Climate and climate variability

ATM2106

Climate variability

- Climate is frequently defined as the average weather

- To obtain climate conditions, we need to average over long enough period to smooth out the variability of synoptic systems.

- The interaction between components of the earth system shapes the current climate.

- Climate keeps changing!

Climate variability

- Ice ages
  - 5°C cooler in the middle latitudes than now.
  - Three time more in the volume of ice and ice surface
    - Returns roughly every 100,000 years for the last 800,000 years
- Earth has been mostly in a glacial climate and only 10% of the time in interglacial conditions similar to those of today.

Climate variability

- During the last glacial period (15,000 ~ 60,000 years ago), dramatic discharge of ice have occurred every 10,000 years.
- During the same period, abrupt warming events occurred every 1,500 years. → warming of roughly 10°C within 20~50 years lasted a few hundreds of years.

Climate variability

- Little ice age : Fluctuations in regional scale in the order of 1~2°C. ➞ Europe in 17th century
- Long time ago (100 million years ago), scientists speculate that Earth was totally frozen over in a “snowball”.
- The point is that Earth’s climate keeps changing.

Mechanisms operating at different timescales

Timescale

Processes	days			years		thousands of years			millions of years		
	h/d	w	m	y	10 y	10^2y	10^3y	10^4y	10^5y	10^6y	10^9y
Weather	■	■									
Land surface	■	■	■								
Ocean mixed layer	■	■	■								
Sea ice		■	■	■							
Volcanos		■	■	■							
Vegetation	■	■	■	■	■	■	■	■	■	■	
Thermocline				■	■	■					
Mountain glaciers					■	■					
Deep ocean						■	■	■			
Ice sheets						■	■	■	■		
Orbital forcing								■	■		
Tectonics										■	■
Weathering									■	■	■
Solar "constant"				■	■	■	■	■	■	■	■

The ocean as a buffer of temperature change

- Ocean's heat capacity enable the ocean to store lots of heat.

$$\gamma_O = \rho_{ref} c_w h$$

$$\gamma_A = \rho_s c_p H$$

- The ocean is 1000 times more dense than air.
- The ocean's specific heat is about 4 times that of air
- The ocean covers about 70% of the Earth's surface

$$\frac{\gamma_O}{\gamma_A} \sim 40 \; with \; h = 100 \; m$$

Typical depth of the mixed layer

Changes of sea surface temperature

$$\gamma_O \frac{dT}{dt} = -\lambda T + Q_{net}$$

λ: 15 W m^{-2} K^{-1}

- With no Q_{net}, the solution to the above equation is

$$T = T_{init} \exp\left(\frac{-\lambda}{\gamma_O} t\right)$$

Changes of sea surface temperature

$$T = T_{init} \exp\left(\frac{-\lambda}{\gamma_O} t\right)$$

- E-folding time scale : γ_O / λ $\longrightarrow$ ~ 300 days with h = 100 m

~ 40 years with h = 5 km

TABLE 9.3. Physical properties of liquid water.

Specific heat	c_w	4.18×10^3	J kg^{-1} K^{-1}
Latent heat of fusion	L_f	3.33×10^5	J kg^{-1}
Latent heat of evaporation	L_e	2.25×10^6	J kg^{-1}
Density of fresh water	ρ_{fresh}	0.999×10^3	kg m^{-3}
Viscosity	μ_{water}	10^{-3}	kg m^{-1} s^{-1}
Kinematic viscosity	$\nu = \frac{\mu_{water}}{\rho}$	10^{-6}	m^2 s^{-1}
Thermal diffusivity	k	1.4×10^{-7}	m^2 s^{-1}

Time scale for adjustment of the deep ocean is more like 1000 years.

Climate variability v.s. climate change

- "**Climate variability**" : natural variability
  - Natural "modes" of variability

- "**Climate change**" : anthropogenic forcing
  - Due to man-made changes in greenhouse gases, land surfaces, species distributions, etc.

