ATM 241, Spring 2020
Lecture 11a
Climate Oscillations

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Marshall & Plumb

Ch. 12.1

In this section…

Definitions

- Teleconnection
- Arctic Oscillation
- North Atlantic Oscillation
- Atlantic Multidecadal Oscillation
- Pacific Decadal Oscillation
- Indian Ocean Dipole

Questions

- What are the typical timescales of the Earth system?
- What are the primary teleconnection regions of the world?
- What regional and global patterns are expressed by these teleconnections?

Timescales of the Earth System

Climate

How do we define climate?

- **Climate** is the pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods.

- Climate can be contrasted to **weather**, which is the conditions of these variables presently or over short periods.

- **Climate also describes the variability of weather events**, e.g. the probability of a major rainfall event occurring in July in San Francisco, or variations in temperature that typically occur in January in Chicago.

The Earth System

What are the components of the Earth system?

- **Atmosphere**
- **Hydrosphere (Oceans and Water)**
- **Land and Land Surface**
- **Cryophere (Sea and Land Ice)**
- **Biosphere**

- When talking about the **coupled human-Earth system** it is also typical to include **humans (the anthropogenic component)**

Timescales of the Earth System

How do the ocean and atmosphere act in response to temperature change?

- The ocean has a much greater capacity to store heat than the atmosphere, and so acts to "damp" out climatological changes.
- That is, if the atmosphere becomes too hot excess energy will tend to be stored in the ocean.
- If the atmosphere becomes too cool, the ocean will release energy.

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

Thermal adjustment of the ocean

Net air-sea flux

Thermal balance

Timescales of the Earth System

Heat capacity of a "slab" of ocean is $\gamma_O = \rho_{\mathrm{ref}} c_w h$

ρ_{ref}	Reference density (1000 kg/m^3)
c_w	Heat capacity of water (4.18 x 10^3 J/kg/K)
h	Layer depth (100 m for mixed layer, 5km for whole depth)

Heat capacity of a "slab" of atmosphere is $\gamma_A = \langle \rho \rangle c_p H$

$\langle \rho \rangle$	Mean layer density (1.0 kg/m^3)
c_p	Heat capacity at constant pressure (1.007 x 10^3 J/kg/K)
H	Vertical scale height (8km)

Timescales of the Earth System

If only considering the oceanic mixed layer

$$\gamma_O / \gamma_A \approx 50$$

If considering the whole depth of the ocean

$$\gamma_O / \gamma_A \approx 2500$$

Adjustment rate of the ocean is $\lambda \approx 15 \text{ W m}^{-2} \text{ K}^{-1}$

Adjustment timescale (e-folding time) is $\gamma_O / \lambda \approx 322 \text{ days}$

Adjustment for whole ocean is ≈ 1000 yr due to slow circulation of abyss.

