



## 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/](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/](https://grwei.github.io/SJTU_2021-2022-2_MS8401/).

**Keywords:** keyword 1, keyword 2



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## 1 Introduction

Empirical orthogonal function (EOF)<sup>12</sup>

El Niño Southern Oscillation (ENSO)<sup>3</sup>

The Pacific Decadal Oscillation (PDO)<sup>4</sup>

The Atlantic Multi-decadal Oscillation (AMO)<sup>5</sup>

The North Atlantic Oscillation (NAO)<sup>6</sup>

## 2 Data and Methods

使用 [NOAA Extended Reconstructed Sea Surface Temperature \(SST\) V5](#) 的 *Monthly Mean* 数据<sup>7</sup>, 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<sup>8</sup>;
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<sup>9</sup>.

然后, 分别在 5 个区域作 EOF 分析, 通过调用 CDT 的 eof 函数<sup>10</sup>: (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~.

<sup>1</sup> <https://doi.org/10.1007/978-90-481-3702-2>

<sup>2</sup> <https://doi.org/10.1016/B978-0-12-387782-6.00004-1>

<sup>3</sup> <https://psl.noaa.gov/enso/>

<sup>4</sup> <https://climatedataguide.ucar.edu/climate-data/pacific-decadal-oscillation-pdo-definition-and-indices>

<sup>5</sup> <https://climatedataguide.ucar.edu/climate-data/atlantic-multi-decadal-oscillation-amo>

<sup>6</sup> <https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-pc-based>

<sup>7</sup> <https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html>

<sup>8</sup> [https://www.chadagreene.com/CDT/detrend3\\_documentation.html](https://www.chadagreene.com/CDT/detrend3_documentation.html)

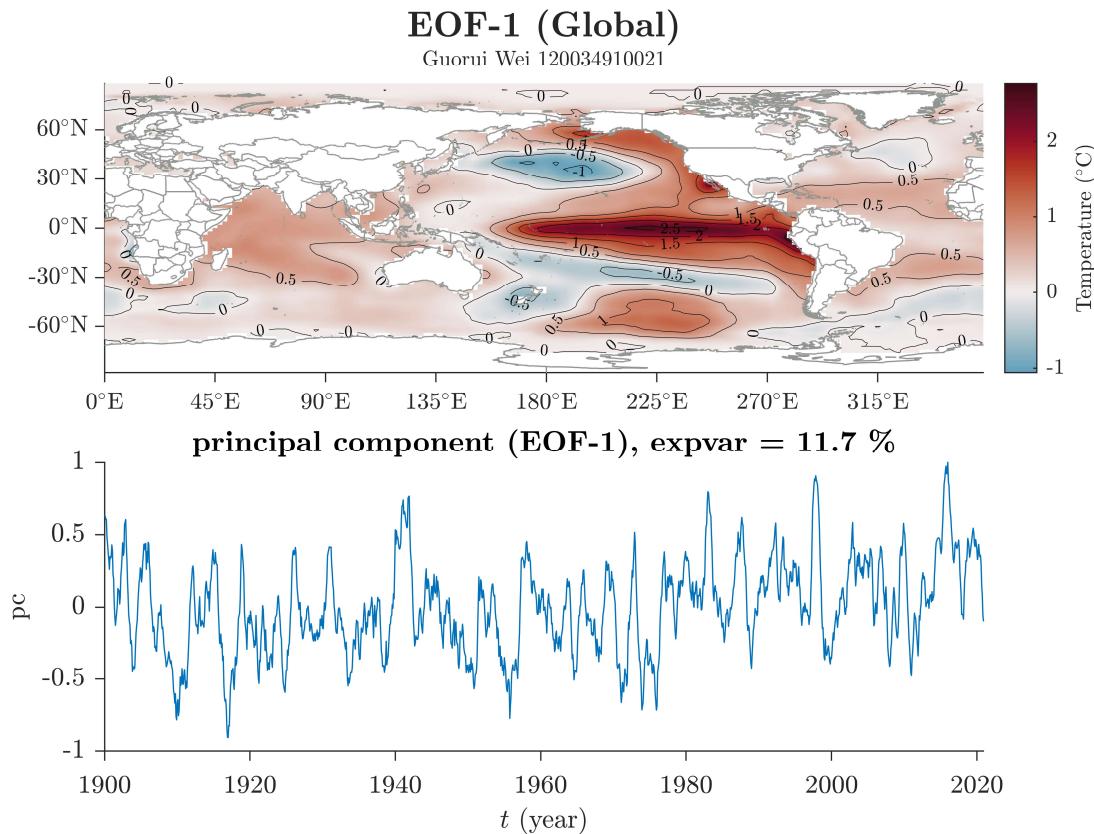
<sup>9</sup> [https://www.chadagreene.com/CDT/deseason\\_documentation.html](https://www.chadagreene.com/CDT/deseason_documentation.html)

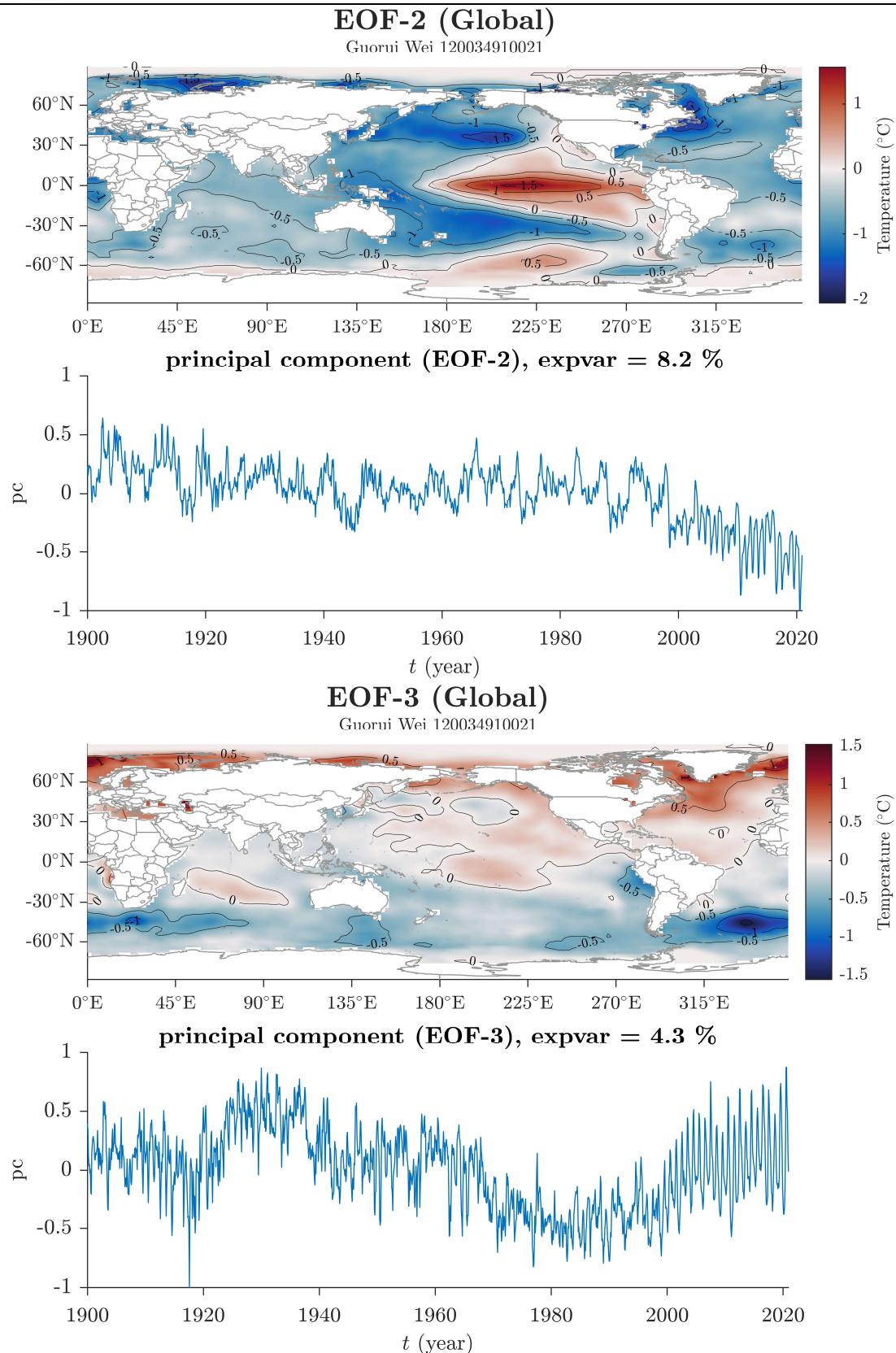
<sup>10</sup> [https://www.chadagreene.com/CDT/eof\\_documentation.html](https://www.chadagreene.com/CDT/eof_documentation.html)