Elements of the climate system

- Sun
- Atmosphere
- Ocean
- Cryosphere (ice, snow)
- Land surface
- Biological and chemical cycles

Climate forcing

- **External forcing**
  - Earth orbit parameters (solar distance factors)
  - Solar luminosity
  - Moon orbit
  - Volcanoes and other geothermal sources
  - Greenhouse gases…

Climate forcing

- **Internal forcing** : forcing between each element of the climate system

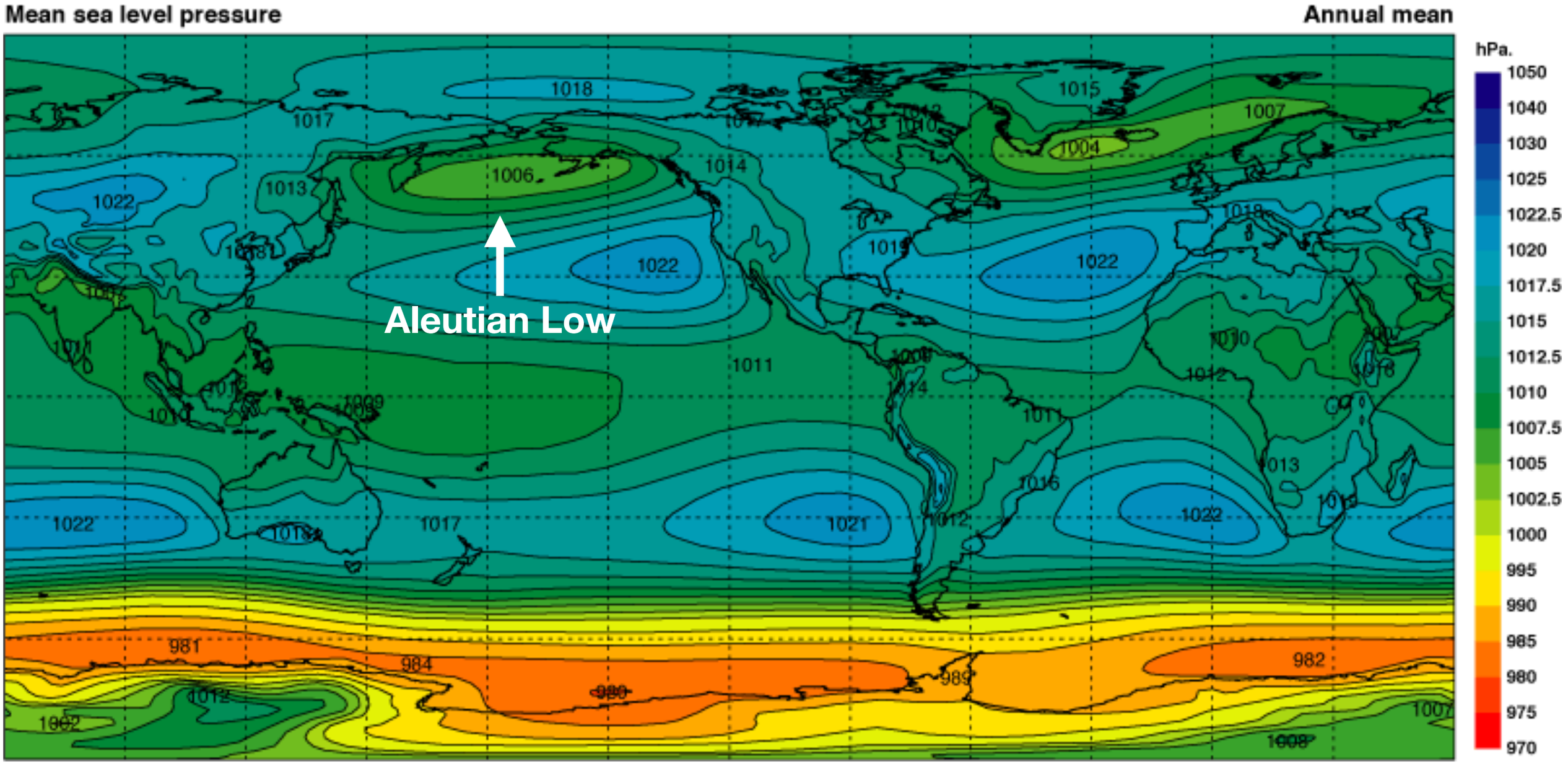
  - Wind forcing to the ocean

  - Ice extent forcing to the atmosphere or the ocean

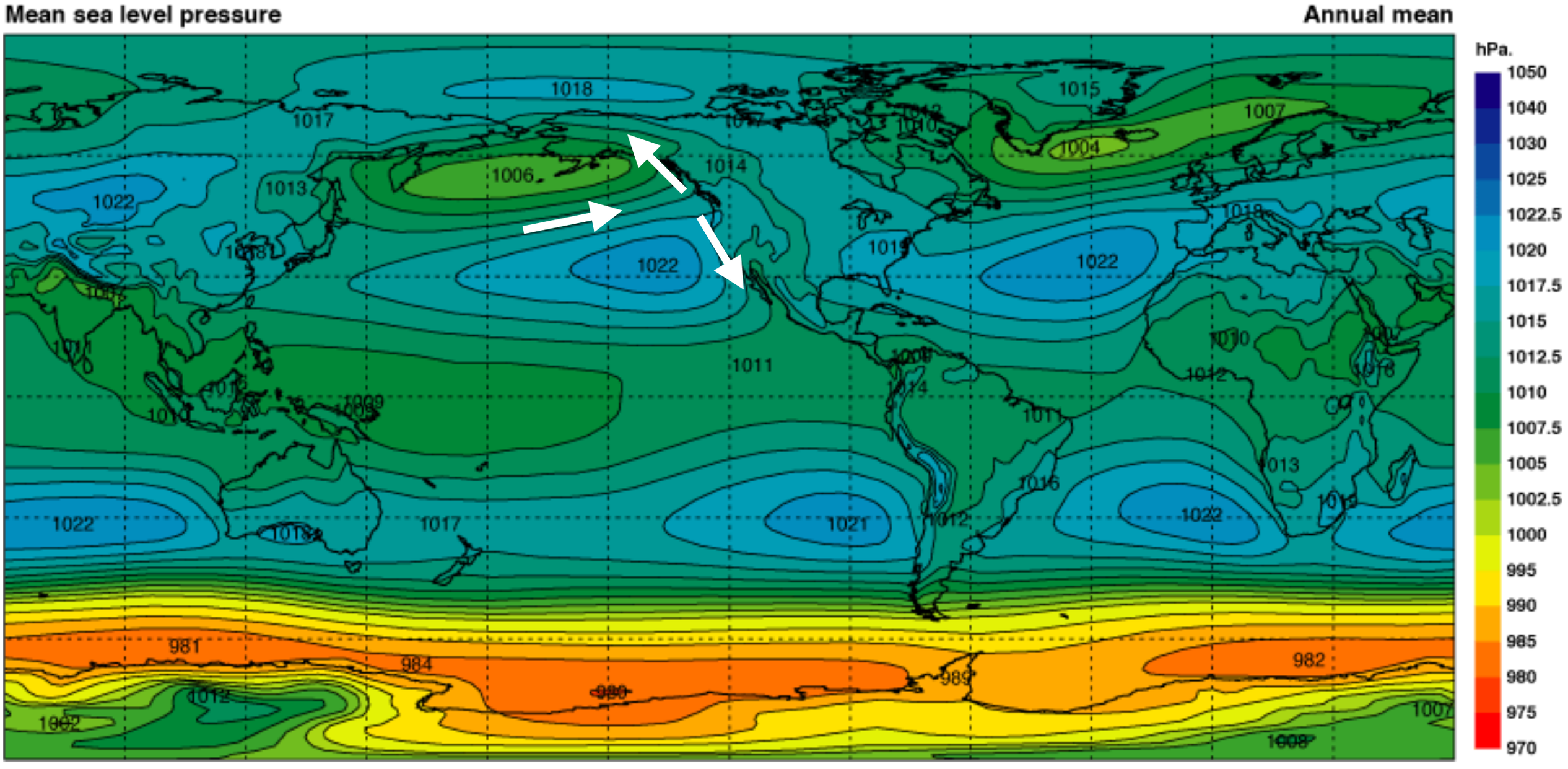
Natural climate modes with interannual to millennial time scales

- **Interannual : 1 year to 10 years**
  - ENSO
- **Decadal : 10 years to multiple decades**
  - **Pacific Decadal Oscillation**
  - North Atlantic Oscillation
  - Southern Annular Mode
- Centennial : multiple hundreds years

