# 第 3 次作业

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**摘　要：**本文使用的程序和文档发布于 https://grwei.github.io/SJTU_2021-2022-2-MS8402/.

**关键词：**词 1，词 2

# Homework 3

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**Abstract:** The programs and documents used in this article are published at https://grwei.github.io/SJTU_2021-2022-2-MS8402/.

**Keywords:** keyword 1, keyword 2

# 目 录

# 1 Question 1

Plot the spatial pattern of the stream function for the subtropical-gyre circulation based on the mathematical expression we derived in class (Hint: use the commands “contour” or “contourf” in Matlab or Python to make this plot).

## 1.1 Solution

结果示于图 1.1.

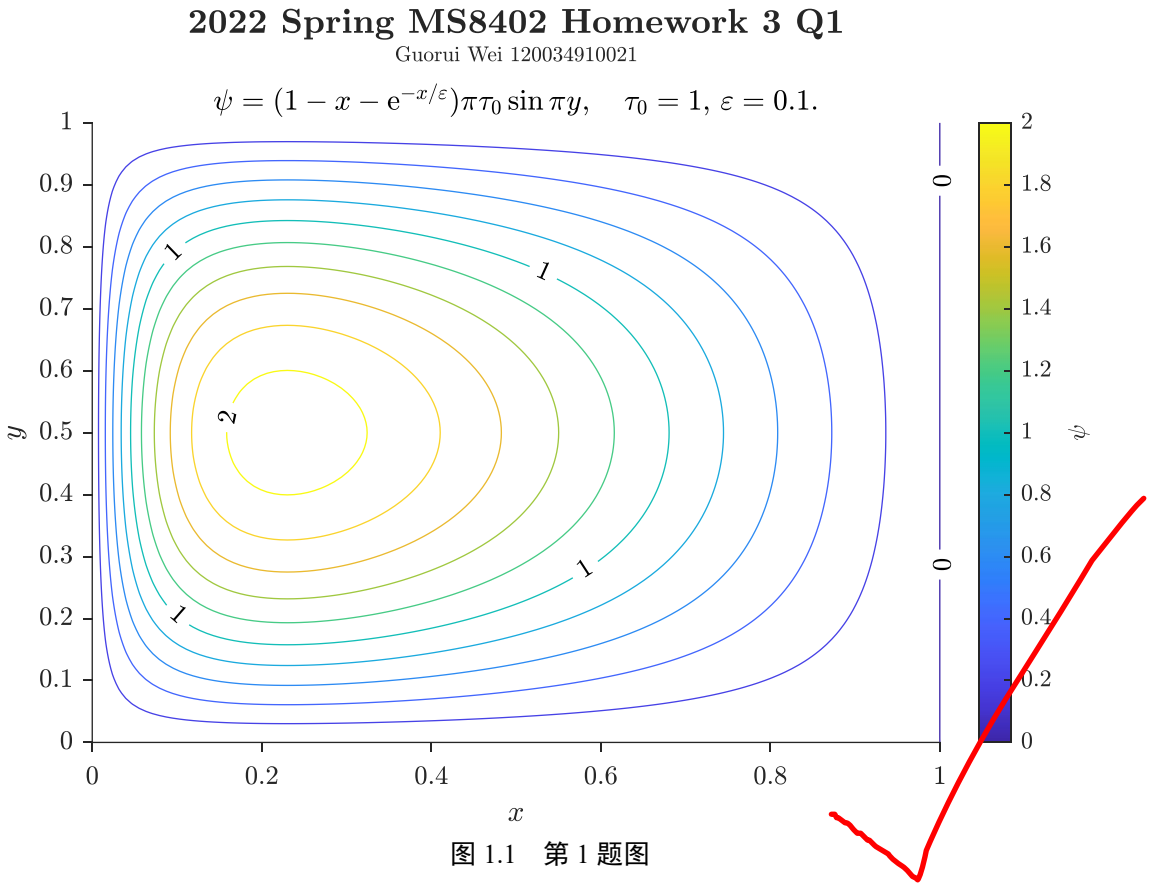


图 1.1 第 1 题图

# 2 Question 2

Download one global ocean reanalysis product during a winter month (Hint: you can find different products produced by different research agencies at https://reanalyses.org/ocean/overview-current-reanalyses, and download the monthly-mean data), and plot the vertical profiles of the stratification frequency $N$ for one location in the tropical ocean, one location in the mid-latitude ocean and one location in the polar ocean (give the longitude and latitude information for these locations). Describe the differences in these profiles and try to give the reasons.

## 2.1 Solution

使用 CMEMS Global Ocean Ensemble Reanalysis product (https://doi.org/10.48670/moi-00024) 的 global-reanalysis-phy-001-031-grepv2-mnstd-daily dataset 中的 2019 年 1 月的全球海水位温和盐度数据（分别对应变量 thetao_mean 和 so_mean）. 在北半球的热带、中纬度和极地地区分别选点（图 2.1），记为 A, B, C. 遵循 TEOS-10 规范 (McDougall et al., 2011)，计算浮力频率$N^2$（图 2.2）. 另外，使用 ORAS5 global ocean reanalysis monthly data (Hao et al., 2018) 的 2022 年 1 月海表温度和盐度数据，绘制纬向平均的海表面温度和盐度分布（图 2.3）.

