第 2 次作业

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摘　要：EOF 分析的结果高度依赖于区域选取. 全球 EOF 的结果不是各区域分别 EOF 的结果的简单叠加. 在全球 EOF 中，局部重要的气候模态可能被“淹没”在众多模态中，而不能被 EOF 很好地分辨出. 本文使用的程序和文档发布于 https://grwei.github.io/SJTU_2021-2022-2_MS8401/.

关键词：词 1，词 2

Homework 2

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Abstract: The programs and documents used in this article are published at https://grwei.github.io/SJTU_2021-2022-2_MS8401/.

Keywords: keyword 1, keyword 2

目 录

1 Introduction

Empirical orthogonal function (EOF)[1][2]
El Niño Southern Oscillation (ENSO)[3]
The Pacific Decadal Oscillation (PDO)[4]
The Atlantic Multi-decadal Oscillation (AMO)[5]
The North Atlantic Oscillation (NAO)[6]

2 Data and Methods

使用 NOAA Extended Reconstructed Sea Surface Temperature (SST) V5 的 *Monthly Mean* 数据[7]，选择时间范围 Jan 1900 至 Dec 2020.

对原始 SST 数据，依次作以下处理：

1. 规定数据点是等时间间隔的；
2. 逐空间点，去除该点处的 SST 时间序列的线性趋势，通过调用 Climate Data Tools for Matlab (CDT) [1] 的 detrend3 函数[8]；
3. 逐空间点，去除该点处的 SST 时间序列的 seasonal (aka. annual) cycle，通过调用 CDT 的 deseason 函数[9].

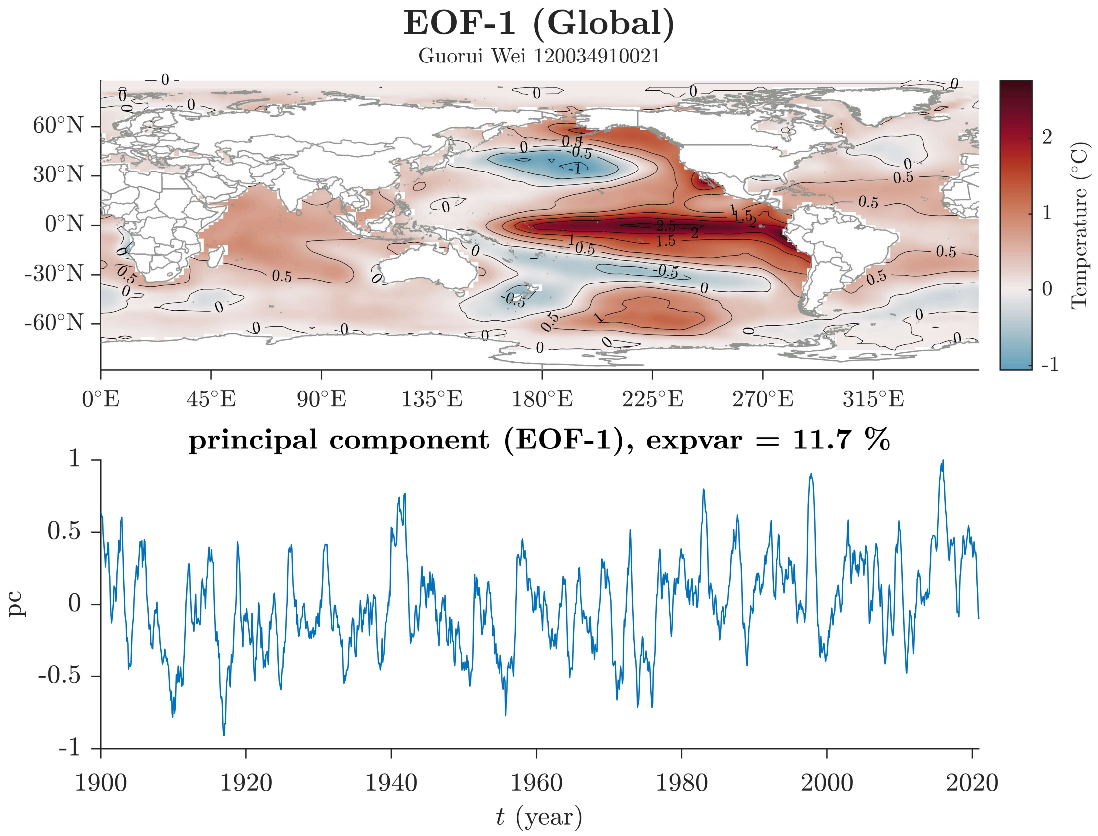
然后，分别在 5 个区域作 EOF 分析，通过调用 CDT 的 eof 函数[10]：（1）全球；（2）太平洋，范围~；（3）北太平洋，范围~；（4）大西洋，范围~；（5）北大西洋，范围~.

[1] https://doi.org/10.1007/978-90-481-3702-2
[2] https://doi.org/10.1016/B978-0-12-387782-6.00004-1
[3] https://psl.noaa.gov/enso/
[4] https://climatedataguide.ucar.edu/climate-data/pacific-decadal-oscillation-pdo-definition-and-indices
[5] https://climatedataguide.ucar.edu/climate-data/atlantic-multi-decadal-oscillation-amo
[6] https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-pc-based
[7] https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html
[8] https://www.chadagreene.com/CDT/detrend3_documentation.html
[9] https://www.chadagreene.com/CDT/deseason_documentation.html
[10] https://www.chadagreene.com/CDT/eof_documentation.html