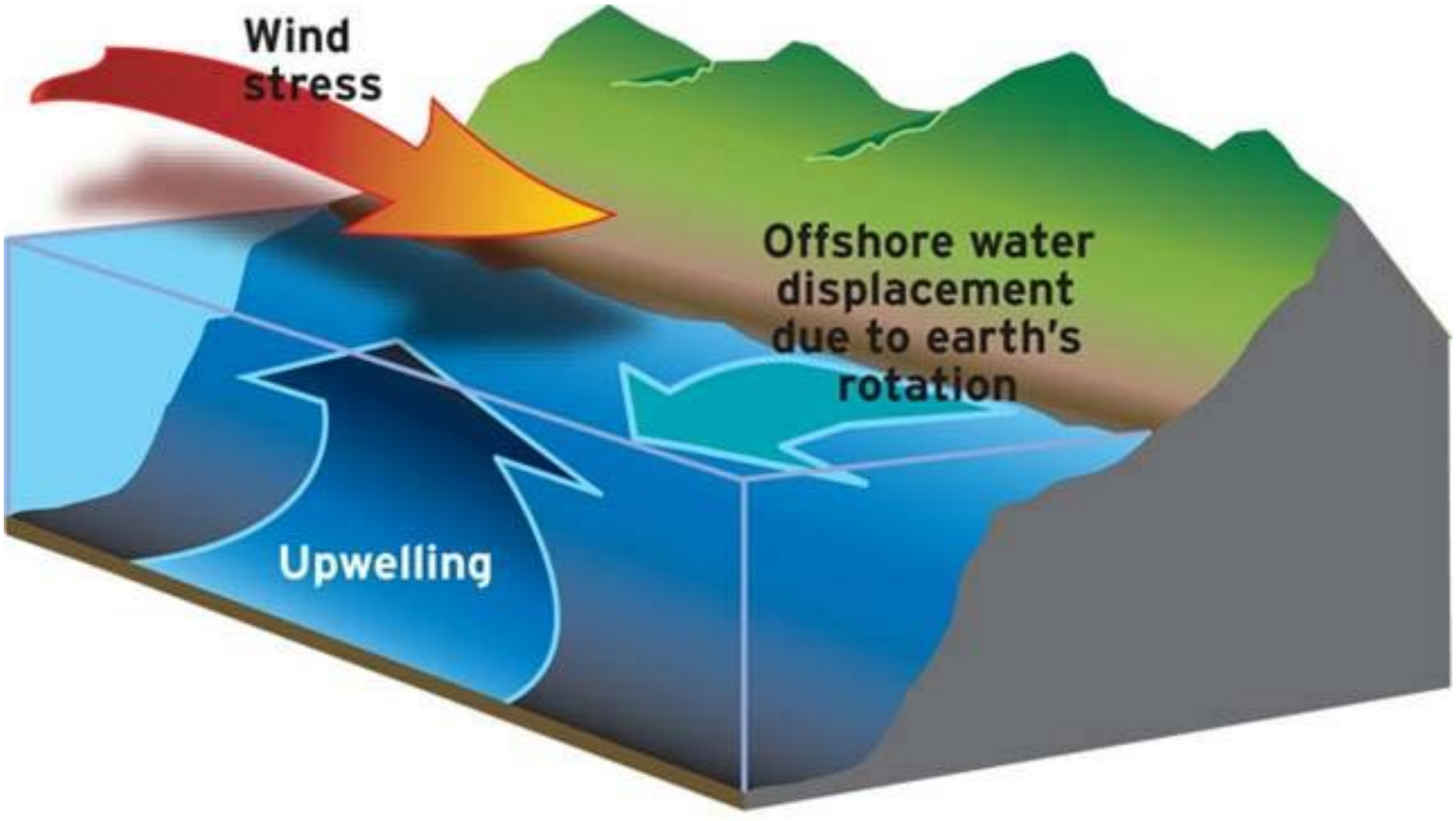
Mean sea level pressure



Mean sea level pressure



Coastal upwelling



From https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/db-coastal-upwelling-index.cfm