由图 2.2 可见，位于热带的 A 点（5.75°N, -77.50°E）在 10 米深度附近存在一个浮力频率$N^2$的极大值（~$4\times10^{-3}$ rad$^2$/s$^2$），位于极地的 C 点（81.75°N, 141.25°E）在 33 米深度附近存在一个$N^2$的极大值（~$7\times10^{-4}$ rad$^2$/s$^2$），而位于中纬度的 B 点（45.25°N, -125.75°E）在 83 米深度附近存在一个$N^2$的极大值（~$3\times10^{-4}$ rad$^2$/s$^2$）.

根据图 2.1，对上述结果作如下解释：

（1）在位于热带的 A 地点处，在海表附近有一个薄至数米的高温低盐混合层，这混合层很可能是由 ITCZ 下较高的降水减蒸发量，以及较强的向下净辐射加热作用来维持. 混合层下方存在一个温度、盐度梯度均很大的跃层，跃层内温度梯度向上而盐度梯度向下，温、盐梯度均加强向下的密度梯度，这导致了 A 点处 10 米深度附近较大的浮力频率$N^2$值.

（2）在位于极地的 C 地点处，1 月时正是寒冷的极夜，表层海水因长波辐射降温和对北极极寒大气的强烈散热而形成一个厚约数十米的低温混合层. 同时，这混合层也是低盐的，这可能与极夜海水结冰析盐（难道不是造成海表盐度增加？或者，新生的高盐海水迅速沉底，对流调整的结果是海表低盐度混合层维持？），或海冰融化（在极夜？），或某种洋流有关，需结合海洋学常识和其他资料作进一步分析. 其下，是一个具有较大的向下的盐度梯度，和较小的向下的温度梯度的跃层. 温、盐梯度方向分别利于削弱、加强向下的密度梯度，综合结果是位势密度梯度在混合层内几乎为零甚至略向上，在温（盐）跃层内向下. 上述原因导致了 C 点处海表附近浮力频率$N^2$很小，甚至在某些点处为微弱的负数，负值量级约 $O(10^{-7})$. 83 米深度附近出现浮力频率$N^2$的极值，但不及 A 点的强.

（3）在位于中纬度的 B 地点处，海表附近有一厚约 50 米的高温、低盐混合层，其下是一温、盐梯度不很大的跃层. 故其浮力频率$N^2$的极值比 A, C 两点的小.

（4）当海洋局部发生静力不稳定（$N^2<0$），就容易触发对流调整，这种调整倾向于恢复海水“上轻下重”的静力稳定配置，故$N^2<0$ 的状态通常不易长时间维持，除非有某种持续的外强迫作用（例如，辐射加热/降温等）. 本例采取的数据是按月平均的结果，局地、暂时的静力不稳定信号难以被捕捉，故位势密度梯度基本上是向下的，相应地，而浮力频率$N^2$基本上是正值（图 2.2）.

