][i].semp - x[j][i+1].semp;
    }
}

/* Test whether we are on the right edge of the global array */
if (xinte == info->mx) {
    i      = info->mx - 1;
    xinte = xinte - 1;
    /* right edge */
    for (j=info->ys; j<info->ys+info->ym; j++) {
        f[j][i].u      = x[j][i].u;
        f[j][i].v      = x[j][i].v;
        f[j][i].omega = x[j][i].omega - (x[j][i].v - x[j-1][i].v)*dhx;
        f[j][i].temp   = x[j][i].temp - (PetscReal)(grashof>0);
        f[j][i].semp   = x[j][i].semp - x[j-1][i].semp;
    }
}

```

#### 4.1.4 增加 Semperature

```

/* Omega */
u          = x[j][i].omega;
uxx       = (2.0*u - x[j][i-1].omega - x[j][i+1].omega)*hydhw;
uyy       = (2.0*u - x[j-1][i].omega - x[j+1][i].omega)*hxhy;
f[j][i].omega = uxx + uyy + (vxp*(u - x[j][i-1].omega) + vxm*(x[j][i+1].omega - u))*hy +
                (vyp*(u - x[j-1][i].omega) + vym*(x[j+1][i].omega - u))*hx -
                .5*grashof*(x[j][i+1].temp - x[j][i-1].temp)*hy;

/* Temperature */
u          = x[j][i].temp;
uxx       = (2.0*u - x[j][i-1].temp - x[j][i+1].temp)*hydhw;
uyy       = (2.0*u - x[j-1][i].temp - x[j+1][i].temp)*hxhy;
f[j][i].temp = uxx + uyy + prandtl*((vxp*(u - x[j][i-1].temp) + vxm*(x[j][i+1].temp - u))*hy +
                                         (vyp*(u - x[j-1][i].temp) + vym*(x[j+1][i].temp - u))*hx);

/* Semperature */
u          = x[j][i].semp;
uxx       = (2.0*u - x[j][i-1].semp - x[j][i+1].semp)*hydhw;
uyy       = (2.0*u - x[j-1][i].semp - x[j+1][i].semp)*hxhy;
f[j][i].semp = uxx + uyy + arandtl*((vxp*(u - x[j][i-1].semp) + vxm*(x[j][i+1].semp - u))*hy +
                                         (vyp*(u - x[j-1][i].semp) + vym*(x[j+1][i].semp - u))*hx);

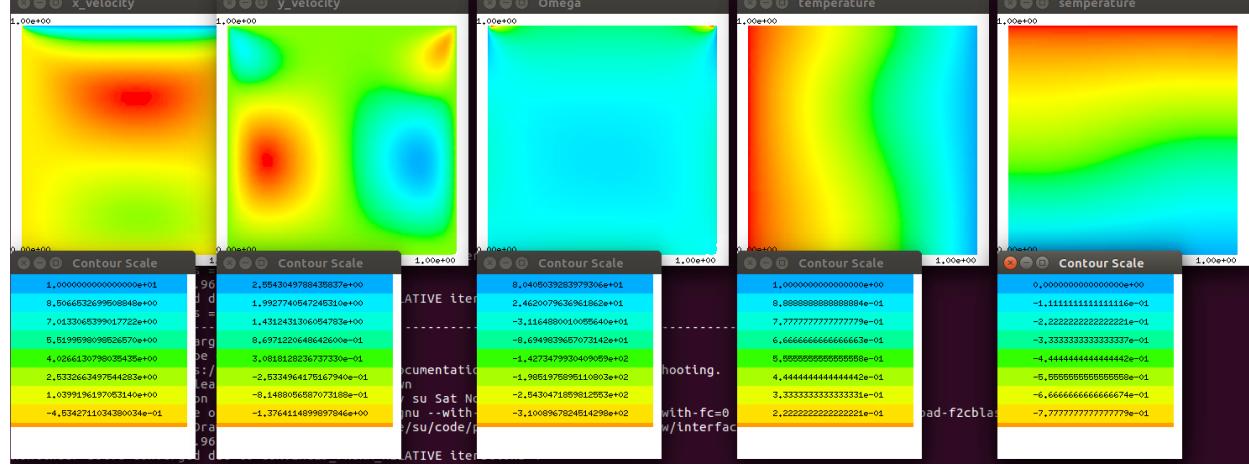
```

## 4.2 比较和结论

4.2.1 A(arandt1)=1 B(brashof)=0