### 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?





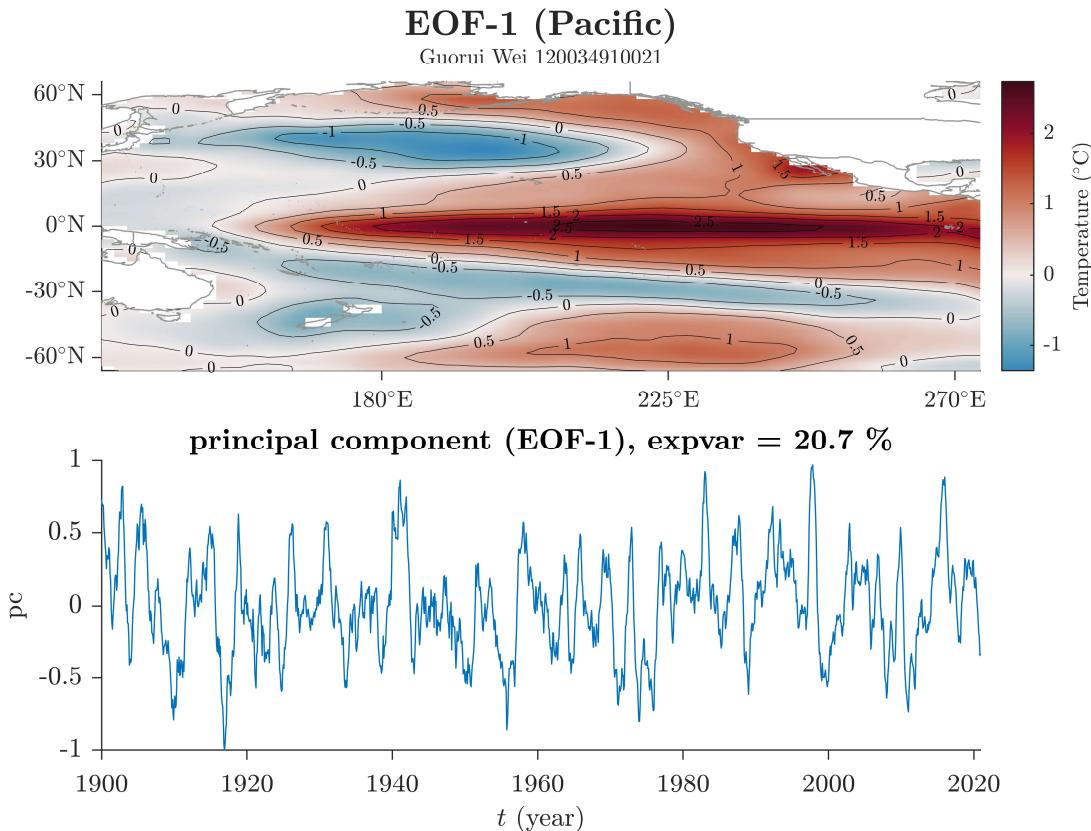
**Figure 1** 全球 EOF 的前 3 个 mode, 相应的 principal component time series 和 percent of variance explained by each mode. (a) EOF-1, (b) EOF-2, (c) EOF-3.



### 3.2 The Pacific Ocean

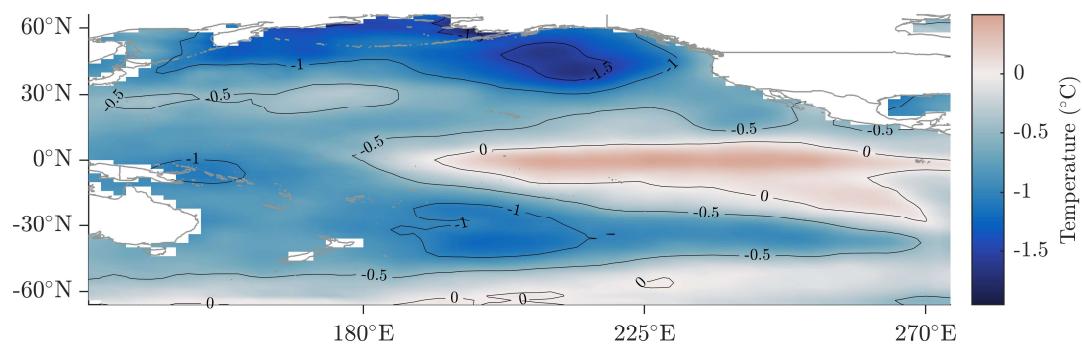
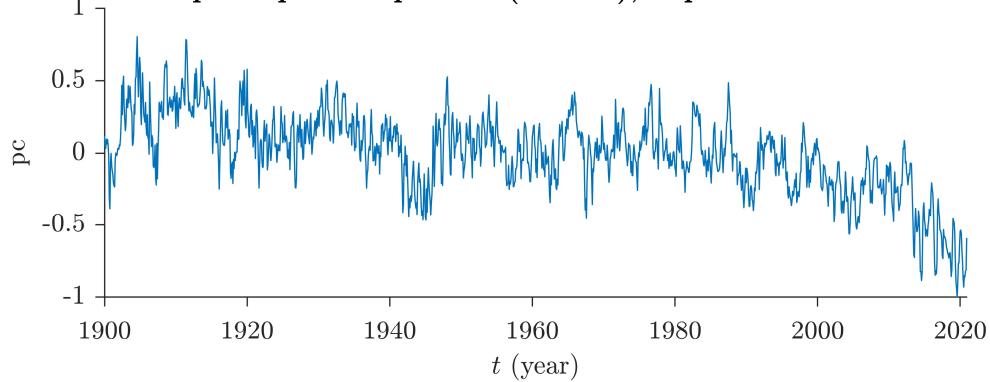
太平洋区域 EOF. 第一模态, 体现 ENSO, 解释方差>20%, 年际的. 第二模态, 体现 PDO? ~期的? 第三模态?

