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

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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.

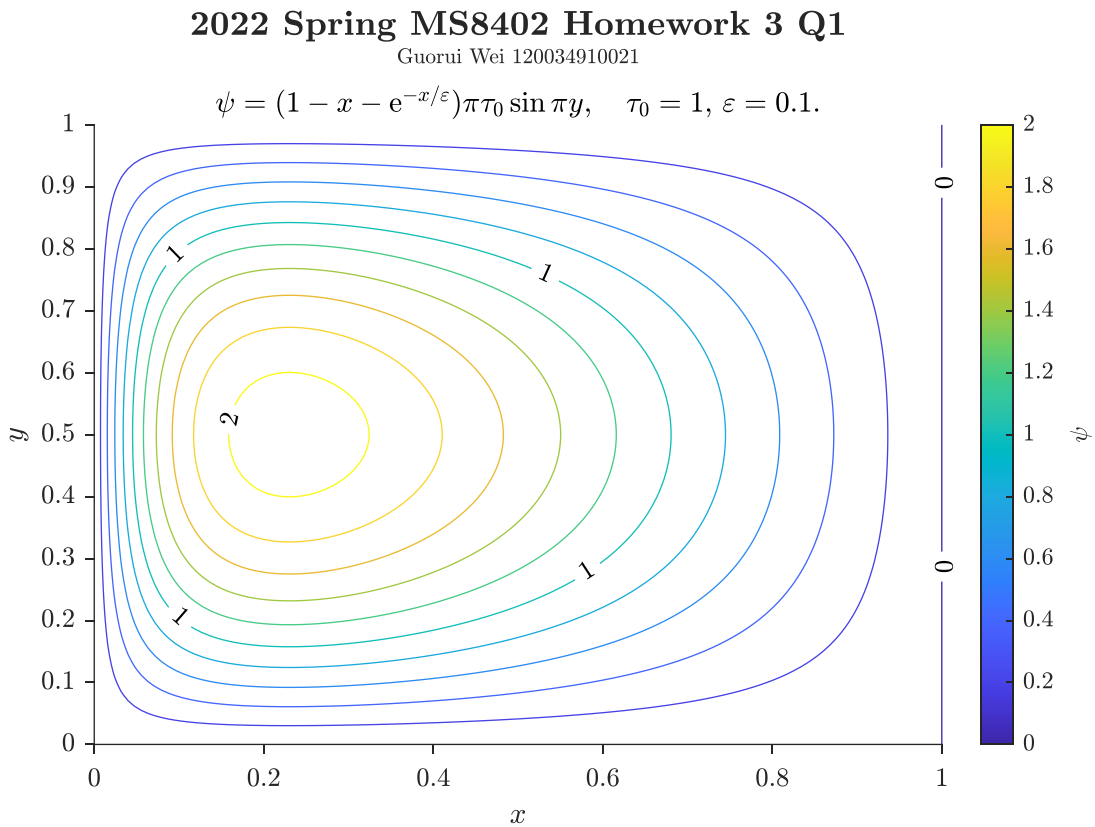

图 1.1 第 1 题图

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（~4×10^{-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（~7×10^{-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（~3×10^{-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 $\mathrm{O}(10^{-7})$. 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）.