3 Results

3.1 Global

全球范围 EOF. 第一模式，体现 ENSO，年际的，解释方差>11%. 第二模式，体现 PDO？~期的？第三模式，体现 AMO？



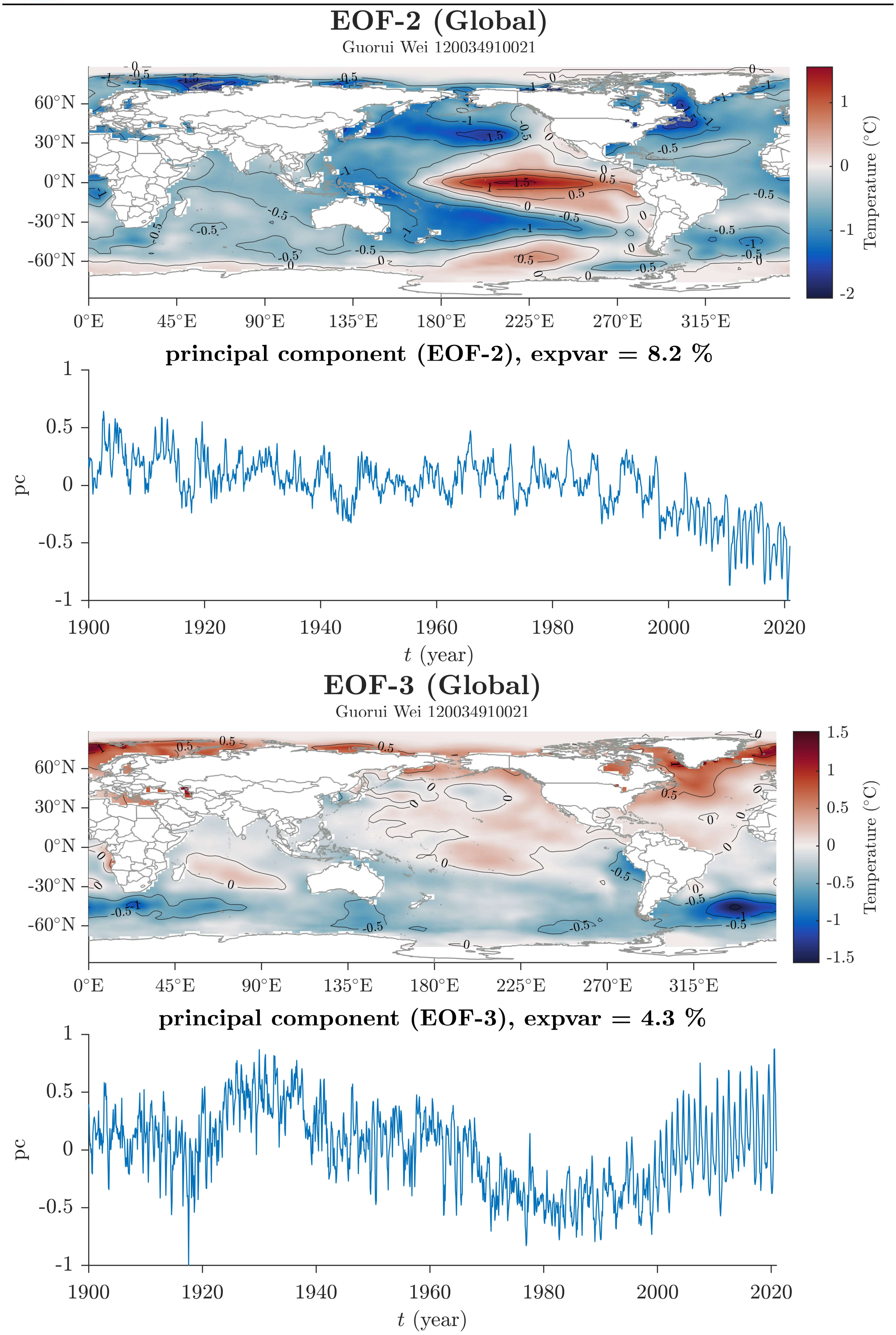
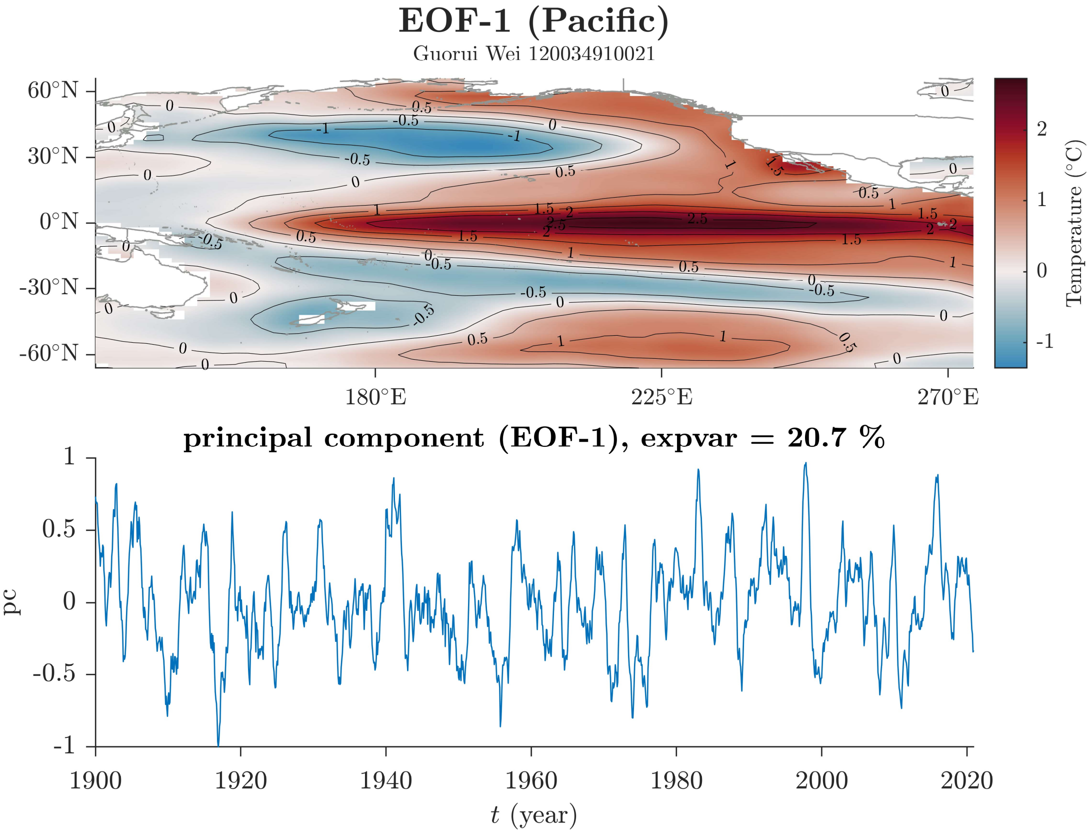


Figure 1 全球 EOF 的前 3 个 mode，相应的 principal component time series 和 percent of variance explained by each mode. (a) EOF-1, (b) EOF-2, (c) EOF-3.

3.2 The Pacific Ocean

太平洋区域 EOF. 第一模态，体现 ENSO，解释方差>20%，年际的. 第二模态，体现 PDO? ~期的？第三模态？

太平洋区域 EOF.，第一、二模态的空间 pattern 和全球区域 EOF 类似，且解释方差更高；第三模态在全球区域 EOF 中不明显.