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.

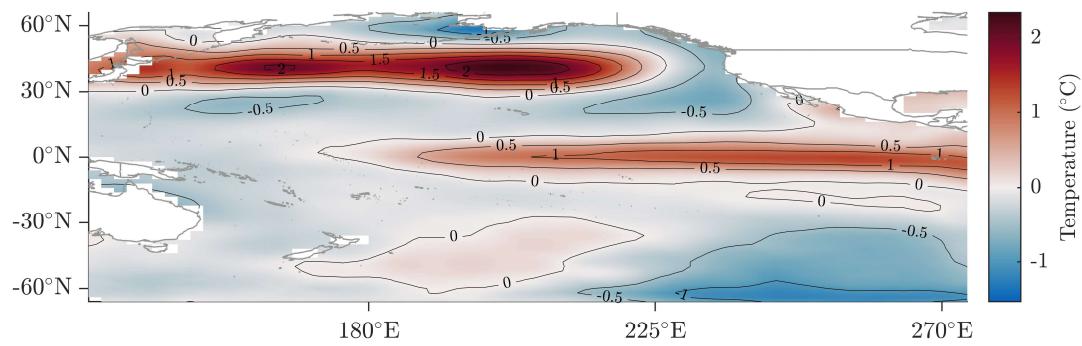
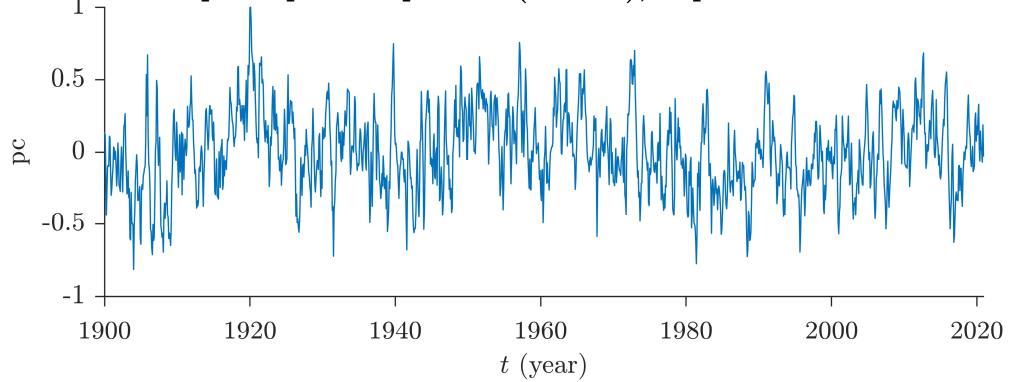


**EOF-2 (Pacific)**

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**principal component (EOF-2), expvar = 9.2 %****EOF-3 (Pacific)**

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**principal component (EOF-3), expvar = 5.9 %**

**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.

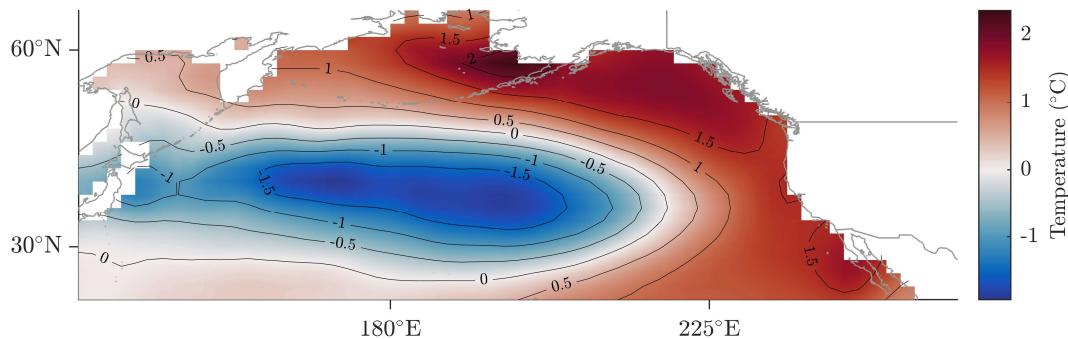


### 3.3 The North Pacific Ocean

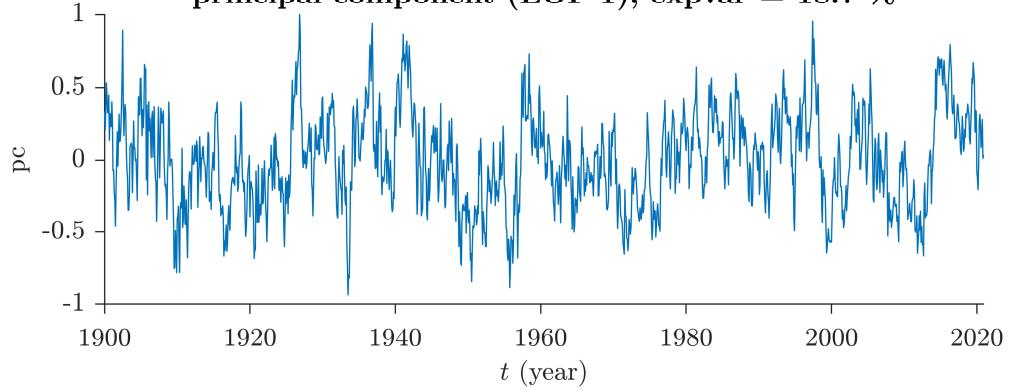
北太平洋区域 EOF. 第一模态是 PDO，解释方差超过 18%.