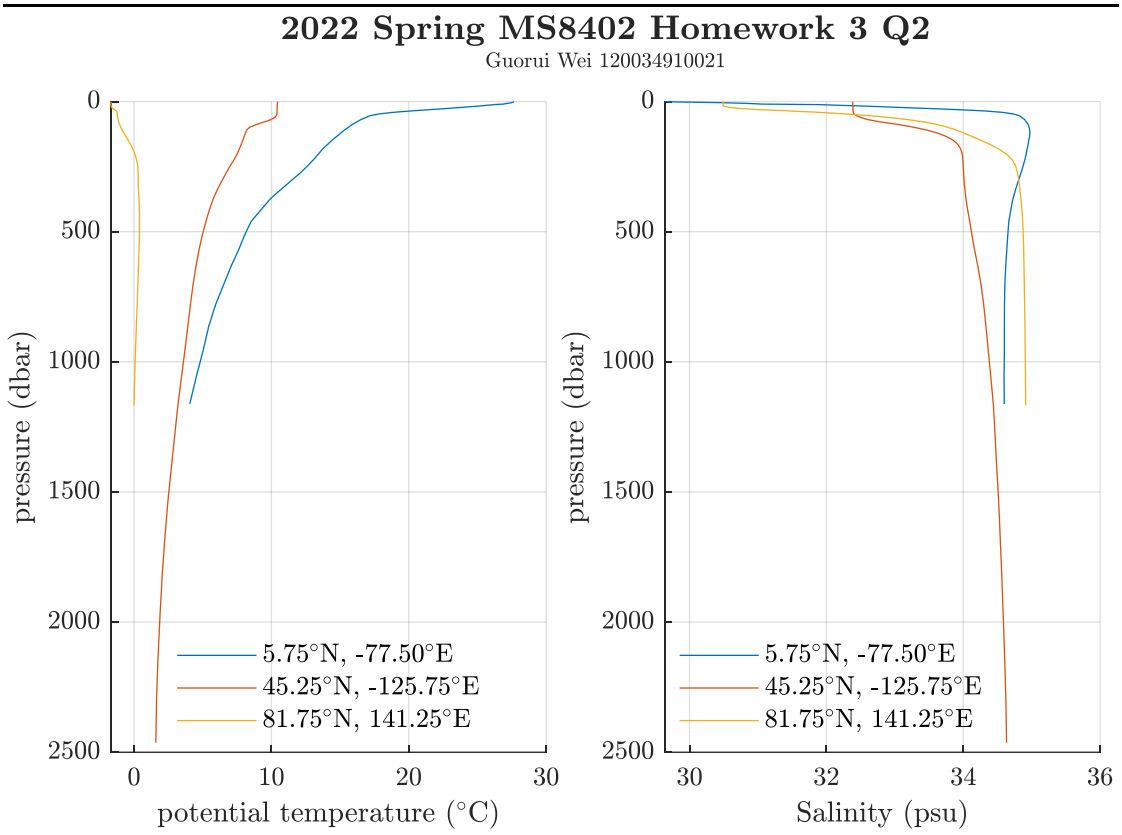


图 2.1　第 2 题图 a

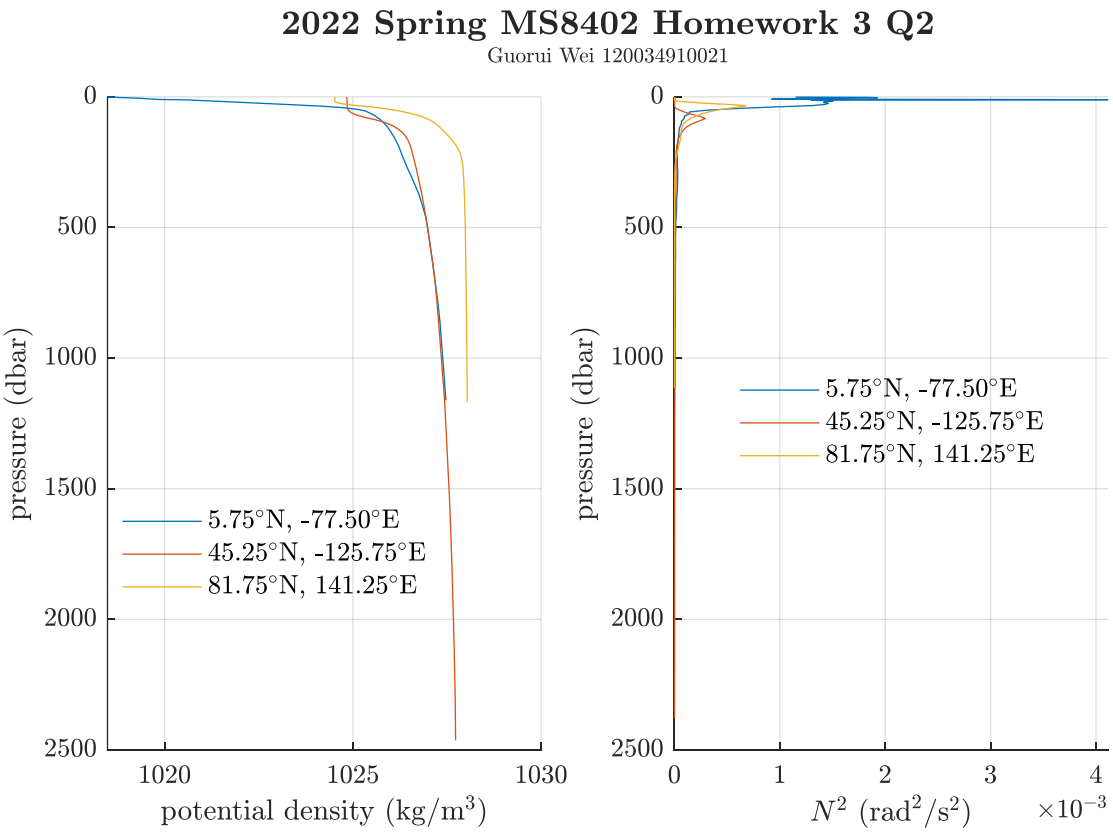


图 2.2　第 2 题图 b

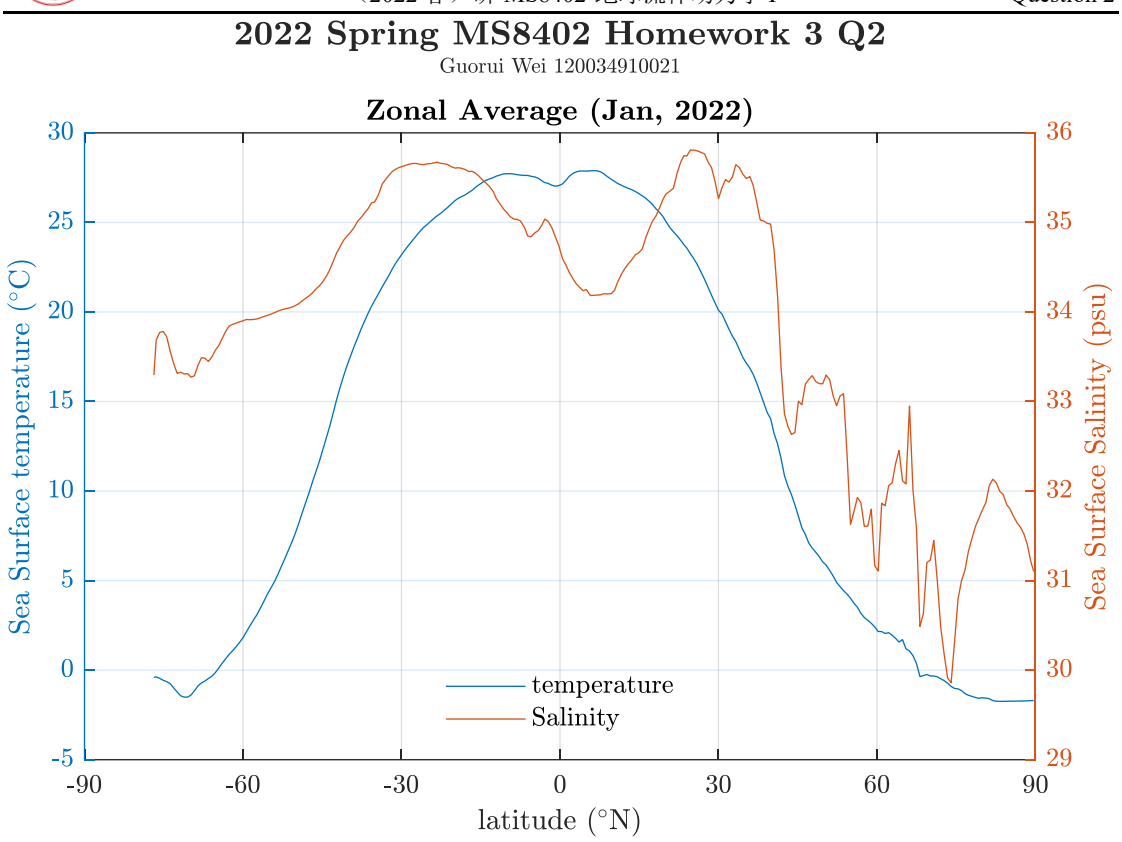


图 2.3　第 2 题图 c. 数据来源：ORAS5 global ocean reanalysis monthly data (Hao et al., 2018).

# References

Hao, Z., Magdalena, A.-B., Mogensen, K., & Steffen, T. (2018). OCEAN5: The ECMWF Ocean Reanalysis System and its Real-Time analysis component. In: ECMWF.

McDougall, Barker, T. J., & M, P. (2011). Getting started with TEOS-10 and the Gibbs Seawater (GSW) oceanographic toolbox. *Scor/Iapso WG*, *127*, 1-28.

# 附录A 本文使用的 MATLAB 程序源代码

本文使用的程序和文档发布于 https://grwei.github.io/SJTU_2021-2022-2-MS8402/.