Coastal upwelling

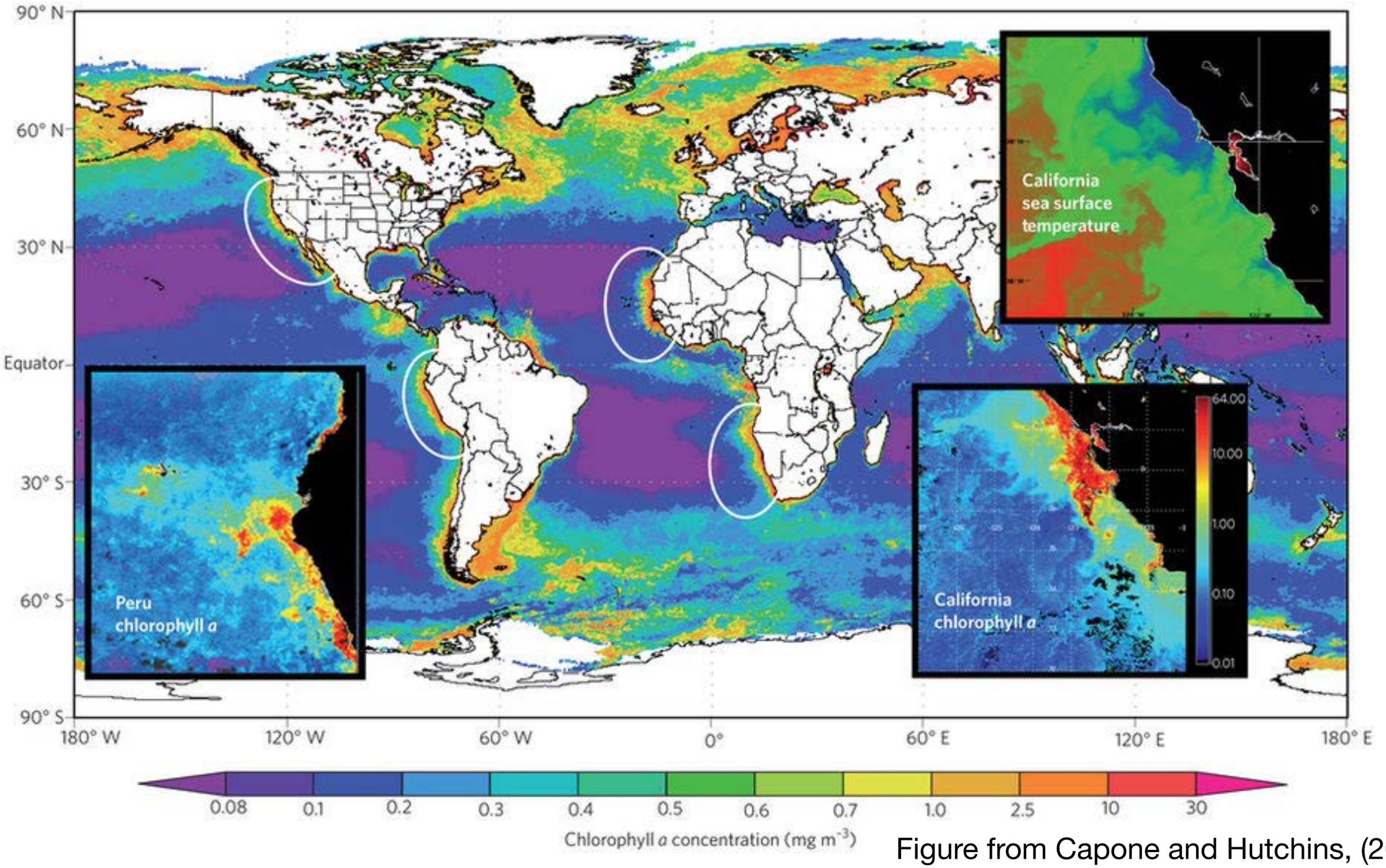