**EOF-1 (North Pacific)**

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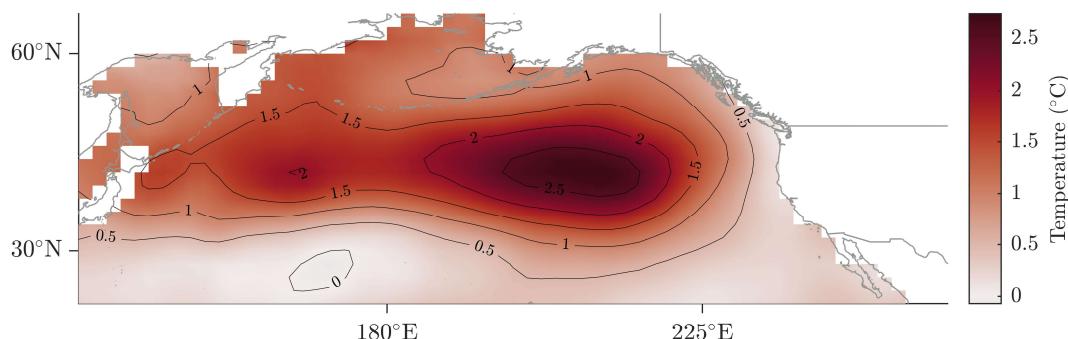


principal component (EOF-1), expvar = 18.7 %

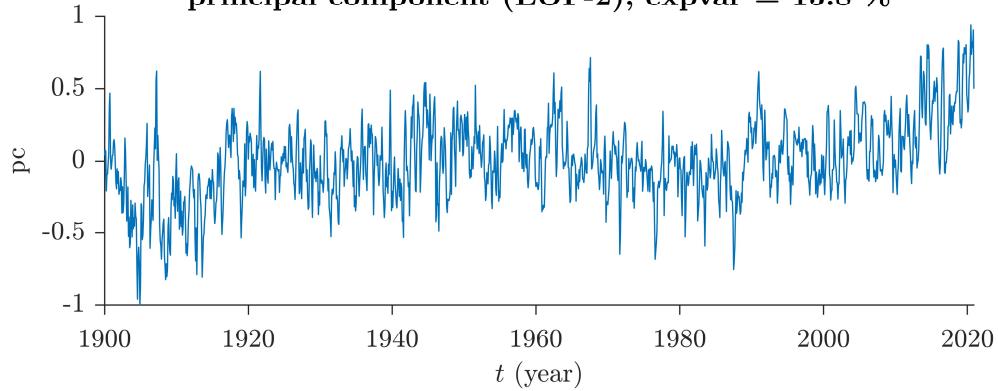


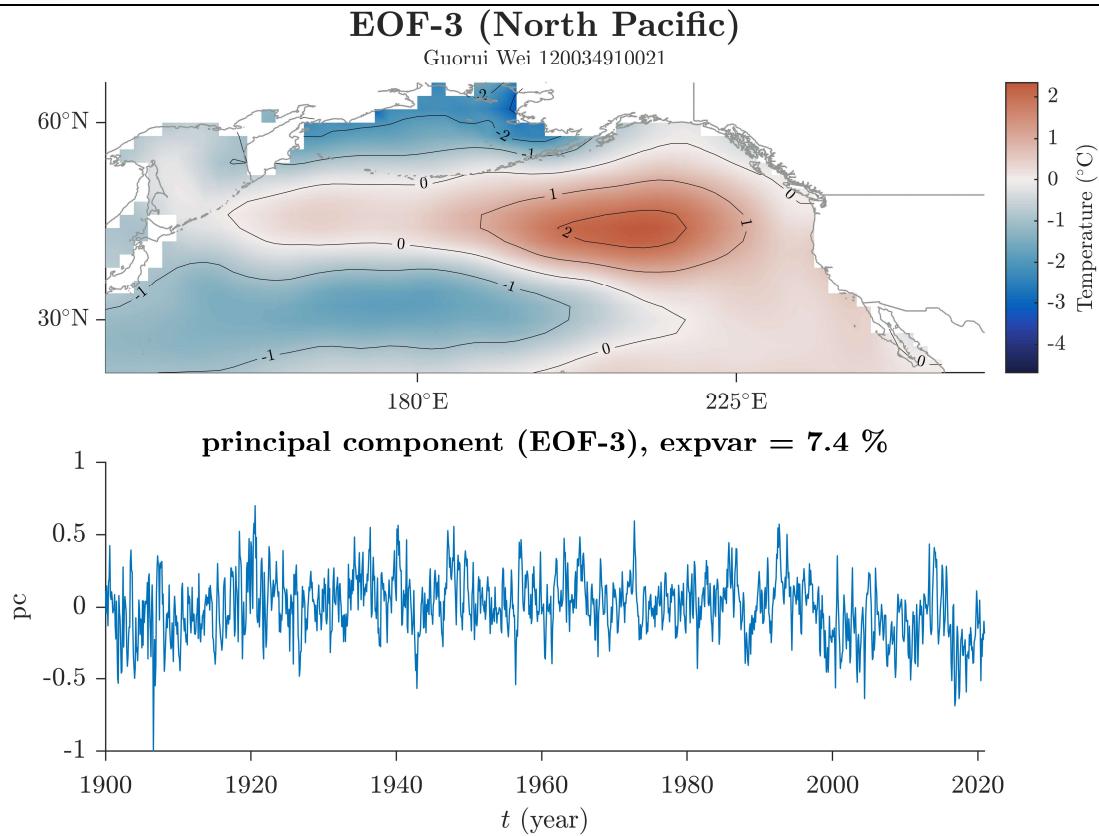
**EOF-2 (North Pacific)**

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principal component (EOF-2), expvar = 15.8 %





**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.

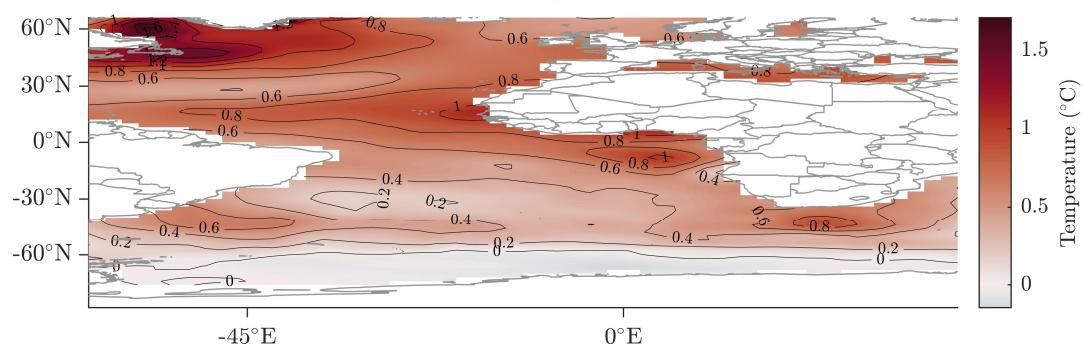
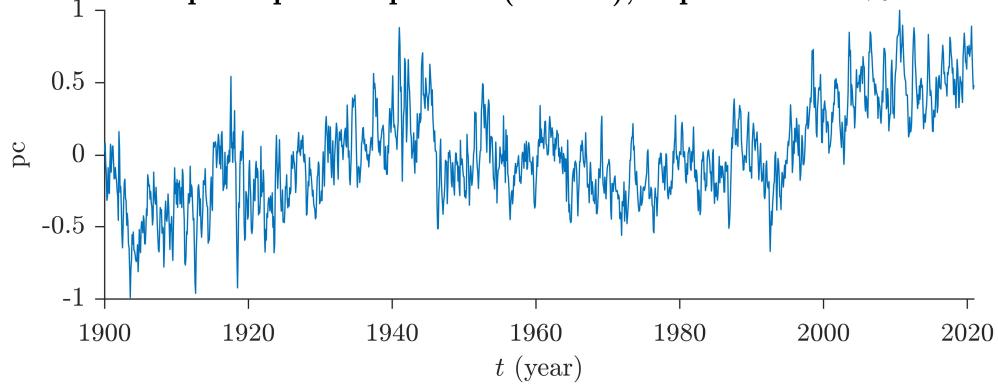
### 3.4 The Atlantic Ocean

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?