## A.1 主程序

```
%% hw3.m
% Description: MATLAB code for homework 3 (MS8402, 2022 Spring)
% Author: Guorui Wei (危国锐) (313017602@qq.com; weiguorui@sjtu.edu.cn)
% Student ID: 120034910021
% Created: 2022-04-01
% Last modified: 2022-04-07
% Data: [1] [ORAS5 global ocean reanalysis monthly data from 1958 to present](https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-oras5)
%       [2] [Global Ocean Ensemble Physics Reanalysis GLOBAL_REANALYSIS_PHY_001_031](https://doi.org/10.48670/moi-00024)
% Toolbox: [3] [Gibbs-SeaWater (GSW) Oceanographic Toolbox](http://www.teos-10.org/software.htm)

%% Initialize project

clc; clear; close all
init_env();

%% Question 1

epsilon = .1;
tau_0 = 1;
N = 127;
x = linspace(0,1,N);
y = x;
[X,Y] = meshgrid(x,y);
psi = pi*tau_0*(1-X-exp(-X/epsilon)).*sin(pi*Y);

% fig.
figure("Name","Question 1")
t_TCL_pt_SP = tiledlayout(1,1,"TileSpacing","tight","Padding","tight");
t_Axes = nexttile(t_TCL_pt_SP,1);
[~,c_contour] = contour(t_Axes,X,Y,psi,"Fill","off");
clabel([],c_contour,c_contour.TextList([1,idivide(end+1,uint8(2)),end]),"Interpreter",'latex')
```

```
c = colorbar(t_Axes,"Location","eastoutside","TickLabelInterpreter","latex");
c.Label.String = "\psi";
set(t_Axes,"YDir",'normal',"TickLabelInterpreter",'latex',"FontSize",10,'Box','off',"TickDir","out");
ylabel(t_Axes,"$y$","Interpreter",'latex');
xlabel(t_Axes,"$x$","Interpreter",'latex');
title(t_Axes,sprintf("$\\psi = (1-x-\\mathrm{e}^{-x/\\varepsilon}) \\pi \\tau_0 \\sin{\\pi y},\\quad \\tau_0 = %.3g$, $\\varepsilon = %.3g.$",tau_0,epsilon),"Interpreter",'latex')
[~,t_title_s] = title(t_TCL_pt_SP,"\bf 2022 Spring MS8402 Homework 3 Q1","Guorui Wei 120034910021","Interpreter",'latex');
set(t_title_s,'FontSize',8)
exportgraphics(t_TCL_pt_SP,"..\\doc\\fig\\hw3_Q1.emf",'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace','rgb')
exportgraphics(t_TCL_pt_SP,"..\\doc\\fig\\hw3_Q1.png",'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace','rgb')

%% Question 2: init

% import data
clear; clc; close all;
path_votemper = "global-reanalysis-phy-001-031-grepv2-mnstd-monthly_1649316520167.nc"; % The temperature of a parcel of sea water would have if moved adiabatically to sea level pressure. This variable is a 3D field.
path_vosaline = path_votemper; % The salt content of sea water as measured on the practical salinity units (PSU) scale. This variable is a 3D field.
finfo = ncinfo(path_votemper);
vec_lat = ncread(path_votemper,'latitude');
vec_lon = ncread(path_votemper,'longitude');
[nav_lat,nav_lon] = meshgrid(vec_lat,vec_lon);
depth = ncread(path_votemper,'depth');
votemper = ncread(path_votemper,'thetao_mean',[1,1,1,1],[Inf,Inf,Inf,1]);
vosaline = ncread(path_vosaline,'so_mean',[1,1,1,1],[Inf,Inf,Inf,1]);
%
n_lat_bin = 255;

Q2_zonal_average(n_lat_bin,'on');
%
lat_center = [6,45,74,82];
lat_tol = 0.5;
%
ind_depth_thrs = find(depth > 750,1);
```

```
TF_is_ocean = ~isnan(vosaline(:,:,ind_depth_thrs));
ind_N2_min = nan(size(lat_center));
ind_N2_max = ind_N2_min;
ind_N2_avg_min = ind_N2_min;
ind_N2_avg_max = ind_N2_min;
val_N2_min = ind_N2_min;
val_N2_max = ind_N2_min;
val_N2_avg_min = ind_N2_min;
val_N2_avg_max = ind_N2_min;
for i = 1:length(lat_center)
    [ind_N2_min(i),ind_N2_max(i),ind_N2_avg_min(i),ind_N2_avg_max(i),val_N2_min(i),val_N2_max(i),val_N2_avg_min(i),val_N2_avg_max(i)] = Q2_gsw_N2_min_max(lat_center(i),lat_tol,TF_is_ocean,nav_lon,nav_lat,deptht,votemper,vosaline);
end

%% Question 2

ind_tropi = ind_N2_max(1);
ind_mid = ind_N2_max(2);
ind_polar = ind_N2_max(4);
ind_vec = [ind_tropi,ind_mid,ind_polar];
%
SP = nan(length(deptht),length(ind_vec));
pt = SP;
p = SP;
SA = SP;
CT = SP;
pot_rho = SP;
N2 = nan(length(deptht)-1,length(ind_vec));
p_mid = N2;
for i = 1:length(ind_vec)
    [x,y] = ind2sub(size(nav_lon),ind_vec(i));
    [SP(:,i),pt(:,i),p(:,i),SA(:,i),CT(:,i),N2(:,i),p_mid(:,i),pot_rho(:,i)] = Q2_gsw_N2(x,y,nav_lon,nav_lat,deptht,votemper,vosaline);
end
%
figure("Name","Q2_pt_SP_vertical_profile")
t_TCL_pt_SP = tiledlayout(1,2,"TileSpacing","tight","Padding","tight");
t_Axes_pt = nexttile(t_TCL_pt_SP);
t_Axes_pt = Q2_plot_vertical(t_Axes_pt,pt,p,ind_vec,nav_lat,nav_lon,"potential temperature $(^{\circ}{\rm{C}})$","pressure (dbar)","temperature");