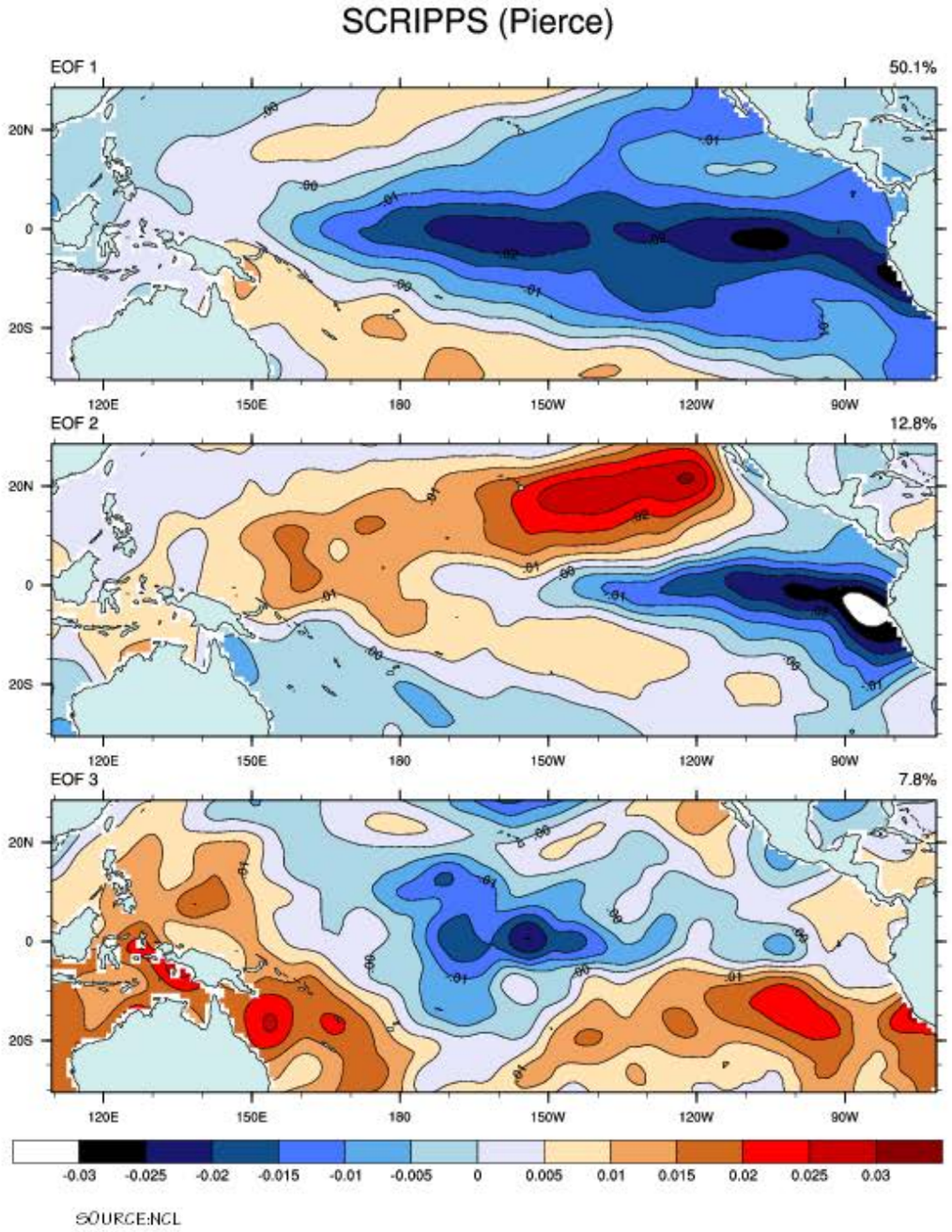
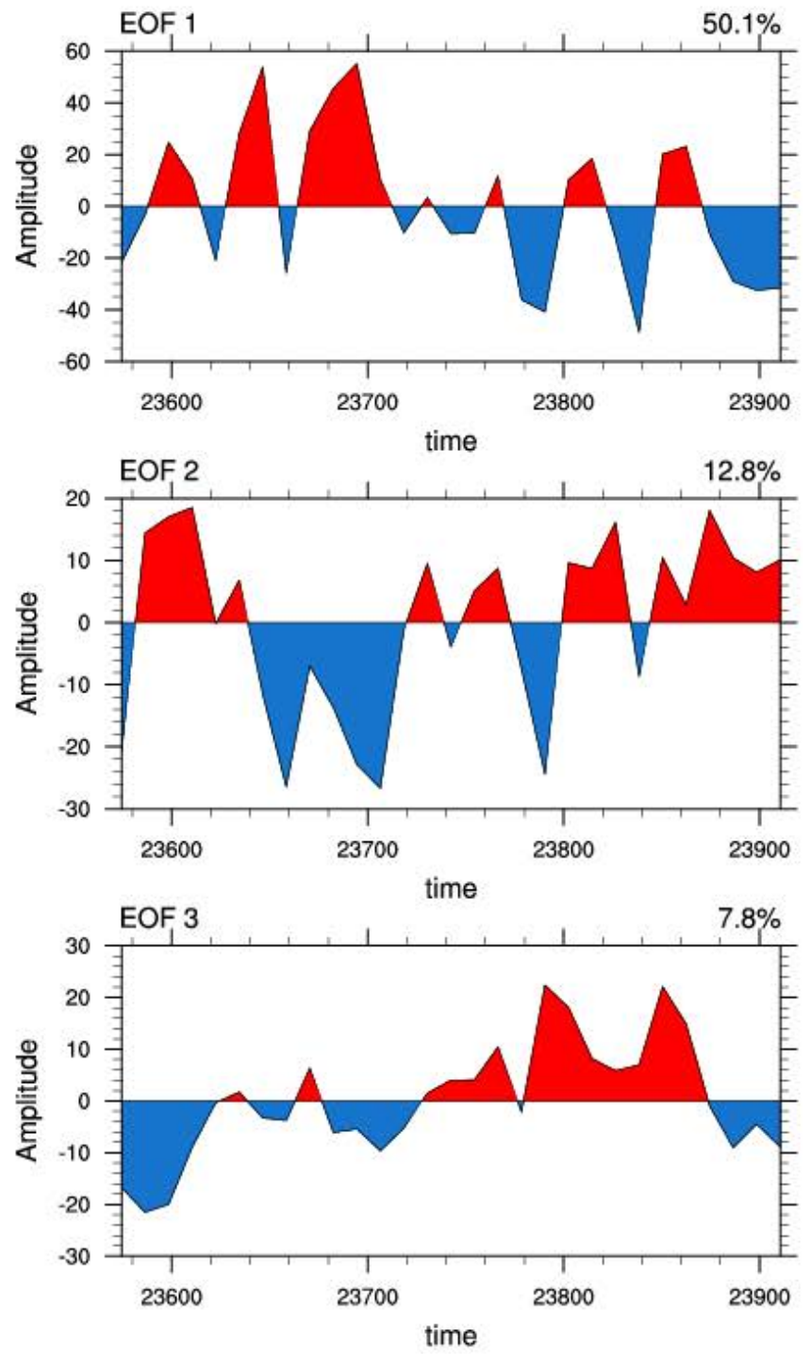