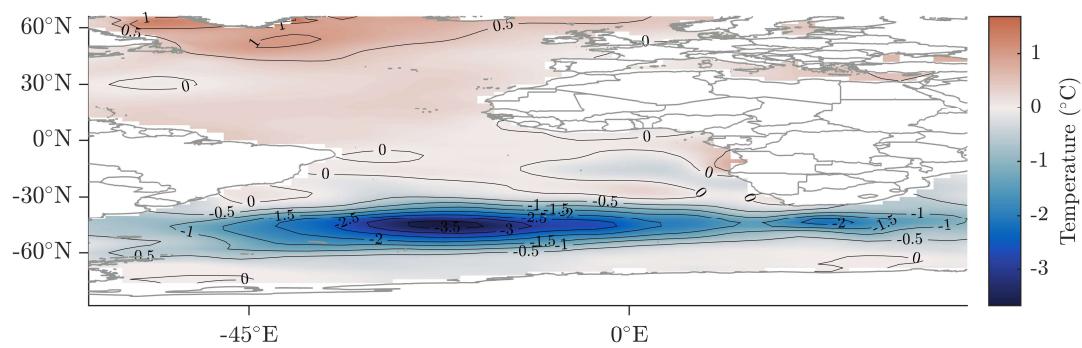
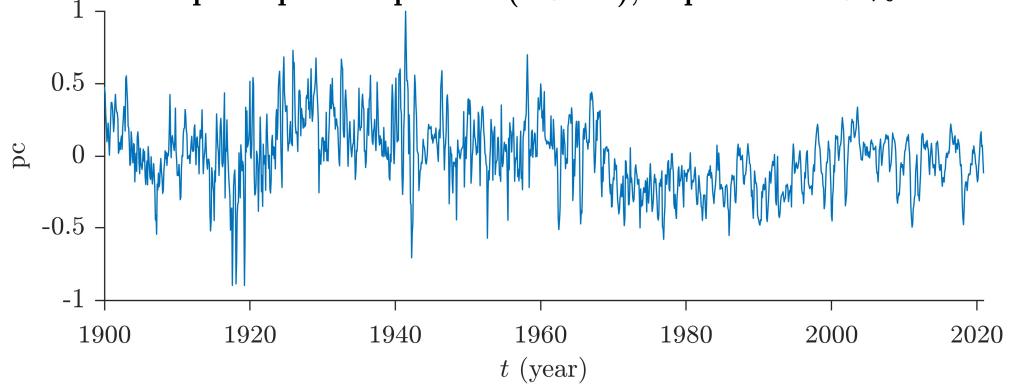
大西洋区域 EOF 前两个模态的解释方差之和>23%.

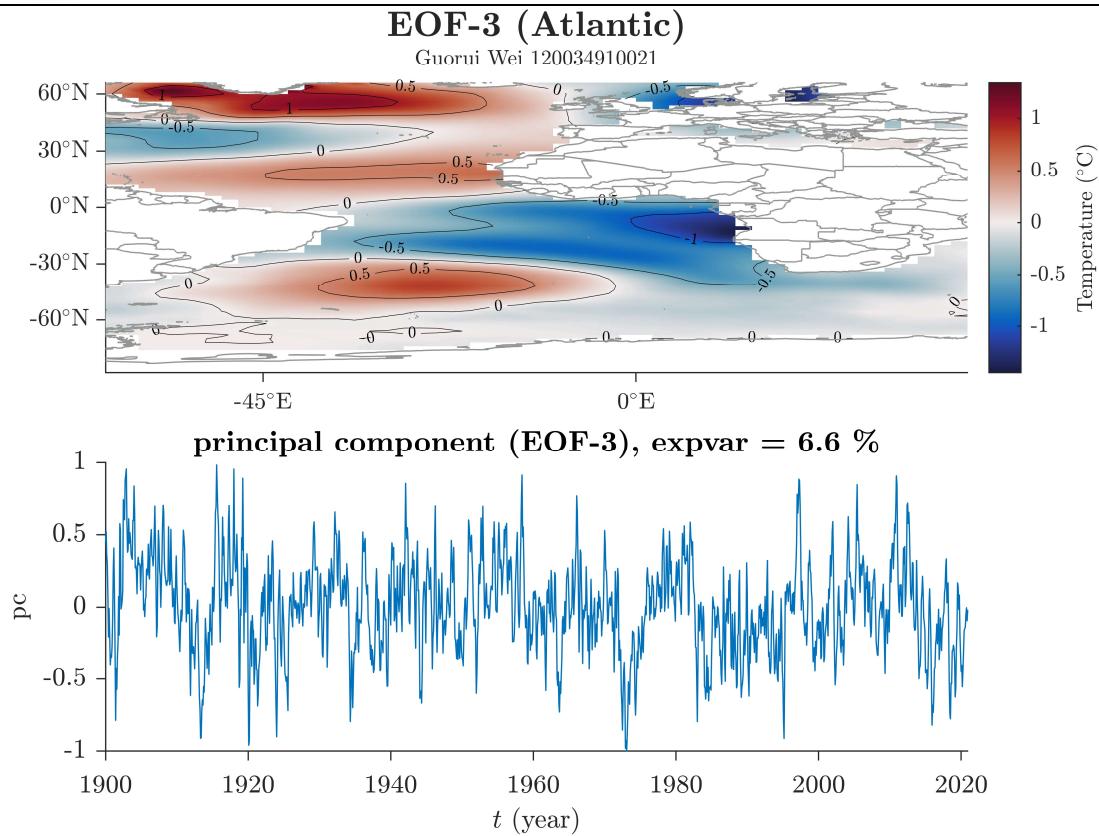
**EOF-1 (Atlantic)**

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**principal component (EOF-1), expvar = 12.1 %****EOF-2 (Atlantic)**

Guorni Wei 120034910021

**principal component (EOF-2), expvar = 11.5 %**



**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.

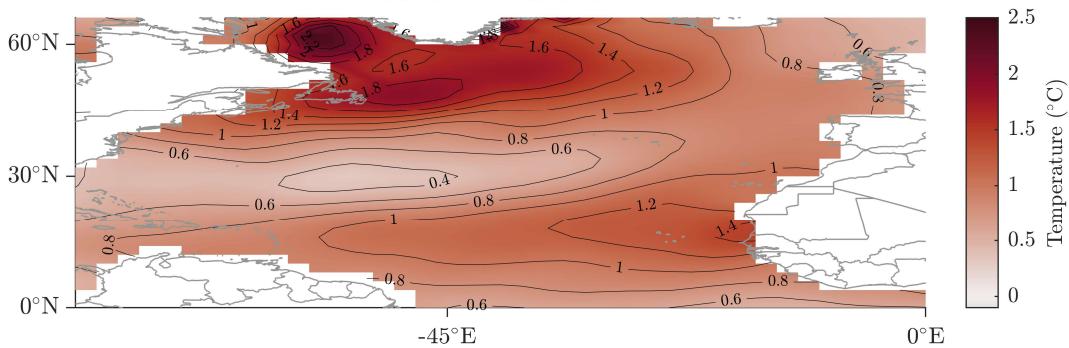
### 3.5 The North Atlantic Ocean

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%.