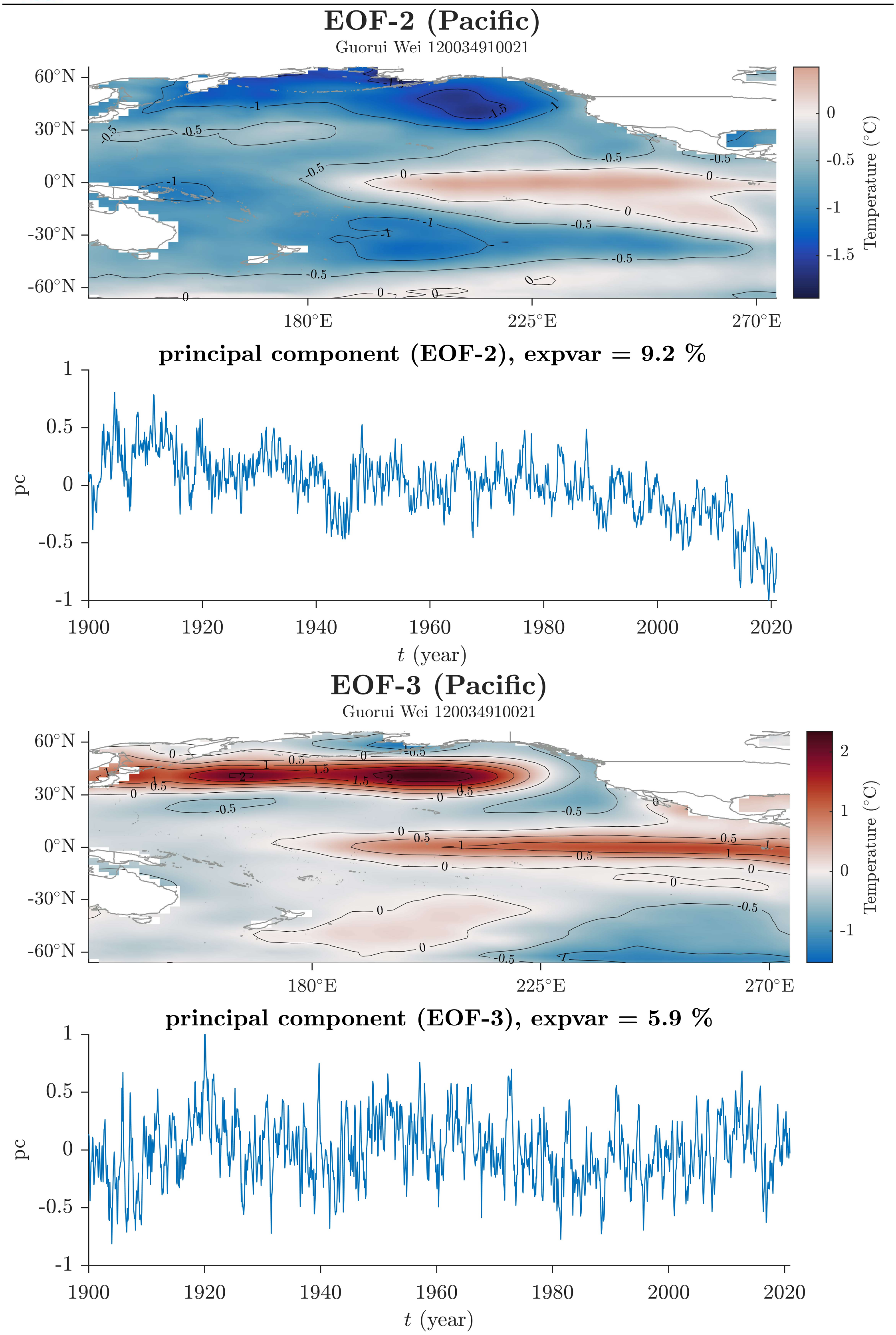
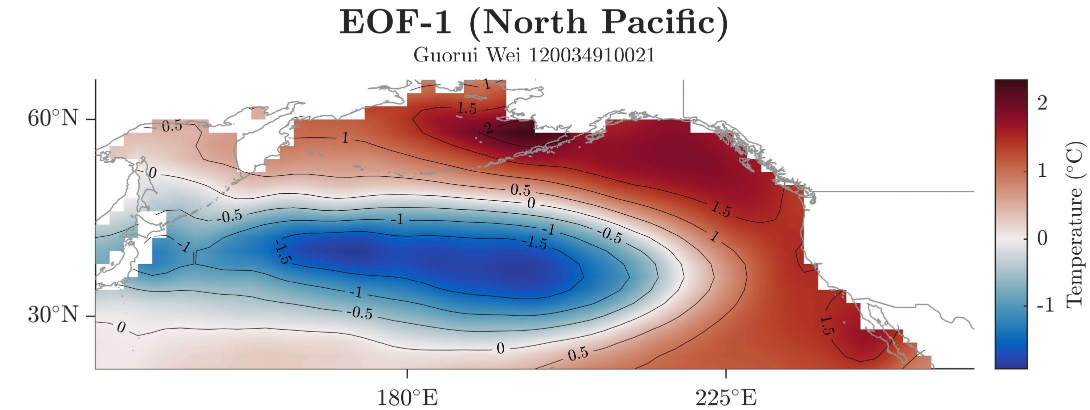
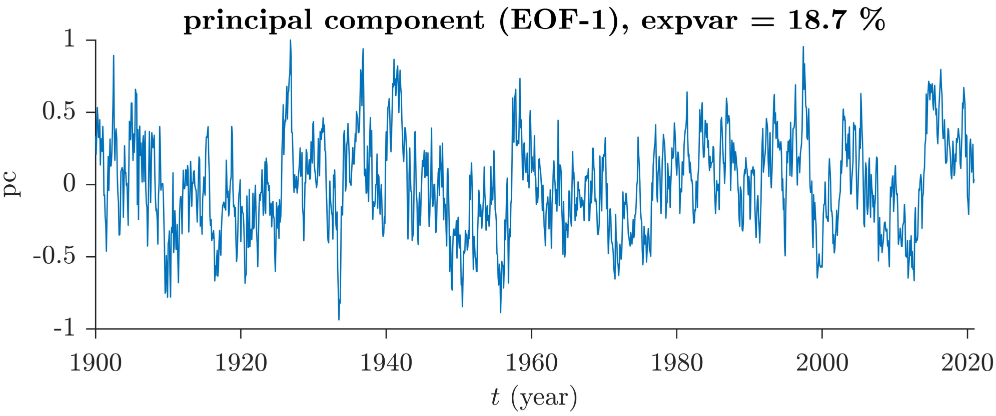


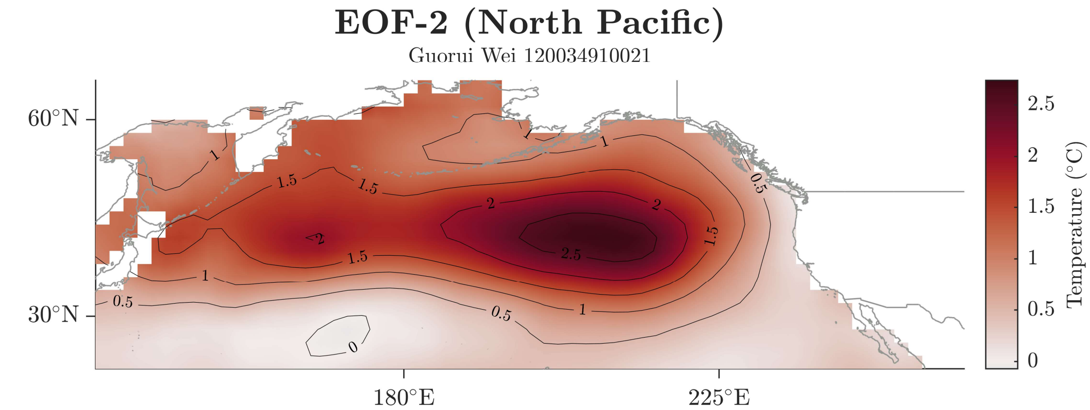
Figure 2 太平洋区域 EOF 的前 3 个 mode，相应的 principal component time series 和 percent of variance explained by each mode. (a) EOF-1, (b) EOF-2, (c) EOF-3.

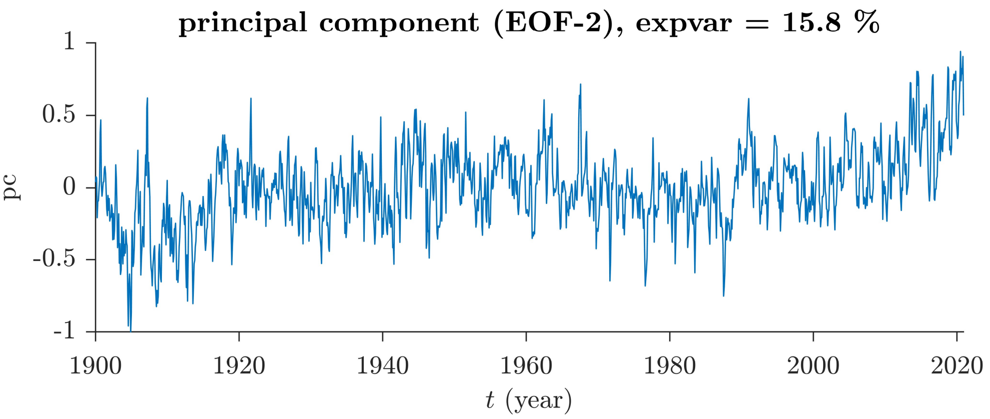
3.3 The North Pacific Ocean

北太平洋区域 EOF. 第一模态是 PDO，解释方差超过 18%.