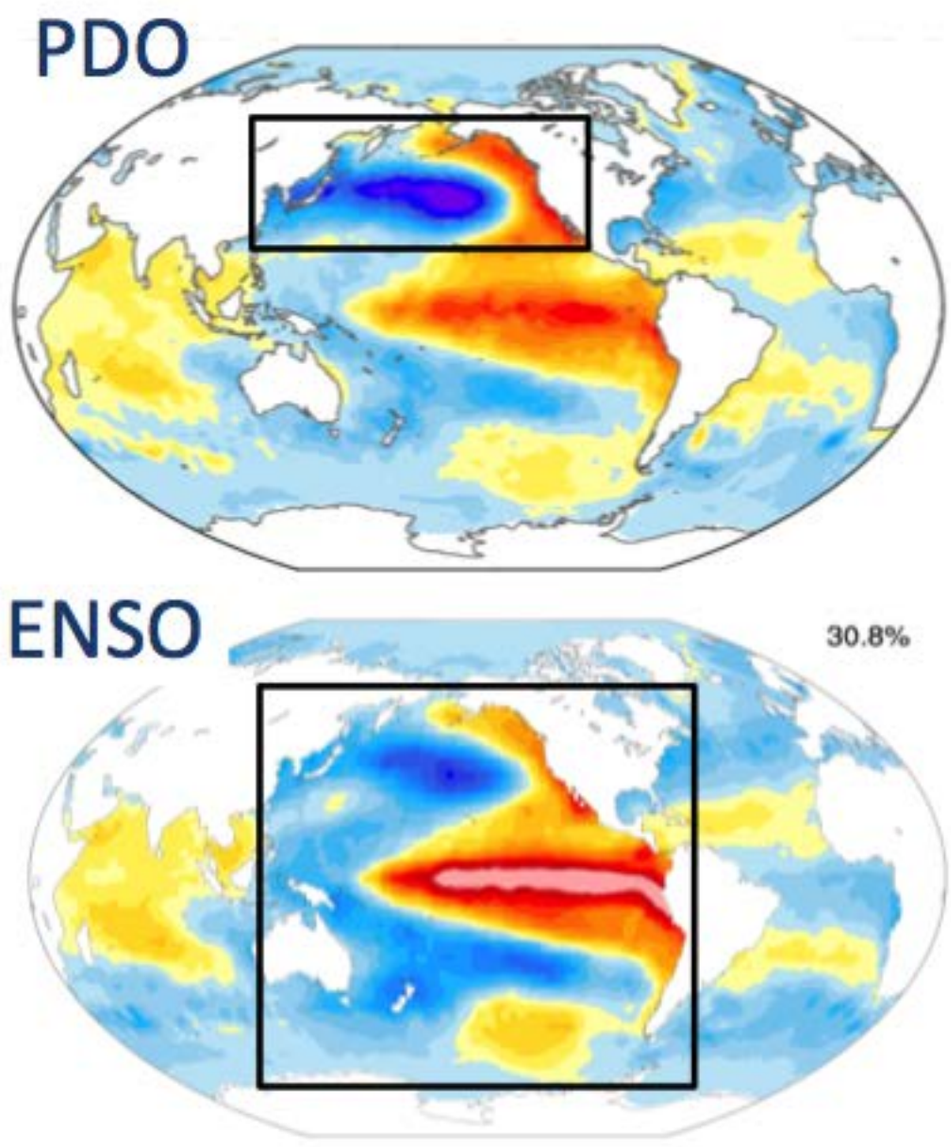
Figure from Capone and Hutchins, (2013)