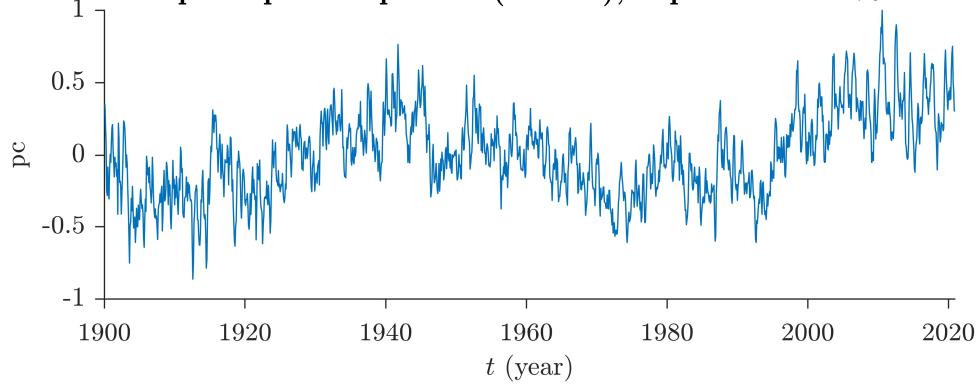
与大西洋区域 EOF 相比, 北大西洋区域 EOF 的第一模态的 AMO 特征更明显, 解释方差更高. 北大西洋区域 EOF 的第二、三模态的解释方差较高, 在大西洋区域 EOF 和全球 EOF 中体现不明显?

**EOF-1 (North Atlantic)**

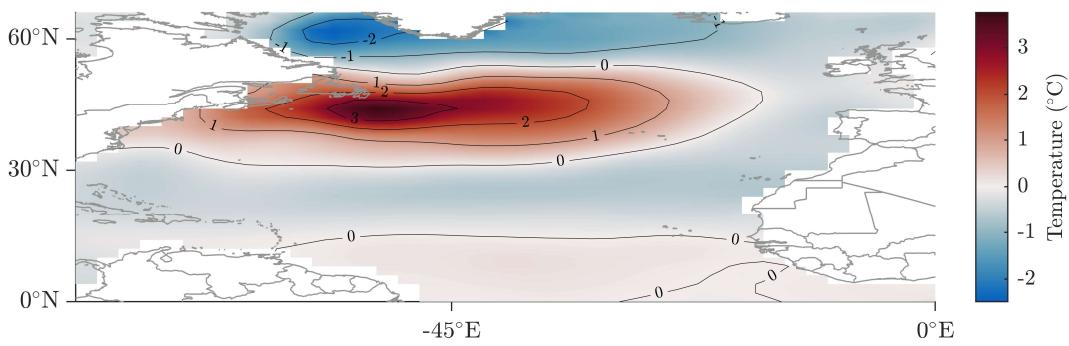
Guorui Wei 120034910021



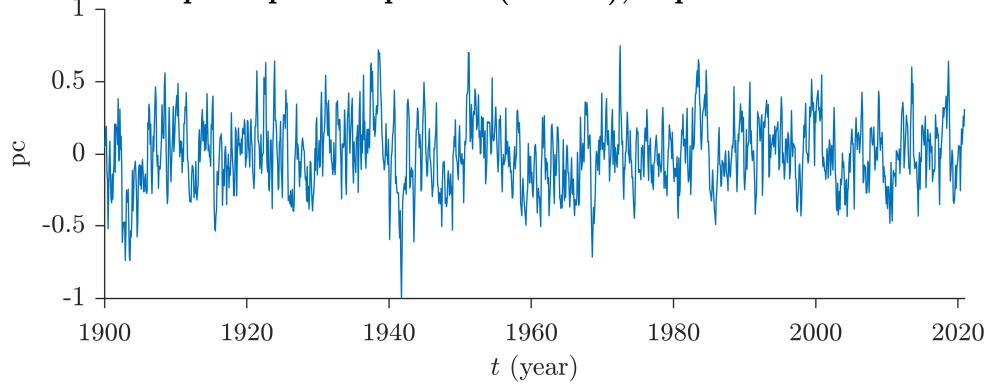
principal component (EOF-1), expvar = 24.1 %