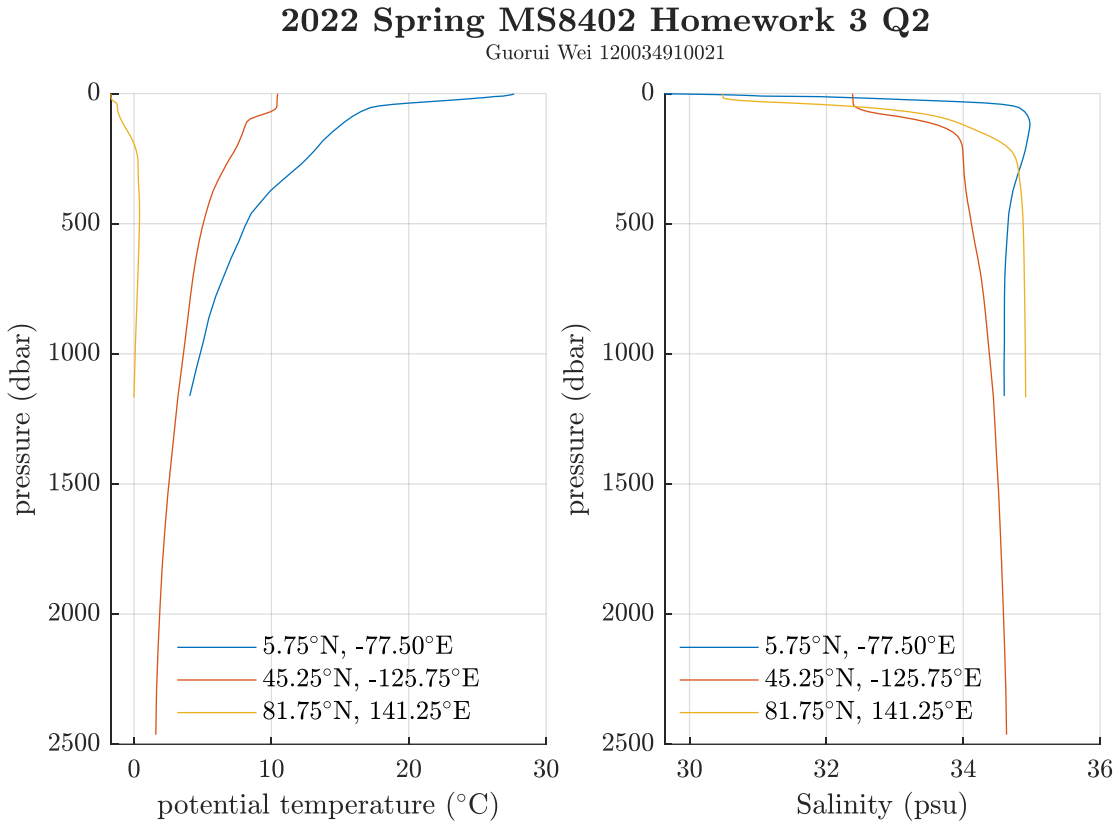

图 2.1　第 2 题图 a

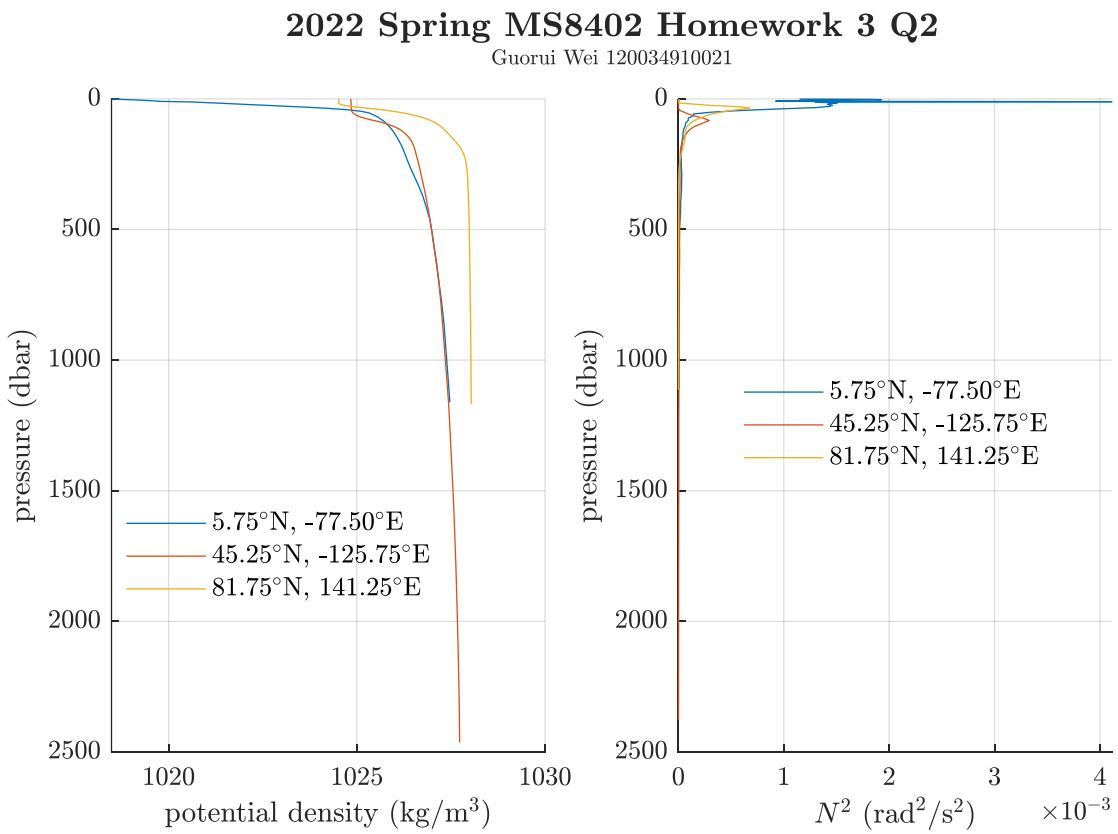

图 2.2　第 2 题图 b

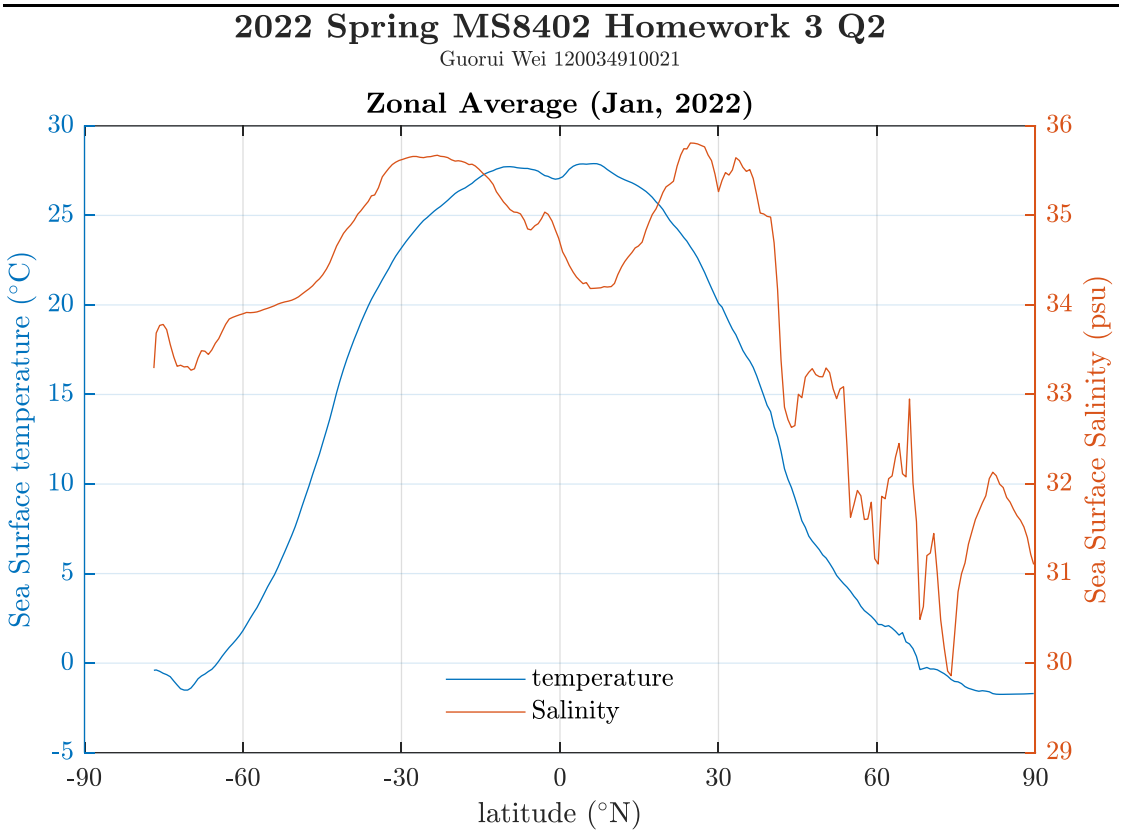

图 2.3　第 2 题图 c. 数据来源：ORAS5 global ocean reanalysis monthly data (Hao et al., 2018).

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);
```

```
t_Axes_SP = Q2_plot_vertical(t_Axes_SP,SP,p,ind_vec,nav_lat,nav_lon,"Salinity (psu)","pressure (dbar)","Salinity");
%
[~,t_title_s] = title(t_TCL_pt_SP,"\bf 2022 Spring MS8402 Homework 3 Q2","Guorui Wei 120034910021","Interpreter",'latex');
set(t_title_s,'FontSize',8)
%
exportgraphics(t_TCL_pt_SP,"..\\doc\\fig\\hw3_Q2_pt_SP_vertical_profile.emf",'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace','rgb')
exportgraphics(t_TCL_pt_SP,"..\\doc\\fig\\hw3_Q2_pt_SP_vertical_profile.png",'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace','rgb')
%
figure("Name","Q2_rho_N2_vertical_profile")
t_TCL_rho_N2 = tiledlayout(1,2,"TileSpacing","tight","Padding","tight");
t_Axes_rho = nexttile(t_TCL_rho_N2);
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");