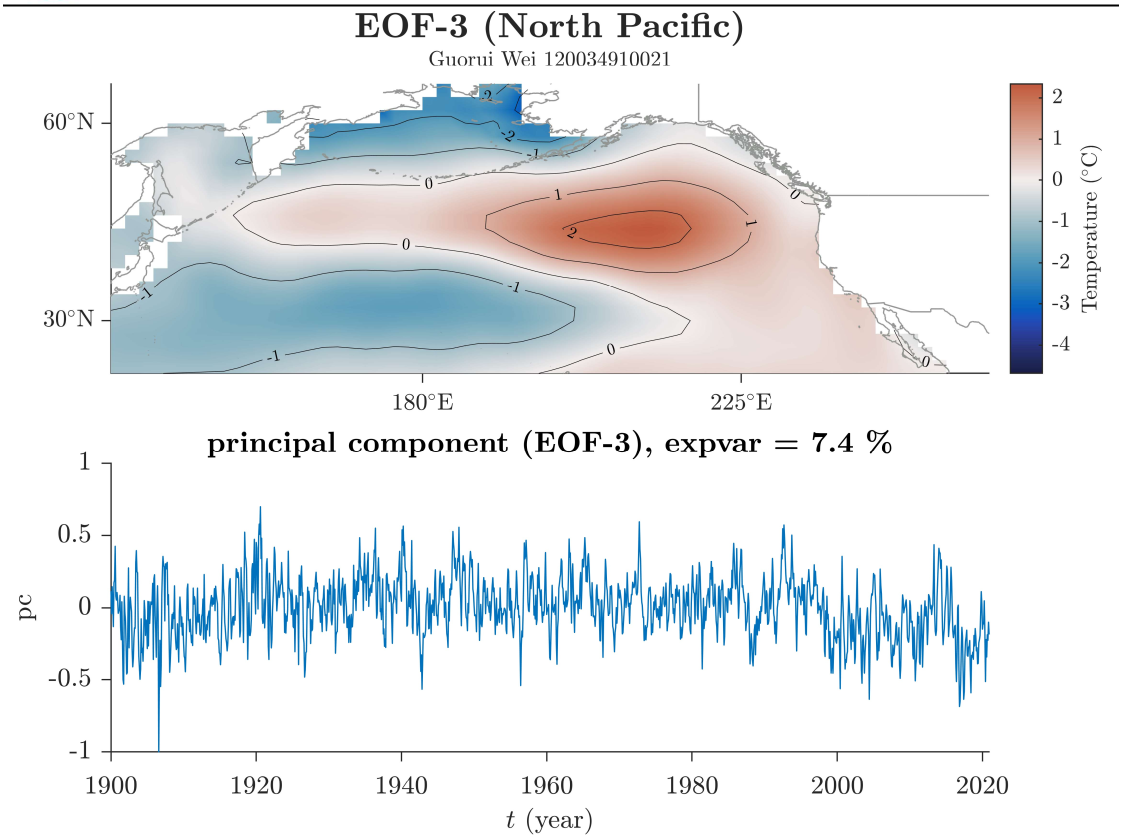
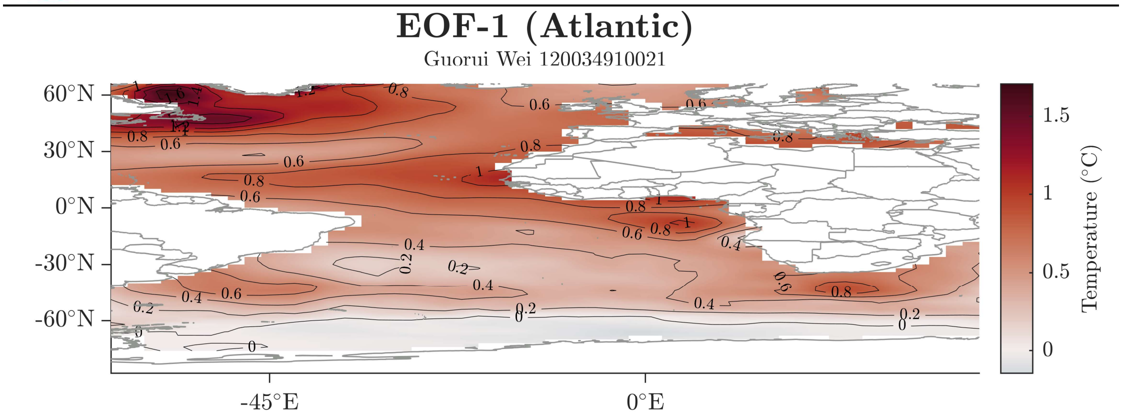


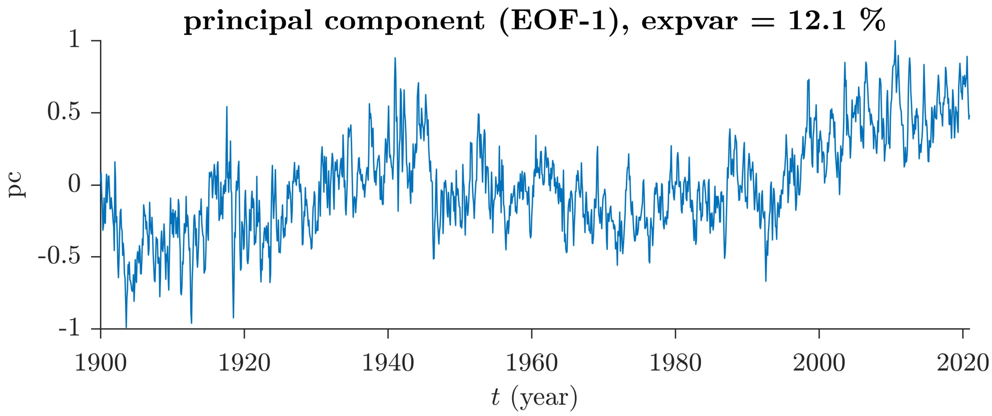
Figure 3 北太平洋区域 EOF 的前 3 个 mode，相应的 principal component time series 和 percent of variance explained by each mode. (a) EOF-1, (b) EOF-2, (c) EOF-3.