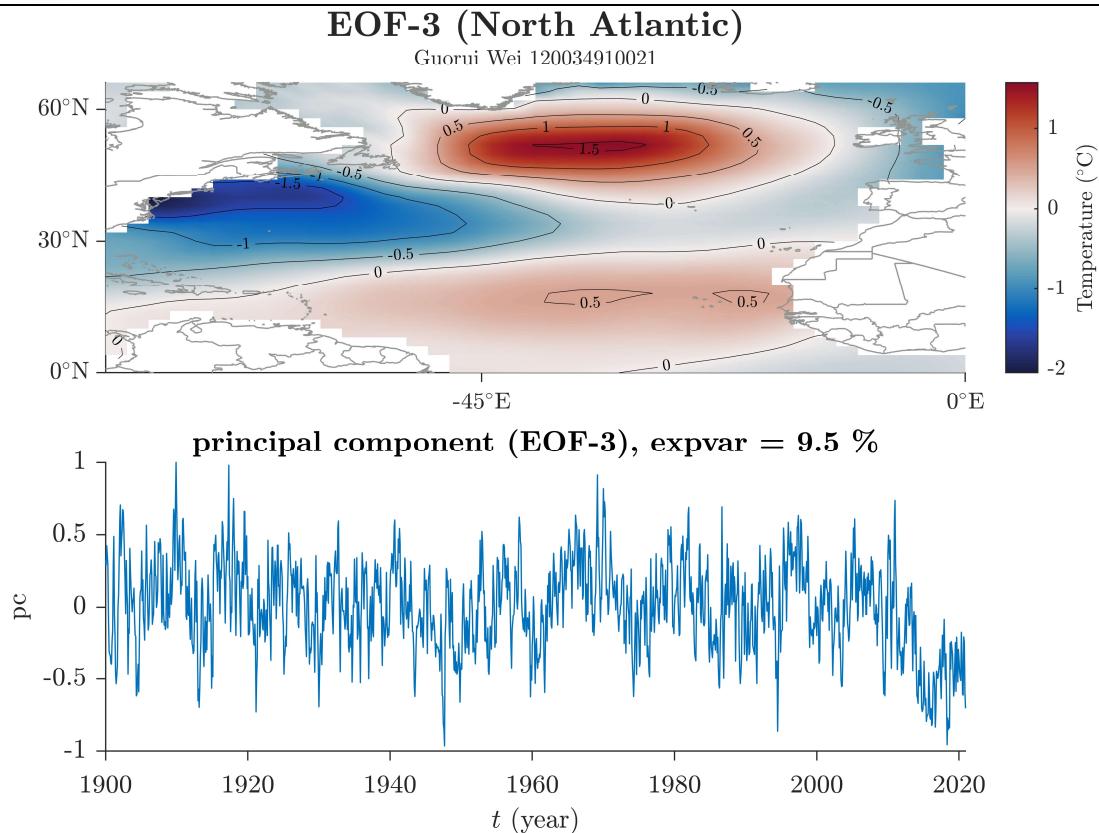
**EOF-2 (North Atlantic)**

Guorui Wei 120034910021



principal component (EOF-2), expvar = 12.5 %





**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/](https://grwei.github.io/SJTU_2021-2022-2_MS8401/).

### A.1 主程序

```
1 %% hw2.m
2 % Description: MATLAB code for Homework 2 (MS8401, 2022 Spring)
3 % Author: Guorui Wei (危国锐) (313017602@qq.com; weiguorui@sjtu.edu.cn)
4 % Student ID: 120034910021
5 % Created: 2022-05-12
6 % Last modified: 2022-05-14
7 % References: [1] [CDT::eof
documentation](https://www.chadagreene.com/CDT/eof_documentation.html)
8 % [2] [Pacific Decadal Oscillation
(PDO)](https://psl.noaa.gov/pdo/)
9 % [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.
10 % [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.
11 % [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.
12 % [6] [ENSO] [El Niño Southern Oscillation
(ENSO)](https://psl.noaa.gov/enso/)
13 % Toolbox: [T1] [M_Map: A mapping package for
Matlab](https://www.eoas.ubc.ca/~rich/map.html)
14 % [T2] [Climate Data Tools for
Matlab](https://github.com/chadagreene/CDT)
15 % Data: [D1] [NOAA Extended Reconstructed Sea Surface Temperature (SST)
V5](https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html)
16
17 %% Initialize project
18
19 clc; clear; close all
```



```
20 init_env();
21
22 %% Read data
23
24 nc_path = "..\data\sst.mnmean.nc";
25 nc_info = ncinfo(nc_path);
26 sst = double(ncread(nc_path,'sst')); % [deg C] sst(lon,lat,time_month)
27 sst(sst == ncreadatt(nc_path,'/sst','missing_value')) = NaN; % Monthly Means
of Sea Surface Temperature (SST)
28 lon = double(ncread(nc_path,'lon')); % [deg E]
29 lat = double(ncread(nc_path,'lat')); % [deg N]
30 time_month = (datetime(1854,1,15) + calmonths(0:size(sst,3)-1)).';
31
32 %% pre-processing
33
34 sst_dtr = detrend3(sst,'omitnan'); % Remove the global warming signal
(detrended)
35 sst_var = deseason(sst_dtr,time_month); % Remove seasonal cycles (detrended
and seasonal cycle removed -> variability)
36
37 %% 1. global
38
39 TF_lon_range = lon > -Inf & lon < +Inf;
40 TF_lat_range = lat > -Inf & lat < +Inf;
41 TF_time_range = datetime(1900,1,1) < time_month & time_month <
datetime(2020,12,30);
42
43 %%% eof
44
45 n_eof = 3; % only calculates the first n modes of variability
46 [eof_maps,pc,expvar] =
eof(sst_var(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
47 % Optional scaling of Principal Components and EOF maps
48 for k = 1:size(pc,1)
49     % Find the the maximum value in the time series of each principal
component:
50     maxval = max(abs(pc(k,:)));
51     % Divide the time series by its maximum value:
52     pc(k,:) = pc(k,:)/maxval;
53     % Multiply the corresponding EOF map:
54     eof_maps(:,:,:k) = eof_maps(:,:,:k)*maxval;
55 end
56
57 %%% Create figure.
```



```
58 for num_EOF = 1:3
59     EOF_fig(num_EOF,"Global",lon(TF_lon_range),lat(TF_lat_range),time_month(T
      F_time_range),eof_maps,pc,expvar,1)
60 end
61
62 %% 2. the Pacific Ocean (85°33'S ~ 65°44'N, 99°10'E -> 180°+78°08'E)
63
64 TF_lon_range = lon > 134 & lon < 276;
65 TF_lat_range = lat > -67 & lat < 67;
66 TF_time_range = datetime(1900,1,1) < time_month & time_month <
      datetime(2020,12,30);
67
68 %% eof
69
70 n_eof = 3; % only calculates the first n modes of variability
71 [eof_maps,pc,expvar] =
    eof(sst_var(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
72 % Optional scaling of Principal Components and EOF maps
73 for k = 1:size(pc,1)
    % Find the the maximum value in the time series of each principal
    component:
74     maxval = max(abs(pc(k,:)));
75     % Divide the time series by its maximum value:
76     pc(k,:) = pc(k,:)/maxval;
77     % Multiply the corresponding EOF map:
78     eof_maps(:,:,:k) = eof_maps(:,:,:k)*maxval;
80 end
81
82 %% Create figure.
83 for num_EOF = 1:3
84     EOF_fig(num_EOF,"Pacific",lon(TF_lon_range),lat(TF_lat_range),time_month(
      TF_time_range),eof_maps,pc,expvar,1)
85 end
86
87 %% 3. the Atlantic Ocean
88
89 %% prepare
90
91 % convert longitude from 0~360 deg E to -180~180 deg E
92 n_lon_W = sum(lon >= 180);
93 lon_0 = circshift(lon,n_lon_W);
94 lon_0(lon_0 >= 180) = lon_0(lon_0 >= 180) - 360;
95 sst_var_0 = circshift(sst_var,n_lon_W,1);
96 %
```



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

100
101 %% eof
102
103 n_eof = 3; % only calculates the first n modes of variability
104 [eof_maps,pc,expvar] =
eof(sst_var_0(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
105 % Optional scaling of Principal Components and EOF maps
106 for k = 1:size(pc,1)
107     % Find the the maximum value in the time series of each principal
component:
108     maxval = max(abs(pc(k,:)));
109     % Divide the time series by its maximum value:
110     pc(k,:) = pc(k,:)/maxval;
111     % Multiply the corresponding EOF map:
112     eof_maps(:,:,k) = eof_maps(:,:,k)*maxval;
113 end
114
115 %% Create figure.
116 for num_EOF = 1:3
117     EOF_fig(num_EOF,"Atlantic",lon_0(TF_lon_range),lat(TF_lat_range),time_mon
th(TF_time_range),eof_maps,pc,expvar,1)
118 end
119
120 %% 4. the North Atlantic Ocean
121
122 %% prepare
123
124 % convert longitude from 0~360 deg E to -180~180 deg E
125 n_lon_W = sum(lon >= 180);
126 lon_0 = circshift(lon,n_lon_W);
127 lon_0(lon_0 >= 180) = lon_0(lon_0 >= 180) - 360;
128 sst_var_0 = circshift(sst_var,n_lon_W,1);
129 %
130 TF_lon_range = (lon_0 > -81 & lon_0 < 1);
131 TF_lat_range = lat > -1 & lat < 67;
132 TF_time_range = datetime(1900,1,1) < time_month & time_month <
datetime(2020,12,30);