t_Axes_N2 = nexttile(t_TCL_rho_N2);
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");
%
[~,t_title_s] = title(t_TCL_rho_N2,"\bf 2022 Spring MS8402 Homework 3 Q2","Guorui Wei 120034910021","Interpreter",'latex');
set(t_title_s,'FontSize',8)
%
exportgraphics(t_TCL_rho_N2,"..\\doc\\fig\\hw3_Q2_rho_N2_vertical_profile.emf",'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace','rgb')
exportgraphics(t_TCL_rho_N2,"..\\doc\\fig\\hw3_Q2_rho_N2_vertical_profile.png",'Resolution',600,'ContentType','auto','BackgroundColor','none','Colorspace','rgb')

%% local functions

%% Initialize environment
function [] = init_env()
% Initialize environment
%
    % set up project directory
```

```
    if ~isfolder("../doc/fig/")
        mkdir ../doc/fig/
    end
    % configure searching path
    mfile_fullpath = mfilename('fullpath'); % the full path and name of the file in which the call occurs, not including the filename extension.
    mfile_fullpath_without_fname = mfile_fullpath(1:end-strlength(mfilename));
    addpath(genpath(mfile_fullpath_without_fname + "../data"), ...
            genpath(mfile_fullpath_without_fname + "../inc")); % adds the specified folders to the top of the search path for the current MATLAB® session.

    return;
end

%% surface zonal average
function [] = Q2_zonal_average(n_lat_bin,fig_EN)
% hw3 Q2
%
    arguments
        n_lat_bin
        fig_EN string = 'on'
    end

    nav_lat = ncread("..\data\sosstsst_control_monthly_highres_2D_202201_OPER_v0.1.nc",'nav_lat');
    [lat_bin_num,lat_edges] = discretize(nav_lat,n_lat_bin);
    sosstsst = ncread("..\data\sosstsst_control_monthly_highres_2D_202201_OPER_v0.1.nc",'sosstsst'); % [deg C] Water temperature close to the ocean surface. This variable is a 2D field.
    sosaline = ncread("..\data\sosaline_control_monthly_highres_2D_202201_OPER_v0.1.nc",'sosaline'); % [psu] Salt concentration close to the ocean surface. This variable is a 2D field.
    %
    TF_so_avail = ~isnan(sosstsst);
    n_lat_bin = length(lat_edges)-1;
    lat_bin_avg = zeros(n_lat_bin,1);
    N_pts_bin = lat_bin_avg;
    sosstsst_zonal_avg = lat_bin_avg;
    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')
```