t_Axes_SP = nexttile(t_TCL_pt_SP);
```

```
103 t_Axes_SP =
    Q2_plot_vertical(t_Axes_SP,SP,p,ind_vec,nav_lat,nav_lon,"Salinity
    (psu)","pressure (dbar)","Salinity");
104 %
105 [~,t_title_s] = title(t_TCL_pt_SP,"\bf 2022 Spring MS8402 Homework 3
    Q2","Guorui Wei 120034910021","Interpreter",'latex');
106 set(t_title_s,'FontSize',8)
107 %
108 exportgraphics(t_TCL_pt_SP,"..\\doc\\fig\\hw3_Q2_pt_SP_vertical_profile.emf"
    ,'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace'
    ,'rgb')
109 exportgraphics(t_TCL_pt_SP,"..\\doc\\fig\\hw3_Q2_pt_SP_vertical_profile.png"
    ,'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace'
    ,'rgb')
110 %
111 figure("Name","Q2_rho_N2_vertical_profile")
112 t_TCL_rho_N2 = tiledlayout(1,2,"TileSpacing","tight","Padding","tight");
113 t_Axes_rho = nexttile(t_TCL_rho_N2);
114 t_Axes_rho =
    Q2_plot_vertical(t_Axes_rho,pot_rho,p,ind_vec,nav_lat,nav_lon,"potential
    density $(\rm{kg}/\rm{m}^3)$","pressure (dbar)","density");
115 t_Axes_N2 = nexttile(t_TCL_rho_N2);
116 t_Axes_N2 =
    Q2_plot_vertical(t_Axes_N2,N2,p_mid,ind_vec,nav_lat,nav_lon,"$N^2$ $(\rm{rad
    }^2 / s^2)$","pressure (dbar)","Stratification frequency");
117 %
118 [~,t_title_s] = title(t_TCL_rho_N2,"\bf 2022 Spring MS8402 Homework 3
    Q2","Guorui Wei 120034910021","Interpreter",'latex');
119 set(t_title_s,'FontSize',8)
120 %
121 exportgraphics(t_TCL_rho_N2,"..\\doc\\fig\\hw3_Q2_rho_N2_vertical_profile.em
    f",'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspac
    e','rgb')
122 exportgraphics(t_TCL_rho_N2,"..\\doc\\fig\\hw3_Q2_rho_N2_vertical_profile.pn
    g",'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspac
    e','rgb')
123
124 %% local functions
125
126 %% Initialize environment
127 function [] = init_env()
128 % Initialize environment
129 %
130     % set up project directory
```

```
131     if ~isfolder("../doc/fig/")
132         mkdir ../doc/fig/
133     end
134     % configure searching path
135     mfile_fullpath = mfilename('fullpath'); % the full path and name of the
    file in which the call occurs, not including the filename extension.
136     mfile_fullpath_without_fname = mfile_fullpath(1:end-
    strlength(mfilename));
137     addpath(genpath(mfile_fullpath_without_fname + "../data"), ...
138             genpath(mfile_fullpath_without_fname + "../inc")); % adds the
    specified folders to the top of the search path for the current MATLAB®
    session.
139
140     return;
141 end
142
143 %% surface zonal average
144 function [] = Q2_zonal_average(n_lat_bin,fig_EN)
145 % hw3 Q2
146 %
147     arguments
148         n_lat_bin
149         fig_EN string = 'on'
150     end
151
152     nav_lat =
    ncread("..\data\sosstsst_control_monthly_highres_2D_202201_OPER_v0.1.nc",'na
    v_lat');
153     [lat_bin_num,lat_edges] = discretize(nav_lat,n_lat_bin);
154     sosstsst =
    ncread("..\data\sosstsst_control_monthly_highres_2D_202201_OPER_v0.1.nc",'so
    sstsst'); % [deg C] Water temperature close to the ocean surface. This
    variable is a 2D field.
155     sosaline =
    ncread("..\data\sosaline_control_monthly_highres_2D_202201_OPER_v0.1.nc",'so
    saline'); % [psu] Salt concentration close to the ocean surface. This
    variable is a 2D field.
156     %
157     TF_so_avail = ~isnan(sosstsst);
158     n_lat_bin = length(lat_edges)-1;
159     lat_bin_avg = zeros(n_lat_bin,1);
160     N_pts_bin = lat_bin_avg;
161     sosstsst_zonal_avg = lat_bin_avg;
162     sosaline_zonal_avg = lat_bin_avg;
```

```
    for bin_num = 1:n_lat_bin
        TF_lat_avail = (lat_bin_num == bin_num) & TF_so_avail;
        N_pts_bin(bin_num) = nnz(TF_lat_avail);
        lat_bin_avg(bin_num) = mean(nav_lat(TF_lat_avail));
        sosstsst_zonal_avg(bin_num) = mean(sosstsst(TF_lat_avail));
        sosaline_zonal_avg(bin_num) = mean(sosaline(TF_lat_avail));
    end
    if (strcmpi(fig_EN,"off"))
        return;
    end

    %
    figure("Name","Q2_sst_zonal_avg")
    t_TCL_1 = tiledlayout(1,1,"TileSpacing","tight","Padding","tight");
    t_Axes_1 = nexttile(t_TCL_1,1);
    yyaxis(t_Axes_1,"left")
    t_plot_sst = plot(t_Axes_1,lat_bin_avg,sosstsst_zonal_avg,'-