133
134 %% eof
135
```



```
136 n_eof = 3; % only calculates the first n modes of variability
137 [eof_maps,pc,expvar] =
138     eof(sst_var_0(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
139 % Optional scaling of Principal Components and EOF maps
140 for k = 1:size(pc,1)
141     % Find the the maximum value in the time series of each principal
142     % component:
143     maxval = max(abs(pc(k,:)));
144     % Divide the time series by its maximum value:
145     pc(k,:) = pc(k,:)/maxval;
146     % Multiply the corresponding EOF map:
147     eof_maps(:,:,k) = eof_maps(:,:,k)*maxval;
148 end
149 %% Create figure.
150 for num_EOF = 1:3
151     EOF_fig(num_EOF,"North
152         Atlantic",lon_0(TF_lon_range),lat(TF_lat_range),time_month(TF_time_range),eo
153         f_maps,pc,expvar,1)
154 end
155 %% 5. the North Pacific Ocean (20°N ~ 65°44'N, 99°10'E -> 180°+78°08'E)
156 TF_lon_range = lon > 134 & lon < 276;
157 TF_lat_range = lat > 20 & lat < 67;
158 TF_time_range = datetime(1900,1,1) < time_month & time_month <
159     datetime(2020,12,30);
160 %% eof
161 n_eof = 3; % only calculates the first n modes of variability
162 [eof_maps,pc,expvar] =
163     eof(sst_var(TF_lon_range,TF_lat_range,TF_time_range),n_eof);
164 % Optional scaling of Principal Components and EOF maps
165 for k = 1:size(pc,1)
166     % Find the the maximum value in the time series of each principal
167     % component:
168     maxval = max(abs(pc(k,:)));
169     % Divide the time series by its maximum value:
170     pc(k,:) = pc(k,:)/maxval;
171     % Multiply the corresponding EOF map:
172     eof_maps(:,:,k) = eof_maps(:,:,k)*maxval;
```



```
173 %% Create figure.
174 for num_EOF = 1:3
175     EOF_fig(num_EOF,"North
176         Pacific",lon(TF_lon_range),lat(TF_lat_range),time_month(TF_time_range),eof_m
177         aps,pc,expvar,1)
178 end
179
180 %% local functions
181
182 function [] = init_env()
183 % Initialize environment
184 %
185 % set up project directory
186 if ~isfolder("../doc/fig/hw2")
187     mkdir ..../doc/fig/hw2
188 end
189 % configure searching path
190 mfile_fullpath = mfilename('fullpath'); % the full path and name of the
191 file in which the call occurs, not including the filename extension.
192 mfile_fullpath_without_fname = mfile_fullpath(1:end-
193 strlength(mfilename));
194 addpath(genpath(mfile_fullpath_without_fname + "../data"), ...
195             genpath(mfile_fullpath_without_fname + "../inc")); % adds the
196 specified folders to the top of the search path for the current MATLAB®
197 session.
198
199 return;
200 end
201
202 %% Create EOF figure.
203
204 function [] =
205 EOF_fig(num_EOF,title_str,lon,lat,time_month,eof_maps,pc,expvar,TF_export)
206     arguments
207         num_EOF
208         title_str
209         lon
210         lat
211         time_month
212         eof_maps
213         pc
214         expvar
```



```
210     TF_export
211 end
212
213 figure('Name',sprintf("EOF-%d (%s)",num_EOF,title_str))
214 t_TCL = tiledlayout(2,1,"TileSpacing","tight","Padding","tight");
215
216 %% EOF
217
218 t_axes = nexttile(t_TCL,1);
219 pcolor(t_axes,lon,lat,eof_maps(:,:,num_EOF).');
220 shading(t_axes,"interp");
221 hold on
222 [C,h] =
223 contour(t_axes,lon,lat,eof_maps(:,:,num_EOF).','LineWidth',0.2,'LineColor',
224 'black','ShowText','off');
225 borders('countries','center',180,'color',rgb('gray'))
226 hold off
227 clabel(C,h,"Interpreter",'latex','FontSize',6)
228 % BEGIN patch
229 cl = caxis;
230 if (cl(1) >= 0)
231     cl(1) = -0.1;
232     caxis(t_axes,cl)
233 end
234 % END patch
235 colormap(t_axes,cmocean('balance','pivot',0))
236 cb = colorbar(t_axes,"eastoutside","TickLabelInterpreter","latex");
237 set(cb.Label,"String","Temperature
($^{\circ}\text{C}$)","Interpreter","latex")
238 set(t_axes,"TickLabelInterpreter","latex","TickDir","out",'YDir','normal'
,'Box','off');
239 xticks(t_axes,-180:45:360)
240 xtickformat(t_axes,'%g$^{\circ}\text{C}$')
241 yticks(-90:30:90)
242 ytickformat(t_axes,'%g$^{\circ}\text{C}$')
243 % xlabel(t_axes,"longitude (deg E)","Interpreter",'latex')
244 % ylabel(t_axes,"latitude (deg N)","Interpreter",'latex')
245 %
246 [~,t_title_s] = title(t_TCL,sprintf("\bf EOF-%d
(%s)",num_EOF,title_str),"Guorui Wei 120034910021",'Interpreter','latex');
247 set(t_title_s,'FontSize',8);
248 %% pc
```



```
249     t_axes = nexttile(t_TCL,2);
250     plot(t_axes,time_month,pc(num_EOF,:),'-',"DisplayName",'pc');
251     set(t_axes,"YDir",'normal',"TickLabelInterpreter",'latex',"FontSize",10,'
252     Box','off','TickDir','out','XLimMethod','tight');
253     %
254     legend(t_axes,"Location",'best','Interpreter','latex',"Box","off",'FontSize'
255     ,10);
256     xticks(t_axes,datetime(1900,1,15) + calyears(0:20:120))
257     xtickformat(t_axes,'yyyy')
258     xlabel(t_axes,"$t\$ (year)",FontSize=10,Interpreter="latex");
259     ylabel(t_axes,"pc","FontSize",10,"Interpreter","latex");
260     title(t_axes,sprintf("\bf principal component (EOF-%d), expvar = %.1f
261     \\\%",num_EOF,expvar(num_EOF)),"Interpreter","latex");
262
263     %% export
264
265     if (TF_export)
266         exportgraphics(t_TCL,sprintf(..\doc\fig\hw2\hw2_EOF-%d_%s.emf",n
267         um_EOF,title_str),'Resolution',800,'ContentType','auto','BackgroundColor','n
268         one','Colorspace','rgb')
269         exportgraphics(t_TCL,sprintf(..\doc\fig\hw2\hw2_EOF-%d_%s.png",n
270         um_EOF,title_str),'Resolution',800,'ContentType','auto','BackgroundColor','n
271         one','Colorspace','rgb')
272     end
273
274     return;
275 end
276
277 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/](https://grwei.github.io/SJTU_2021-2022-2_MS8401/).