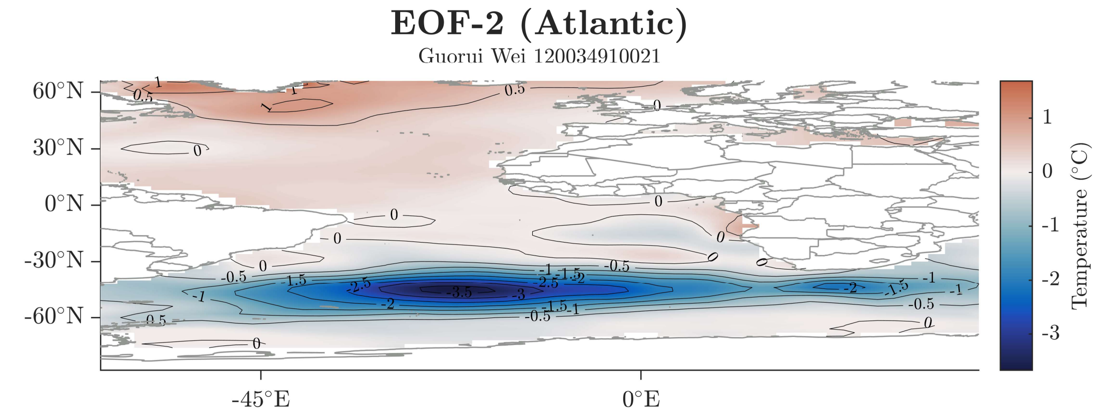
3.4 The Atlantic Ocean

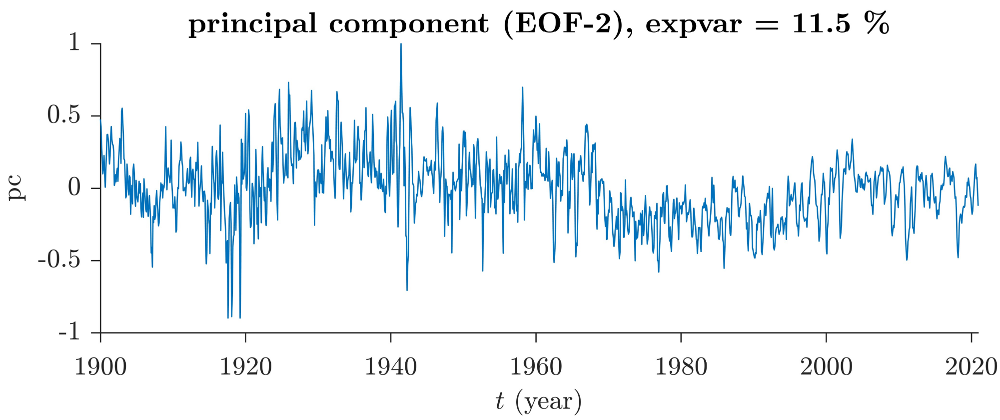
大西洋区域 EOF. 第一模态，体现 AMO，60-80 年期的，解释方差>12%；第二模态？解释方差>11%；第三模态？

大西洋区域 EOF 前两个模态的解释方差之和>23%.


EOF-1 (Atlantic)
Guorui Wei 120034910021
60°N
30°N
0°N
-30°N
-60°N
-45°E
0°E
1.5
1
0.5
0
Temperature (°C)


principal component (EOF-1), expvar = 12.1 %
pc
1
0.5
0
-0.5
-1
1900
1920
1940
1960
1980
2000
2020
t (year)


EOF-2 (Atlantic)
Guorui Wei 120034910021
60°N
30°N
0°N
-30°N
-60°N
-45°E
0°E
1
0
-1
-2
-3
Temperature (°C)


principal component (EOF-2), expvar = 11.5 %
pc
1
0.5
0
-0.5
-1
1900
1920
1940
1960
1980
2000
2020
t (year)

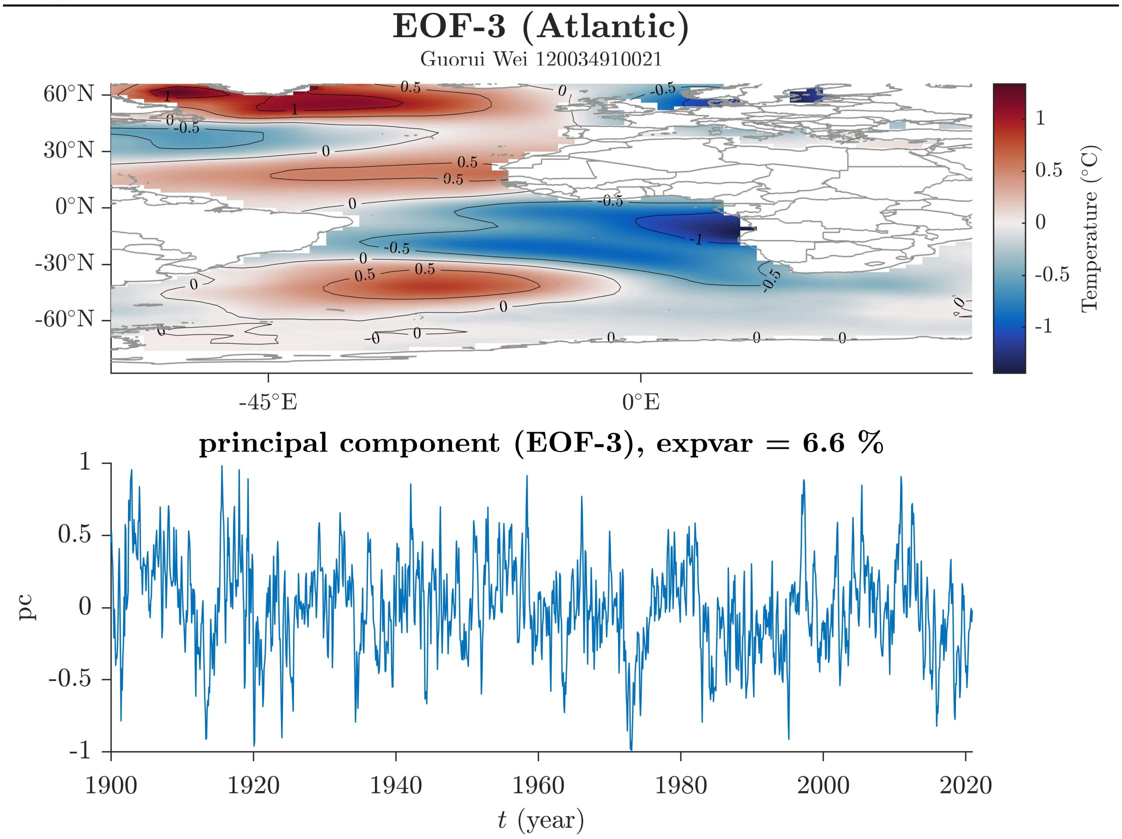
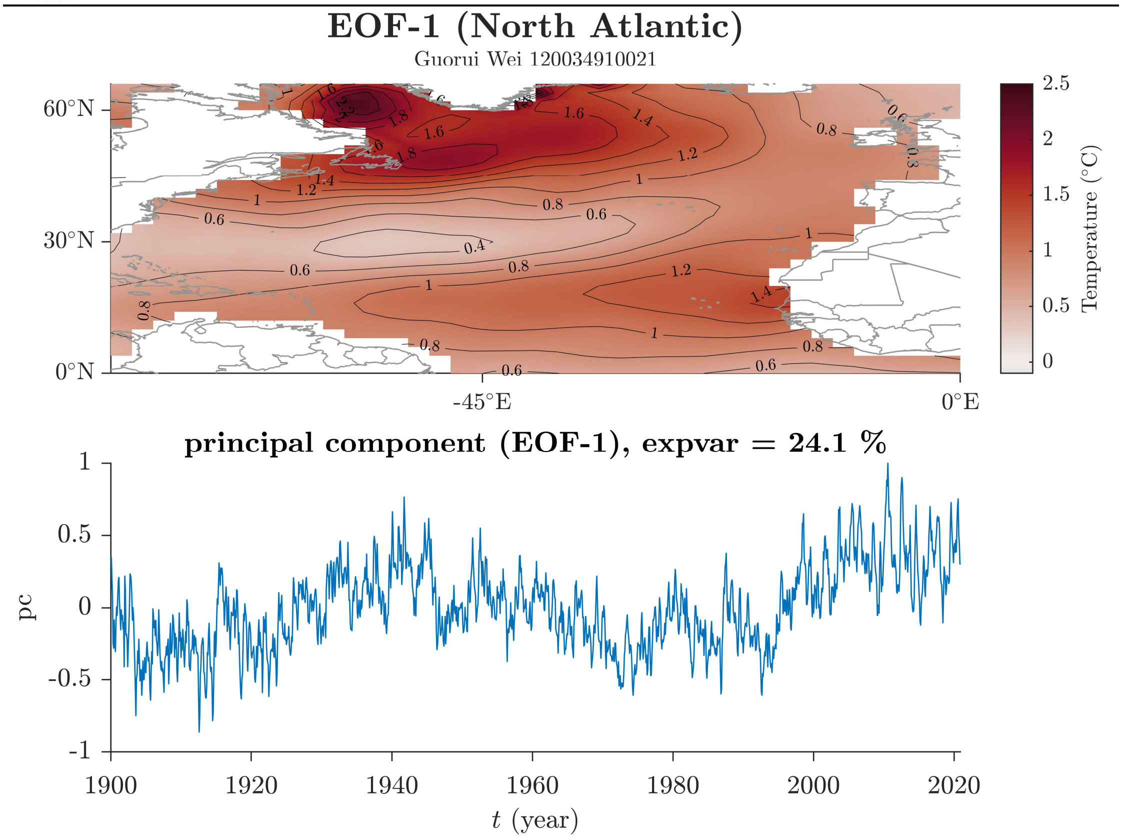