','DisplayName','temperature');
    set(t_Axes_1,'YColor','#0072BD','XLim',[-90
90],"YDir",'normal','XTick',linspace(-
90,90,7),"TickLabelInterpreter",'latex',"FontSize",10,'Box','off');
    xlabel(t_Axes_1,"latitude $(^{\circ}{\rm{N}})$","Interpreter",'latex');
    ylabel(t_Axes_1,"Sea Surface temperature
$(^{\circ}{\rm{C}})$","Interpreter",'latex');
    yyaxis(t_Axes_1,"right")
    t_plot_sal = plot(t_Axes_1,lat_bin_avg,sosaline_zonal_avg,'-
','DisplayName','Salinity');
    set(t_Axes_1,"YDir",'normal');
    ylabel(t_Axes_1,"Sea Surface Salinity (psu)","Interpreter",'latex');
    title(t_Axes_1,"\bf Zonal Average (Jan, 2022)",'Interpreter','latex')
    grid on
    %
    legend([t_plot_sst,t_plot_sal],"Location",'south','Interpreter','latex',
"Box","off",'FontSize',10);
    [~,t_title_s] = title(t_TCL_1,"\bf 2022 Spring MS8402 Homework 3
Q2","Guorui Wei 120034910021","Interpreter",'latex');
    set(t_title_s,'FontSize',8)
    %
    exportgraphics(t_TCL_1,"..\\doc\\fig\\hw3_Q2_sea_surface_zonal_avg.emf",
'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace',
'rgb')
    exportgraphics(t_TCL_1,"..\\doc\\fig\\hw3_Q2_sea_surface_zonal_avg.png",
'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace',
'rgb')
```

```
196
197     return;
198 end
199
200 %% find nearest data point
201 function [x,y,arclen] = Q2_location_query(lon,lat,nav_lon,nav_lat)
202 % find nearest data point
203 % OUTPUT:
204 % x: lon index
205 % y: lat index
206 % arclen: the lengths, arclen, of the great circle arcs connecting pairs
207 % of points on the surface of a sphere.
208     arguments
209         lon
210         lat
211         nav_lon
212         nav_lat
213     end
214     arclen = nan(size(nav_lon));
215     for j = 1:size(nav_lon,2)
216         arclen(:,j) = distance(lat,lon,nav_lat(:,j),nav_lon(:,j));
217     end
218     [arclen,I] = min(arclen,[],"all","omitnan","linear");
219     [x,y] = ind2sub(size(nav_lon),I);
220
221     return;
222 end
223
224 %%
225 function [SP,pt,p,SA,CT,N2,p_mid,pot_rho] =
    Q2_gsw_N2(x,y,nav_lon,nav_lat,deptht,votemper,vosaline,p_ref,mem_EN,path_vot
    emper,path_vosaline)
226 % Q2
227 %
228     arguments
229         x
230         y
231         nav_lon
232         nav_lat
233         deptht
234         votemper
235         vosaline
236         p_ref = 0; % reference pressure of potential density
237         mem_EN string = 'on' % accelerate by storing large data in memory
```

```
238         path_votemper =
    "..\data\votemper_control_monthly_highres_3D_202201_OPER_v0.1.nc";
239         path_vosaline =
    "..\data\vosaline_control_monthly_highres_3D_202201_OPER_v0.1.nc";
240     end
241
242     if (strcmpi(mem_EN,"on"))
243         SP = squeeze(vosaline(x,y,:));
244         pt = squeeze(votemper(x,y,:));
245     else
246         SP =
    squeeze(ncread(path_vosaline,'vosaline',[x,y,1,1],[1,1,Inf,1]));
247         pt =
    squeeze(ncread(path_votemper,'votemper',[x,y,1,1],[1,1,Inf,1]));
248     end
249     if (nargout < 3)
250         p = uint8(0); SA = p; CT = p; N2 = p; p_mid = p;
251         return;
252     end
253
254     z = -depth; % [m] Height (z) is NEGATIVE in the ocean.
255     lat = nav_lat(x,y); % [deg N]
256     p = gsw_p_from_z(z,lat);
257     if (nargout < 4)
258         SA = uint8(0); CT = SA; N2 = SA; p_mid = SA;
259         return;
260     end
261
262     if (min(isnan(SP),[],"all"))
263         SA = uint8(0); CT = SA; N2 = SA; p_mid = SA;
264         warning("warning: no data! (x,y) = (%i,%i)\n",x,y);
265         return;
266     end
267     lon = nav_lon(x,y); % [deg E]
268     [SA,in_ocean] = gsw_SA_from_SP(SP,p,lon,lat);
269     CT = gsw_CT_from_pt(SA,pt);
270 %     if(~min(gsw_infunnel(SA,CT,p)))
271 %         warning("warning: not in funnel! (x,y) = (%i,%i)\n",x,y);
272 %     end
273     if (nargout < 6)
274         N2 = uint8(0); p_mid = N2;
275         return;
276     end
277
```

```
278     [N2,p_mid] = gsw_Nsquared(SA,CT,p,lat);
279     if (nargout < 8)
280         return;
281     end
282 
283     pot_rho = gsw_rho(SA,CT,p_ref);
284 
285     return;
286 end
287 
288 %%
289 function
    [ind_N2_min,ind_N2_max,ind_N2_avg_min,ind_N2_avg_max,val_N2_min,val_N2_max,v