```
    return;
end

%% find nearest data point
function [x,y,arclen] = Q2_location_query(lon,lat,nav_lon,nav_lat)
% find nearest data point
% OUTPUT:
% x: lon index
% y: lat index
% arclen: the lengths, arclen, of the great circle arcs connecting pairs
% of points on the surface of a sphere.
    arguments
        lon
        lat
        nav_lon
        nav_lat
    end
    arclen = nan(size(nav_lon));
    for j = 1:size(nav_lon,2)
        arclen(:,j) = distance(lat,lon,nav_lat(:,j),nav_lon(:,j));
    end
    [arclen,I] = min(arclen,[],"all","omitnan","linear");
    [x,y] = ind2sub(size(nav_lon),I);

    return;
end

%%
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)
% Q2
%
    arguments
        x
        y
        nav_lon
        nav_lat
        deptht
        votemper
        vosaline
        p_ref = 0; % reference pressure of potential density
        mem_EN string = 'on' % accelerate by storing large data in memory
```

```
        path_votemper = "..\data\votemper_control_monthly_highres_3D_202201_OPER_v0.1.nc";
        path_vosaline = "..\data\vosaline_control_monthly_highres_3D_202201_OPER_v0.1.nc";
    end

    if (strcmpi(mem_EN,"on"))
        SP = squeeze(vosaline(x,y,:));
        pt = squeeze(votemper(x,y,:));
    else
        SP = squeeze(ncread(path_vosaline,'vosaline',[x,y,1,1],[1,1,Inf,1]));
        pt = squeeze(ncread(path_votemper,'votemper',[x,y,1,1],[1,1,Inf,1]));
    end
    if (nargout < 3)
        p = uint8(0); SA = p; CT = p; N2 = p; p_mid = p;
        return;
    end

    z = -depth; % [m] Height (z) is NEGATIVE in the ocean.
    lat = nav_lat(x,y); % [deg N]
    p = gsw_p_from_z(z,lat);
    if (nargout < 4)
        SA = uint8(0); CT = SA; N2 = SA; p_mid = SA;
        return;
    end

    if (min(isnan(SP),[],"all"))
        SA = uint8(0); CT = SA; N2 = SA; p_mid = SA;
        warning("warning: no data! (x,y) = (%i,%i)\n",x,y);
        return;
    end
    lon = nav_lon(x,y); % [deg E]
    [SA,in_ocean] = gsw_SA_from_SP(SP,p,lon,lat);
    CT = gsw_CT_from_pt(SA,pt);
%     if(~min(gsw_infunnel(SA,CT,p)))
%         warning("warning: not in funnel! (x,y) = (%i,%i)\n",x,y);
%     end
    if (nargout < 6)
        N2 = uint8(0); p_mid = N2;
        return;
    end

```

```
    [N2,p_mid] = gsw_Nsquared(SA,CT,p,lat);
    if (nargout < 8)
        return;
    end

    pot_rho = gsw_rho(SA,CT,p_ref);

    return;
end

%%
function [ind_N2_min,ind_N2_max,ind_N2_avg_min,ind_N2_avg_max,val_N2_min,val_N2_max,val_N2_avg_min,val_N2_avg_max] = Q2_gsw_N2_min_max(lat_center,lat_tol,TF_is_ocean,nav_lon,nav_lat,depth,votemper,vosaline,p_ref,mem_EN,path_votemper,path_vosaline)
% Q2
%
    arguments
        lat_center
        lat_tol
        TF_is_ocean
        nav_lon
        nav_lat
        depth
        votemper
        vosaline
        p_ref = 0; % reference pressure of potential density
        mem_EN string = 'on' % accelerate by storing large data in memory
        path_votemper = "..\data\votemper_control_monthly_highres_3D_202201_OPER_v0.1.nc";
        path_vosaline = "..\data\vosaline_control_monthly_highres_3D_202201_OPER_v0.1.nc";
    end