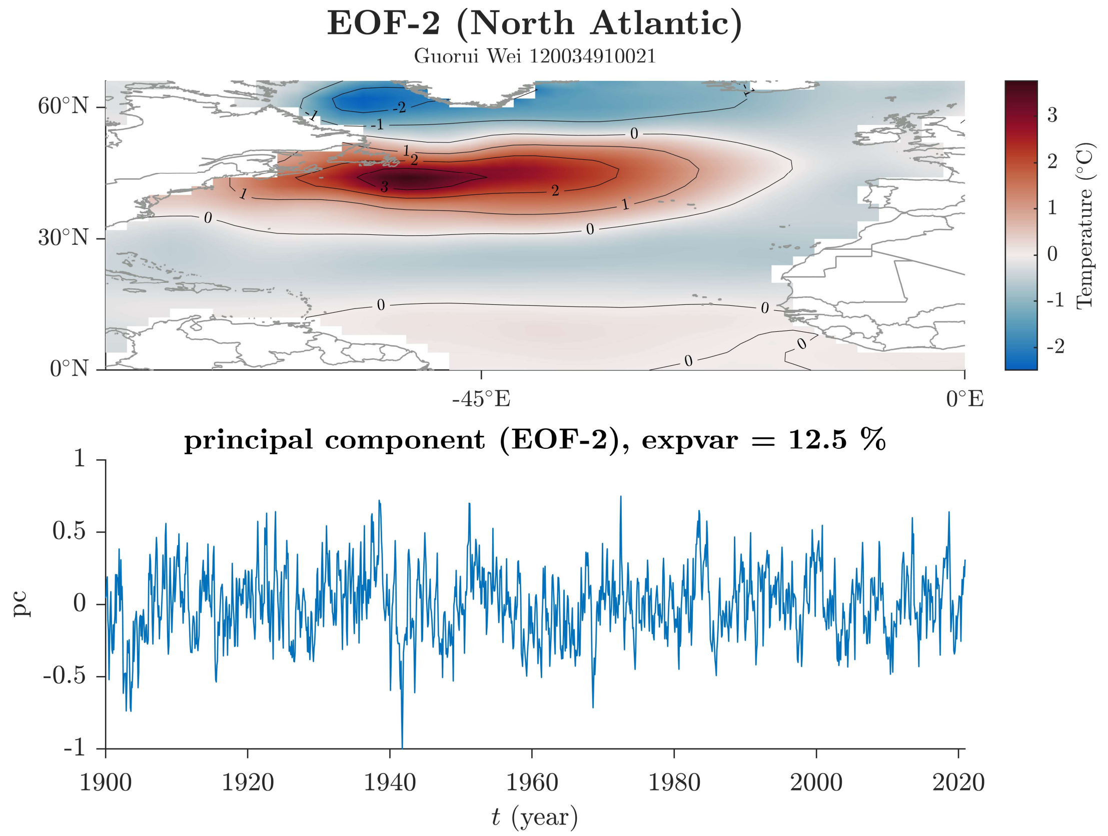
Figure 4 大西洋区域 EOF 的前 3 个 mode，相应的 principal component time series 和 percent of variance explained by each mode. (a) EOF-1, (b) EOF-2, (c) EOF-3.

3.5 The North Atlantic Ocean

北大西洋区域 EOF. 第一模态，体现 AMO，解释方差超过 24%；第二模态，？，解释方差超过 12%；第三模态，？，解释方差接近 10%.

与大西洋区域 EOF 相比，北大西洋区域 EOF 的第一模态的 AMO 特征更明显，解释方差更高. 北大西洋区域 EOF 的第二、三模态的解释方差较高，在大西洋区域 EOF 和全球 EOF 中体现不明显？


EOF-1 (North Atlantic)
Guorui Wei 120034910021
60°N
30°N
0°N
-45°E
0°E
Temperature (°C)
principal component (EOF-1), expvar = 24.1 %
pc
t (year)


EOF-2 (North Atlantic)
Guorui Wei 120034910021
60°N
30°N
0°N
-45°E
0°E
Temperature (°C)
principal component (EOF-2), expvar = 12.5 %
pc
t (year)

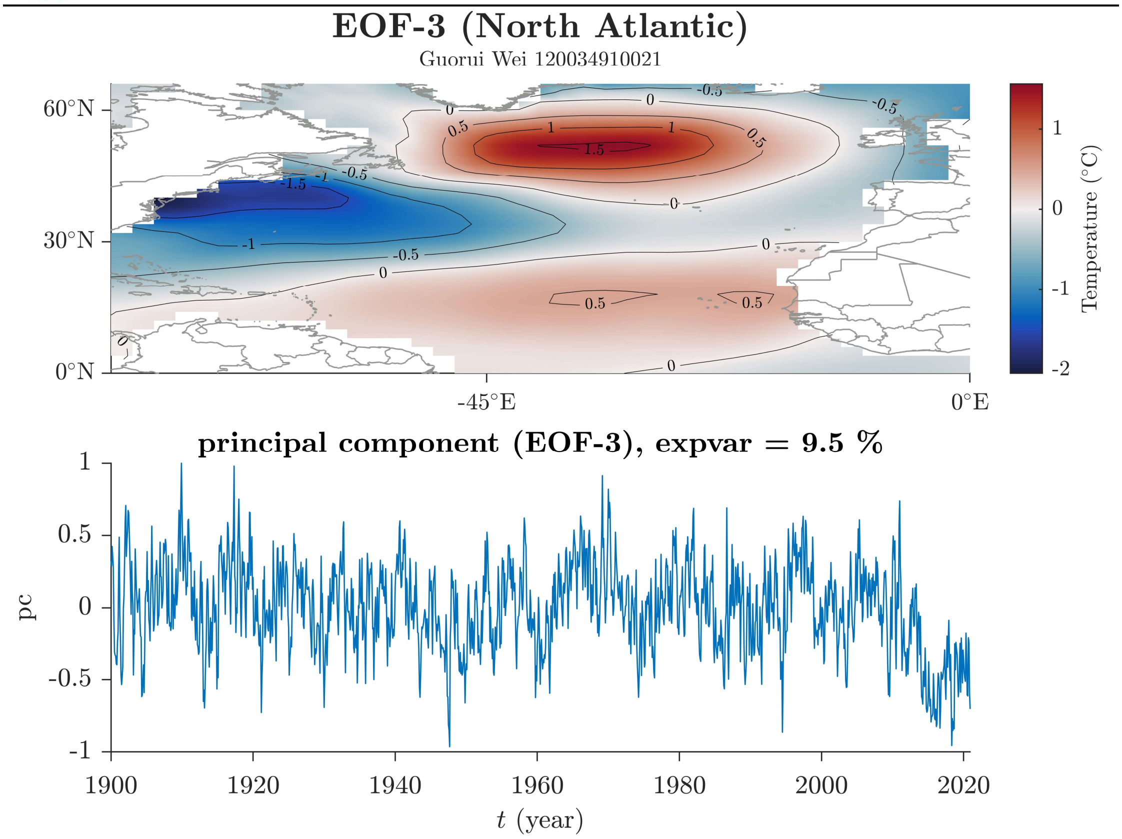


Figure 5 北大西洋区域 EOF 的前 3 个 mode，相应的 principal component time series 和 percent of variance explained by each mode. (a) EOF-1, (b) EOF-2, (c) EOF-3.