```
mpirun -np 4 ./ex19S -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason  
-lidvelocity 10. -prandtl 1. -arandtl 1. -grashof 1000. -brashof 0. -contours 1 -  
draw_pause -2
```

su@ssss: ~/code/petsc/src/sn...ex



4.2.2 A(arandt1)=10 B(brashof)=0

```
mpirun -np 4 ./ex19S -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason  
-lidvelocity 10. -prandtl 1. -arandtl 10. -grashof 1000. -brashof 0. -contours 1 -  
draw_pause -2
```

The figure shows a terminal window with a blue header containing the command: `mpirun -np 4 ./ex19s -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason -l1velocity 10. -prandtl1 10. -grashof 1000. -brashoff 0`. The window displays numerous PETSc error messages related to configuration errors and convergence issues. Below the terminal, five heatmaps are displayed side-by-side, each with a 'Contour Scale' slider at the bottom. The heatmaps represent different variables: x\_velocity, y\_velocity, Omega, temperature, and temperature. Each heatmap has a color scale from blue to red, with values ranging from 1.00e+00 to 1.00e+00.

#### 4.2.3 A(arandt1)=100 B(brashof)=0

```
mpirun -np 4 ./ex19S -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason  
-lidvelocity 10. -prandtl 1. -arandtl 100. -grashof 1000. -brashof 0. -contours 1 -  
draw_pause -2
```

```
sssss@sssss:~/code/petsc/src/snes/examples/tutorials
```

```
mpirun -np 4 ./ex195 -da_grid_x 64 -da_grid_y 64 -snes_monitor -snes_converged_reason -l1dvelocity 10. -prandtl 1. -arandtl 100. -grashof 1000. -brashof
```

```
0. -contour 1 -draw_paves -2
```

```
l1d velocity = 10., prandtl # = 1., grashof # = 1000.
```

```
l1d velocity = 10., prandtl # = 1., grashof # = 1000.
```

```
0 SNES Function norm 8.06598885249e+01
```

```
1 SNES Function norm 8.06598885249e+01
```

```
2 SNES Function norm 8.06598885249e+01
```

```
3 SNES Function norm 8.06598885249e+01
```

```
4 SNES Function norm 1.79738248451e+01
```

```
5 SNES Function norm 1.79738248451e+01
```

```
6 SNES Function norm 1.79738248451e+01
```

```
7 SNES Function norm 1.79738248451e+01
```

```
8 SNES Function norm 1.22377868199e-01
```

```
9 SNES Function norm 1.22377868199e-01
```

```
2 SNES Function norm 1.22377868199e-01
```

```
3 SNES Function norm 1.22377868199e-01
```

```
4 SNES Function norm 9.39202864606e-05
```

```
5 SNES Function norm 9.39202864606e-05
```

```
3 SNES Function norm 9.39202864606e-05
```

```
4 SNES Function norm 9.39202864606e-05
```

```
5 SNES Function norm 5.07383340171e-16
```

```
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
```

```
Number of SNES iterations = 4
```

```
SNES Function norm 9.39202864606e-05
```

```
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
```

```
Number of SNES iterations = 4
```

```
..... Error Message .....
```

```
[0]PETSC ERROR: Invalid argument
```

```
[0]PETSC ERROR: Wrong type of object: Parameter
```

```
See https://www.mcs.anl.gov/petsc/documentation/faq.html for trouble shooting.
```