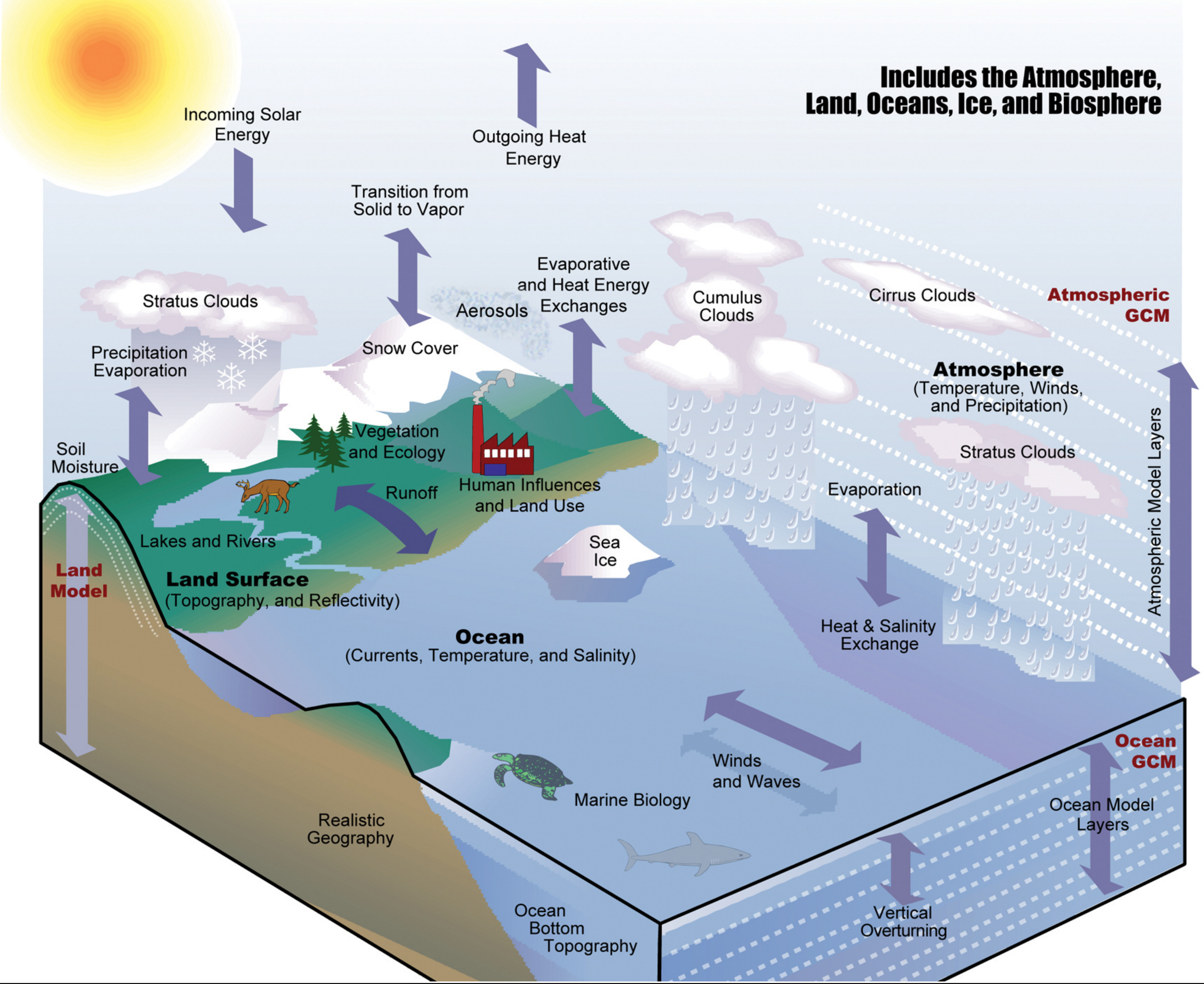
Timescales of the Earth System

Question: We have seen that the ocean is an excellent buffer for energy. How is this calculation different for the land surface?

$$\gamma_L = \rho_{\rm rock}\ c_{\rm rock}\ h_{\rm rock}$$

Processes and Features of the Earth System

…as represented in global Earth system models



Timescales of the Earth System

Atmosphere

Phenomenon	Timescale
Overall response time to heating	Months
Typical spin-down time of wind in absence of forcing	Days
Frontal system lifetime (1000s of kms)	Days
Convective cloud lifetime (100m to km horizontal)	Hours
Time scale for upper level wind	Days

Ocean

Response time of upper ocean (above thermocline) to heating	Months to Years
Response time of deep ocean to atmospheric changes	Decades to Millennia
Ocean eddy lifetime (10km to 100km)	Month
Ocean mixing in the surface layer	Hours to Days
Time for typical ocean current (cm/s) to cross ocean (1000s km)	Decade

Timescales of the Earth System

Cryosphere

Phenomenon	Timescale
Snow cover	Months
Sea ice (extent and thickness variations)	Months to Years
Glaciers	Decades to Centuries
Ice caps	Centuries to Millennia

Land Surface

Response time to heating	Hours
Response time of vegetation to oppose excess evaporation	Hours
Soil moisture response time	Days to Months

Biosphere

Ocean plankton response to nutrient changes	Weeks
Recovery time from deforestation	Years to Decades

Climate Oscillations

Teleconnections

Definition: A **teleconnection** is a relationship between climate anomalies at large distances (typically thousands of kilometers).

- An understanding of teleconnections is important to understanding connections in the climate system.
- Many teleconnections between the tropics and extratropics are understood by the propagation of linear, planetary waves upon a 3D seasonally-varying background state (outside the scope of this class).