4 Discussion

全球 EOF 的前两个模态能分别体现 ENSO 和 PDO.

PDO 在全球 EOF 的第二模态有体现，在太平洋区域 EOF 的第二模态更明显，在北太平洋区域 EOF 中成为第一模态.

AMO 在全球 EOF 中不明显，在大西洋区域 EOF 成为第一模态，在北大西洋区域 EOF 中成为解释方差更高的第一模态.

5 Conclusions

EOF 分析的结果高度依赖于区域选取. 全球 EOF 的结果不是各区域分别 EOF 的结果的简单叠加. 在全球 EOF 中，局部重要的气候模态可能被“淹没”在众多模态中，而不能被 EOF 很好地分辨出.

References

[1] Chad A. Greene, Kaustubh Thirumalai, Kelly A. Kearney, Jose Miguel Delgado, Wolfgang Schwanghart, Natalie S. Wolfenbarger, Kristen M. Thyng, David E. Gwyther, Alex S. Gardner, and Donald D. Blankenship (2019). The Climate Data Toolbox for MATLAB. *Geochemistry, Geophysics, Geosystems*, *20*, 3774-3781. doi:10.1029/2019GC008392

[2] Zhihua Zhang, John C. Moore. Mathematical and Physical Fundamentals of Climate Change, 2015. https://doi.org/10.1016/C2013-0-14403-0

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_MS8401/.

A.1 主程序

```
%% hw2.m
% Description: MATLAB code for Homework 2 (MS8401, 2022 Spring)
% Author: Guorui Wei (危国锐) (313017602@qq.com; weiguorui@sjtu.edu.cn)
% Student ID: 120034910021
% Created: 2022-05-12
% Last modified: 2022-05-14
% References: [1] [CDT::eof documentation](https://www.chadagreene.com/CDT/eof_documentation.html)
%             [2] [Pacific Decadal Oscillation (PDO)](https://psl.noaa.gov/pdo/)
%             [3] [AMO] Trenberth, Kevin, Zhang, Rong & National Center for Atmospheric Research Staff (Eds). Last modified 05 Jun 2021. "The Climate Data Guide: Atlantic Multi-decadal Oscillation (AMO)." Retrieved from https://climatedataguide.ucar.edu/climate-data/atlantic-multi-decadal-oscillation-amo.
%             [4] [PDO] Deser, Clara, Trenberth, Kevin & National Center for Atmospheric Research Staff (Eds). Last modified 06 Jan 2016. "The Climate Data Guide: Pacific Decadal Oscillation (PDO): Definition and Indices." Retrieved from https://climatedataguide.ucar.edu/climate-data/pacific-decadal-oscillation-pdo-definition-and-indices.
%             [5] [NAO] National Center for Atmospheric Research Staff (Eds). Last modified 17 Apr 2022. "The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (PC-based)." Retrieved from https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-pc-based.
%             [6] [ENSO] [El Niño Southern Oscillation (ENSO)](https://psl.noaa.gov/enso/)
% Toolbox:    [T1] [M_Map: A mapping package for Matlab](https://www.eoas.ubc.ca/~rich/map.html)
%             [T2] [Climate Data Tools for Matlab](https://github.com/chadagreene/CDT)
% Data:       [D1] [NOAA Extended Reconstructed Sea Surface Temperature (SST) V5](https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html)

%% Initialize project

clc; clear; close all
```

```
init_env();

%% Read data

nc_path = "..\data\sst.mnmean.nc";
nc_info = ncinfo(nc_path);
sst = double(ncread(nc_path,'sst')); % [deg C] sst(lon,lat,time_month)
sst(sst == ncreadatt(nc_path,'/sst','missing_value')) = NaN; % Monthly Means of Sea Surface Temperature (SST)
lon = double(ncread(nc_path,'lon')); % [deg E]
lat = double(ncread(nc_path,'lat')); % [deg N]
time_month = (datetime(1854,1,15) + calmonths(0:size(sst,3)-1)).';

%% pre-processing

sst_dtr = detrend3(sst,'omitnan'); % Remove the global warming signal (detrended)
sst_var = deseason(sst_dtr,time_month); % Remove seasonal cycles (detrended and seasonal cycle removed -> variability)

%% 1. global

TF_lon_range = lon > -Inf & lon < +Inf;
TF_lat_range = lat > -Inf & lat < +Inf;
TF_time_range = datetime(1900,1,1) < time_month & time_month < datetime(2020,12,30);

%%% eof

n_eof = 3; % only calculates the first n modes of variability
[eof_maps,pc,expvar] = eof(sst_var(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
% Optional scaling of Principal Components and EOF maps
for k = 1:size(pc,1)
   % Find the the maximum value in the time series of each principal component:
   maxval = max(abs(pc(k,:)));
   % Divide the time series by its maximum value:
   pc(k,:) = pc(k,:)/maxval;
   % Multiply the corresponding EOF map:
   eof_maps(:,:,k) = eof_maps(:,:,k)*maxval;
end

%%% Create figure.
```

```
for num_EOF = 1:3
    EOF_fig(num_EOF,"Global",lon(TF_lon_range),lat(TF_lat_range),time_month(TF_time_range),eof_maps,pc,expvar,1)
end

%% 2. the Pacific Ocean (85°33'S ~ 65°44'N, 99°10'E -> 180°+78°08'E)

TF_lon_range = lon > 134 & lon < 276;
TF_lat_range = lat > -67 & lat < 67;
TF_time_range = datetime(1900,1,1) < time_month & time_month < datetime(2020,12,30);

%%% eof

n_eof = 3; % only calculates the first n modes of variability
[eof_maps,pc,expvar] = eof(sst_var(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
% Optional scaling of Principal Components and EOF maps
for k = 1:size(pc,1)
   % Find the the maximum value in the time series of each principal component:
   maxval = max(abs(pc(k,:)));
   % Divide the time series by its maximum value:
   pc(k,:) = pc(k,:)/maxval;
   % Multiply the corresponding EOF map:
   eof_maps(:,:,k) = eof_maps(:,:,k)*maxval;
end

%%% Create figure.
for num_EOF = 1:3
    EOF_fig(num_EOF,"Pacific",lon(TF_lon_range),lat(TF_lat_range),time_month(TF_time_range),eof_maps,pc,expvar,1)
end

%% 3. the Atlantic Ocean

%%% prepare

% convert longitute from 0~360 deg E to -180~180 deg E
n_lon_W = sum(lon >= 180);
lon_0 = circshift(lon,n_lon_W);
lon_0(lon_0 >= 180) = lon_0(lon_0 >= 180) - 360;
sst_var_0 = circshift(sst_var,n_lon_W,1);
%
```

```
TF_lon_range = (lon_0 > -65 & lon_0 < 41);
TF_lat_range = lat > -101 & lat < 67;
TF_time_range = datetime(1900,1,1) < time_month & time_month < datetime(2020,12,30);

%%% eof

n_eof = 3; % only calculates the first n modes of variability
[eof_maps,pc,expvar] = eof(sst_var_0(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
% Optional scaling of Principal Components and EOF maps
for k = 1:size(pc,1)
   % Find the the maximum value in the time series of each principal component:
   maxval = max(abs(pc(k,:)));
   % Divide the time series by its maximum value:
   pc(k,:) = pc(k,:)/maxval;
   % Multiply the corresponding EOF map:
   eof_maps(:,:,k) = eof_maps(:,:,k)*maxval;
end

%%% Create figure.
for num_EOF = 1:3
    EOF_fig(num_EOF,"Atlantic",lon_0(TF_lon_range),lat(TF_lat_range),time_month(TF_time_range),eof_maps,pc,expvar,1)
end

%% 4. the North Atlantic Ocean

%%% prepare

% convert longitute from 0~360 deg E to -180~180 deg E
n_lon_W = sum(lon >= 180);
lon_0 = circshift(lon,n_lon_W);
lon_0(lon_0 >= 180) = lon_0(lon_0 >= 180) - 360;
sst_var_0 = circshift(sst_var,n_lon_W,1);
%
TF_lon_range = (lon_0 > -81 & lon_0 < 1);
TF_lat_range = lat > -1 & lat < 67;
TF_time_range = datetime(1900,1,1) < time_month & time_month < datetime(2020,12,30);

%%% eof