```
[0]PETSC ERROR: Petsc Release Version 3.12.1, unknown
```

```
[0]PETSC ERROR: /ex195 on a linux-gpu named ssss by ssu Sat Nov 2 23:02:49 2019
```

```
[0]PETSC ERROR: Configure options PETSc_ARC3=linux-gpu --with-cc=gcc --with-cxx=g++ --with-fc=0 --download=mpich --download=fzcbblaslapack
```

```
[0]PETSC ERROR: #1 PetscDrawPause() line 24 in /home/ssu/code/petsc/src/sys/classes/draw/interface/dpause.c
```

```
4 SNES Function norm 5.07383340171e-16
```

```
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
```

```
Number of SNES iterations = 4
```

```
..... Error Message .....
```

```
[0]PETSC ERROR: Invalid argument
```

```
[0]PETSC ERROR: Wrong type of object: Parameter # 1
```

```
See https://www.mcs.anl.gov/petsc/documentation/faq.html for trouble shooting.
```

```
[0]PETSC ERROR: Petsc Release Version 3.12.1, unknown
```

```
[0]PETSC ERROR: /ex195 on a linux-gpu named ssss by ssu Sat Nov 2 23:02:49 2019
```

```
[0]PETSC ERROR: Configure options PETSc_ARC3=linux-gpu --with-cc=gcc --with-cxx=g++ --with-fc=0 --download=mpich --download=fzcbblaslapack
```

```
[0]PETSC ERROR: #1 PetscDrawPause() line 24 in /home/ssu/code/petsc/src/sys/classes/draw/interface/dpause.c
```

```
5 SNES Function norm 5.07383340171e-16
```

```
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
```

```
Number of SNES iterations = 4
```

```
..... Error Message .....
```

```
[0]PETSC ERROR: Invalid argument
```

```
[0]PETSC ERROR: Wrong type of object: Parameter # 1
```

```
See https://www.mcs.anl.gov/petsc/documentation/faq.html for trouble shooting.
```

```
[0]PETSC ERROR: Petsc Release Version 3.12.1, unknown
```

```
[0]PETSC ERROR: /ex195 on a linux-gpu named ssss by ssu Sat Nov 2 23:02:49 2019
```

```
[0]PETSC ERROR: Configure options PETSc_ARC3=linux-gpu --with-cc=gcc --with-cxx=g++ --with-fc=0 --download=mpich --download=fzcbblaslapack
```

```
[0]PETSC ERROR: #1 PetscDrawPause() line 24 in /home/ssu/code/petsc/src/sys/classes/draw/interface/dpause.c
```

```
6 SNES Function norm 5.07383340171e-16
```

```
Nonlinear solve converged due to CONVERGED_FNORM_RELATIVE iterations 4
```

```
Number of SNES iterations = 4
```

```
..... Error Message .....
```

```
[0]PETSC ERROR: Invalid argument
```

```
[0]PETSC ERROR: Wrong type of object: Parameter # 1
```

```
See https://www.mcs.anl.gov/petsc/documentation/faq.html for trouble shooting.
```

```
[0]PETSC ERROR: Petsc Release Version 3.12.1, unknown
```

```
[0]PETSC ERROR: /ex195 on a linux-gpu named ssss by ssu Sat Nov 2 23:02:49 2019
```

```
[0]PETSC ERROR: Configure options PETSc_ARC3=linux-gpu --with-cc=gcc --with-cxx=g++ --with-fc=0 --download=mpich --download=fzcbblaslapack
```

```
[0]PETSC ERROR: #1 PetscDrawPause() line 24 in /home/ssu/code/petsc/src/sys/classes/draw/interface/dpause.c
```

```
7 SNES Function norm 5.07383340171e-16
```

比较以上  $A=1, 10, 100$  的  $S$  的图像可得,  $S$  图像发生了变化。