    al_N2_avg_min,val_N2_avg_max] =
    Q2_gsw_N2_min_max(lat_center,lat_tol,TF_is_ocean,nav_lon,nav_lat,deptht,vote
    mper,vosaline,p_ref,mem_EN,path_votemper,path_vosaline)
290 % Q2
291 %
292     arguments
293         lat_center
294         lat_tol
295         TF_is_ocean
296         nav_lon
297         nav_lat
298         deptht
299         votemper
300         vosaline
301         p_ref = 0; % reference pressure of potential density
302         mem_EN string = 'on' % accelerate by storing large data in memory
303         path_votemper =
    "..\data\votemper_control_monthly_highres_3D_202201_OPER_v0.1.nc";
304         path_vosaline =
    "..\data\vosaline_control_monthly_highres_3D_202201_OPER_v0.1.nc";
305     end
306 
307     % params
308     depth_max = 750;
309     %
310     tStart = tic;
311     loc_ind_linear = find(abs(nav_lat-lat_center) < lat_tol & TF_is_ocean);
312     N2_min = nan(size(loc_ind_linear));
313     N2_max = N2_min;
314     N2_avg = N2_min;
315     for i = 1:length(loc_ind_linear)
```

```
316         [x,y] = ind2sub(size(nav_lon),loc_ind_linear(i));
317         [~,~,~,~,~,N2,~,~] =
    Q2_gsw_N2(x,y,nav_lon,nav_lat,deptht,votemper,vosaline,p_ref,mem_EN,path_vot
    emper,path_vosaline);
318         N2_min(i) = min(N2(deptht<depth_max),[],"omitnan");
319         N2_max(i) = max(N2(deptht<depth_max),[],"omitnan");
320         N2_avg(i) = mean(N2(deptht<depth_max),"omitnan");
321 %         fprintf("\rDone: %i/%i, (%.2f N, %.2f E), N2_min = %.2g, N2_max
    = %.2g.", ...
322 %             i,length(loc_ind_linear),nav_lat(loc_ind_linear(i)),nav_lon(loc
    _ind_linear(i)),N2_min(i),N2_max(i));
323     end
324     [val_N2_min,ind_min] = min(N2_min,[],"omitnan",'linear');
325     [val_N2_max,ind_max] = max(N2_max,[],"omitnan",'linear');
326     [val_N2_avg_min,ind_avg_min] = min(N2_avg,[],"omitnan",'linear');
327     [val_N2_avg_max,ind_avg_max] = max(N2_avg,[],"omitnan",'linear');
328     ind_N2_min = loc_ind_linear(ind_min);
329     ind_N2_max = loc_ind_linear(ind_max);
330     ind_N2_avg_min = loc_ind_linear(ind_avg_min);
331     ind_N2_avg_max = loc_ind_linear(ind_avg_max);
332     fprintf("\nSummary: %.1f secs used, %i points processed.\n" + ...
333         "lat = %.2f N, lat_tol = %.2f deg, depth_max = %.2f m.\n" + ...
334         "N2_min = %.2e (%.2f N, %.2f E),\n" + ...
335         "N2_max = %.2e (%.2f N, %.2f E),\n" + ...
336         "N2_avg_min = %.2e (%.2f N, %.2f E),\n" + ...
337         "N2_avg_max = %.2e (%.2f N, %.2f E).\n", ...
338         toc(tStart),length(loc_ind_linear), ...
339         lat_center,lat_tol,depth_max, ...
340         val_N2_min,nav_lat(ind_N2_min),nav_lon(ind_N2_min), ...
341         val_N2_max,nav_lat(ind_N2_max),nav_lon(ind_N2_max), ...
342         val_N2_avg_min,nav_lat(ind_N2_avg_min),nav_lon(ind_N2_avg_min), ...
343         val_N2_avg_max,nav_lat(ind_N2_avg_max),nav_lon(ind_N2_avg_max));
344
345     return;
346 end
347
348 %%
349 function [t_Axes] =
    Q2_plot_vertical(t_Axes,x_data,y_data,ind_vec,nav_lat,nav_lon,xlabel_str,yla
    bel_str,axes_title_str)
350 % Q2
351 %
352     arguments
353         t_Axes
```

```
354         x_data
355         y_data
356         ind_vec
357         nav_lat
358         nav_lon
359         xlabel_str
360         ylabel_str
361         axes_title_str
362     end
363 
364     hold on
365     for i = 1:length(ind_vec)
366         t_plot_pt = plot(t_Axes,x_data(:,i),y_data(:,i),'-
    ',"DisplayName",sprintf("%.2f$^{\\circ}{\\rm{N}}$, %.2f$^{\\circ}{\\rm{E}}$"
    ,nav_lat(ind_vec(i)),nav_lon(ind_vec(i))));
367     end
368     hold off
369     grid on
370     set(t_Axes,"YDir",'reverse',"TickLabelInterpreter",'latex',"FontSize",10
    ,'Box','off');
371     xlabel(t_Axes,xlabel_str,"Interpreter",'latex');
372     ylabel(t_Axes,ylabel_str,"Interpreter",'latex');
373     legend(t_Axes,"Location",'best','Interpreter','latex',"Box","off",'FontS
    ize',10);
374 %     title(t_Axes,axes_title_str,"Interpreter",'latex')
375 
376     return;
377 end
378 
```

## A.2 子程序

本文使用的程序和文档发布于 https://grwei.github.io/SJTU_2021-2022-2-MS8402/.

本文使用的 *Gibbs-SeaWater (GSW) Oceanographic Toolbox* 可从 http://www.teos-10.org/software.htm 获取.