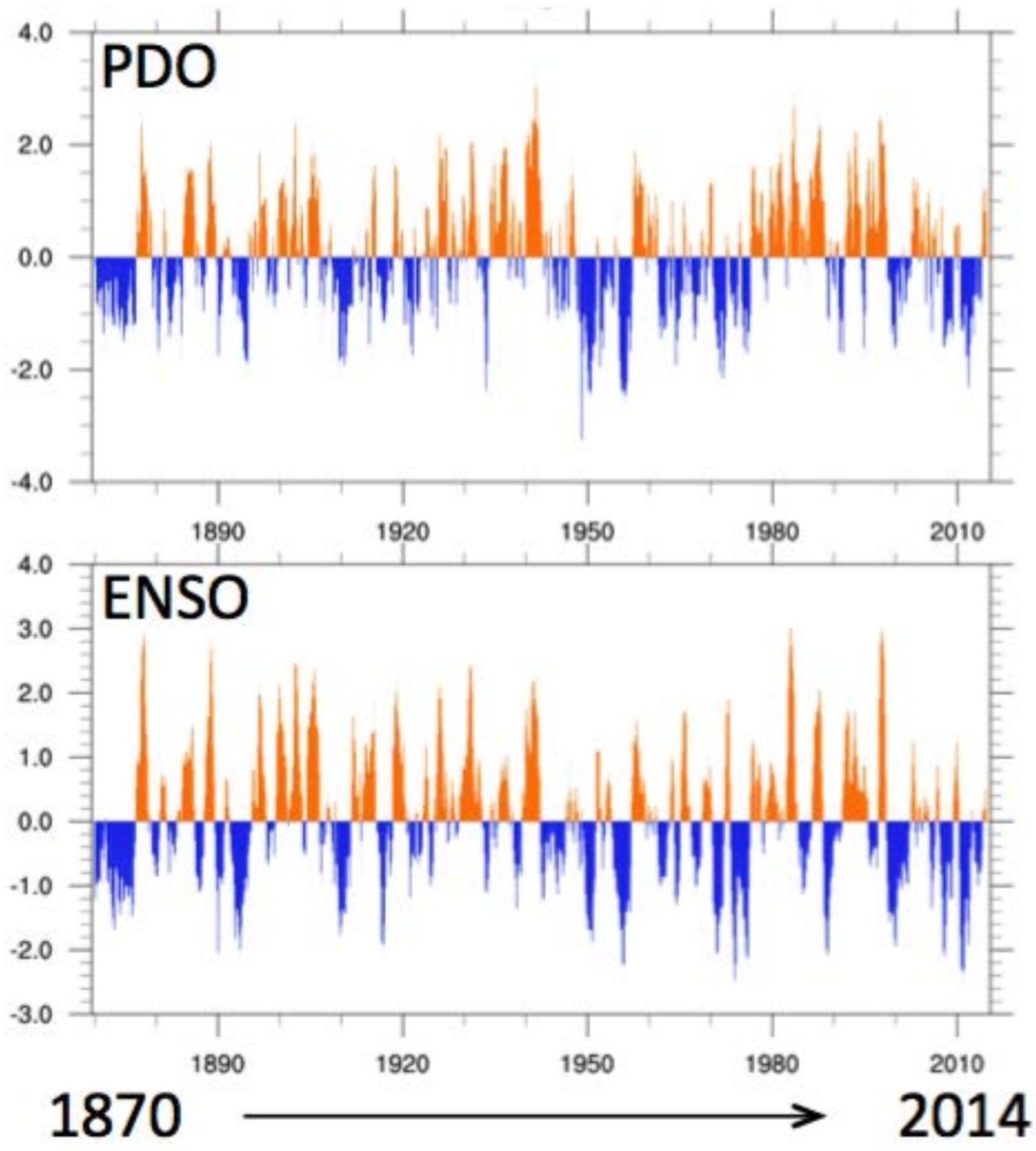
Empirical orthogonal function (EOF)





EOF using sea surface temperature anomaly in the N. Pacific





Teleconnection