    % params
    depth_max = 750;
    %
    tStart = tic;
    loc_ind_linear = find(abs(nav_lat-lat_center) < lat_tol & TF_is_ocean);
    N2_min = nan(size(loc_ind_linear));
    N2_max = N2_min;
    N2_avg = N2_min;
    for i = 1:length(loc_ind_linear)
```

```
        [x,y] = ind2sub(size(nav_lon),loc_ind_linear(i));
        [~,~,~,~,~,N2,~,~] = Q2_gsw_N2(x,y,nav_lon,nav_lat,depth,votemper,vosaline,p_ref,mem_EN,path_votemper,path_vosaline);
        N2_min(i) = min(N2(depth<depth_max),[],"omitnan");
        N2_max(i) = max(N2(depth<depth_max),[],"omitnan");
        N2_avg(i) = mean(N2(depth<depth_max),"omitnan");
%         fprintf("\rDone: %i/%i, (%.2f N, %.2f E), N2_min = %.2g, N2_max = %.2g.", ...
%             i,length(loc_ind_linear),nav_lat(loc_ind_linear(i)),nav_lon(loc_ind_linear(i)),N2_min(i),N2_max(i));
    end
    [val_N2_min,ind_min] = min(N2_min,[],"omitnan",'linear');
    [val_N2_max,ind_max] = max(N2_max,[],"omitnan",'linear');
    [val_N2_avg_min,ind_avg_min] = min(N2_avg,[],"omitnan",'linear');
    [val_N2_avg_max,ind_avg_max] = max(N2_avg,[],"omitnan",'linear');
    ind_N2_min = loc_ind_linear(ind_min);
    ind_N2_max = loc_ind_linear(ind_max);
    ind_N2_avg_min = loc_ind_linear(ind_avg_min);
    ind_N2_avg_max = loc_ind_linear(ind_avg_max);
    fprintf("\nSummary: %.1f secs used, %i points processed.\n" + ...
        "lat = %.2f N, lat_tol = %.2f deg, depth_max = %.2f m.\n" + ...
        "N2_min = %.2e (%.2f N, %.2f E),\n" + ...
        "N2_max = %.2e (%.2f N, %.2f E),\n" + ...
        "N2_avg_min = %.2e (%.2f N, %.2f E),\n" + ...
        "N2_avg_max = %.2e (%.2f N, %.2f E).\n", ...
        toc(tStart),length(loc_ind_linear), ...
        lat_center,lat_tol,depth_max, ...
        val_N2_min,nav_lat(ind_N2_min),nav_lon(ind_N2_min), ...
        val_N2_max,nav_lat(ind_N2_max),nav_lon(ind_N2_max), ...
        val_N2_avg_min,nav_lat(ind_N2_avg_min),nav_lon(ind_N2_avg_min), ...
        val_N2_avg_max,nav_lat(ind_N2_avg_max),nav_lon(ind_N2_avg_max));

    return;
end

%%
function [t_Axes] = Q2_plot_vertical(t_Axes,x_data,y_data,ind_vec,nav_lat,nav_lon,xlabel_str,ylabel_str,axes_title_str)
% Q2
%
    arguments
        t_Axes
```

```
        x_data
        y_data
        ind_vec
        nav_lat
        nav_lon
        xlabel_str
        ylabel_str
        axes_title_str
    end

    hold on
    for i = 1:length(ind_vec)
        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))));
    end
    hold off
    grid on
    set(t_Axes,"YDir",'reverse',"TickLabelInterpreter",'latex',"FontSize",10,'Box','off');
    xlabel(t_Axes,xlabel_str,"Interpreter",'latex');
    ylabel(t_Axes,ylabel_str,"Interpreter",'latex');
    legend(t_Axes,"Location",'best','Interpreter','latex',"Box","off",'FontSize',10);
%     title(t_Axes,axes_title_str,"Interpreter",'latex')

    return;
end

```

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.