```

```matlab
n_eof = 3; % only calculates the first n modes of variability
[eof_maps,pc,expvar] = eof(sst_var_0(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
% Optional scaling of Principal Components and EOF maps
for k = 1:size(pc,1)
   % Find the the maximum value in the time series of each principal component:
   maxval = max(abs(pc(k,:)));
   % Divide the time series by its maximum value:
   pc(k,:) = pc(k,:)/maxval;
   % Multiply the corresponding EOF map:
   eof_maps(:,:,k) = eof_maps(:,:,k)*maxval;
end

%%% Create figure.
for num_EOF = 1:3
    EOF_fig(num_EOF,"North Atlantic",lon_0(TF_lon_range),lat(TF_lat_range),time_month(TF_time_range),eof_maps,pc,expvar,1)
end

%% 5. the North Pacific Ocean (20°N ~ 65°44'N, 99°10'E -> 180°+78°08'E)

TF_lon_range = lon > 134 & lon < 276;
TF_lat_range = lat > 20 & lat < 67;
TF_time_range = datetime(1900,1,1) < time_month & time_month < datetime(2020,12,30);

%%% eof

n_eof = 3; % only calculates the first n modes of variability
[eof_maps,pc,expvar] = eof(sst_var(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
% Optional scaling of Principal Components and EOF maps
for k = 1:size(pc,1)
   % Find the the maximum value in the time series of each principal component:
   maxval = max(abs(pc(k,:)));
   % Divide the time series by its maximum value:
   pc(k,:) = pc(k,:)/maxval;
   % Multiply the corresponding EOF map:
   eof_maps(:,:,k) = eof_maps(:,:,k)*maxval;
end

```

```
%%% Create figure.
for num_EOF = 1:3
    EOF_fig(num_EOF,"North Pacific",lon(TF_lon_range),lat(TF_lat_range),time_month(TF_time_range),eof_maps,pc,expvar,1)
end

%% local functions

%% Initialize environment

function [] = init_env()
% Initialize environment
%
    % set up project directory
    if ~isfolder("../doc/fig/hw2")
        mkdir ../doc/fig/hw2
    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

%% Create EOF figure.

function [] = EOF_fig(num_EOF,title_str,lon,lat,time_month,eof_maps,pc,expvar,TF_export)
    arguments
        num_EOF
        title_str
        lon
        lat
        time_month
        eof_maps
        pc
        expvar
```

```
            TF_export
        end

        figure('Name',sprintf("EOF-%d (%s)",num_EOF,title_str))
        t_TCL = tiledlayout(2,1,"TileSpacing","tight","Padding","tight");

        %%% EOF

        t_axes = nexttile(t_TCL,1);
        pcolor(t_axes,lon,lat,eof_maps(:,:,num_EOF).');
        shading(t_axes,"interp");
        hold on
        [C,h] =
    contour(t_axes,lon,lat,eof_maps(:,:,num_EOF).','LineWidth',0.2,'LineColor','
    black','ShowText','off');
        borders('countries','center',180,'color',rgb('gray'))
        hold off
        clabel(C,h,"Interpreter",'latex','FontSize',6)
        % BEGIN patch
        cl = caxis;
        if (cl(1) >= 0)
           cl(1) = -0.1;
           caxis(t_axes,cl)
        end
        % END patch
        colormap(t_axes,cmocean('balance','pivot',0))
        cb = colorbar(t_axes,"eastoutside","TickLabelInterpreter","latex");
        set(cb.Label,"String","Temperature
    ($^{\circ}\rm{C}$)","Interpreter","latex")
        set(t_axes,"TickLabelInterpreter","latex","TickDir","out",'YDir','normal'
    ,'Box','off');
        xticks(t_axes,-180:45:360)
        xtickformat(t_axes,'%g$^{\\circ}\\rm{E}$')
        yticks(-90:30:90)
        ytickformat(t_axes,'%g$^{\\circ}\\rm{N}$')
        % xlabel(t_axes,"longitude (deg E)",'Interpreter','latex')
        % ylabel(t_axes,"latitude (deg N)",'Interpreter','latex')
        %
        [~,t_title_s] = title(t_TCL,sprintf("\\bf EOF-%d
    (%s)",num_EOF,title_str),"Guorui Wei 120034910021",'Interpreter','latex');
        set(t_title_s,'FontSize',8);

        %%% pc

```

```
    t_axes = nexttile(t_TCL,2);
    plot(t_axes,time_month,pc(num_EOF,:),'-',"DisplayName",'pc');
    set(t_axes,"YDir",'normal',"TickLabelInterpreter",'latex',"FontSize",10,'Box','off','TickDir','out','XLimitMethod','tight');
    % legend(t_axes,"Location",'best','Interpreter','latex',"Box","off",'FontSize',10);
    xticks(t_axes,datetime(1900,1,15) + calyears(0:20:120))
    xtickformat(t_axes,'yyyy')
    xlabel(t_axes,"$t$ (year)",FontSize=10,Interpreter="latex");
    ylabel(t_axes,"pc","FontSize",10,"Interpreter","latex");
    title(t_axes,sprintf("\\bf principal component (EOF-%d), expvar = %.1f \\%%",num_EOF,expvar(num_EOF)),"Interpreter","latex");

    %%% export

    if (TF_export)
        exportgraphics(t_TCL,sprintf("..\\doc\\fig\\hw2\\hw2_EOF-%d_%s.emf",num_EOF,title_str),'Resolution',800,'ContentType','auto','BackgroundColor','none','Colorspace','rgb')
        exportgraphics(t_TCL,sprintf("..\\doc\\fig\\hw2\\hw2_EOF-%d_%s.png",num_EOF,title_str),'Resolution',800,'ContentType','auto','BackgroundColor','none','Colorspace','rgb')
    end

    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_MS8401/.