Teleconnections

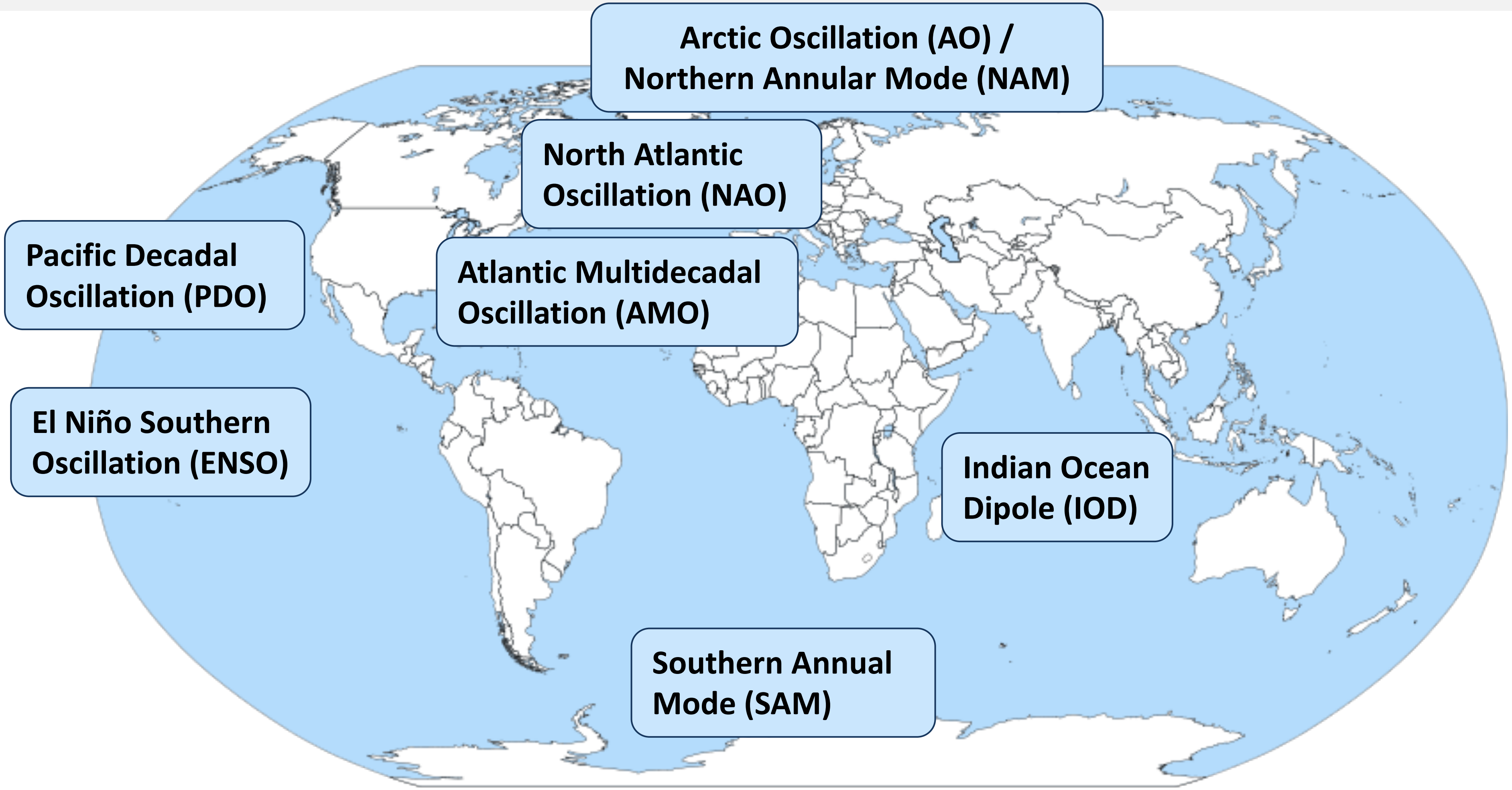


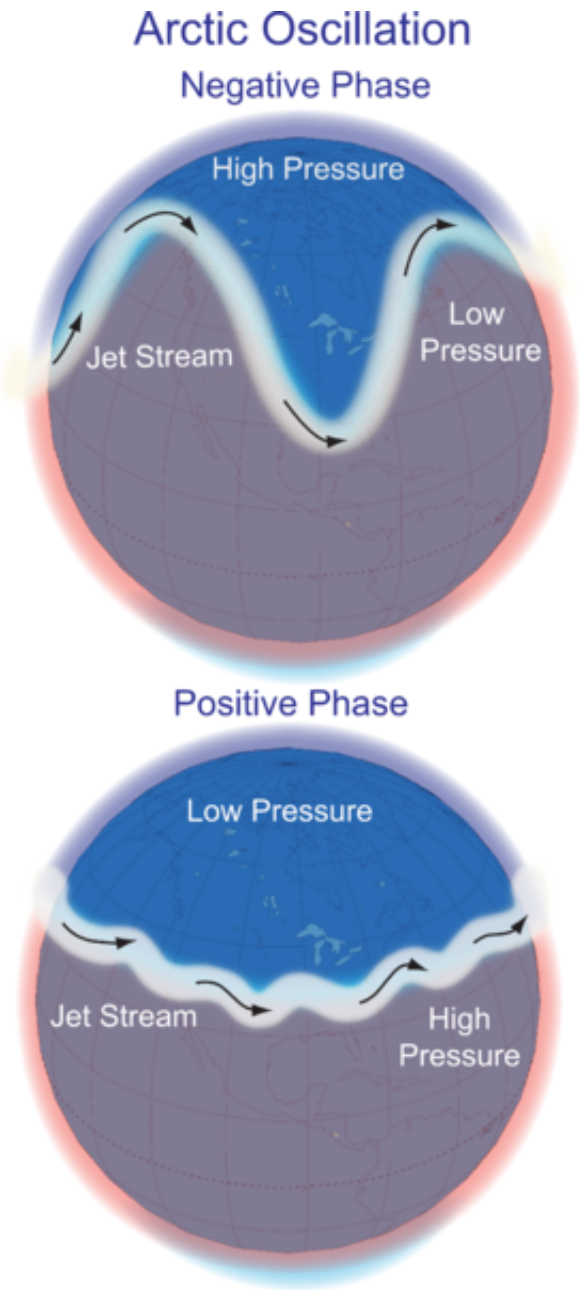
Figure: Major teleconnection centers.

Arctic Oscillation (AO)

Definition: The **Arctic Oscillation** is an atmospheric circulation pattern over mid-to-high latitudes of the Northern Hemisphere which varies over time with no particular periodicity. It is associated with oscillation in the location of the mid-latitude jet stream.

Figure: Behavior of the jet stream during the Arctic Oscillation (AO) positive and negative phase. (Source: Wikipedia)

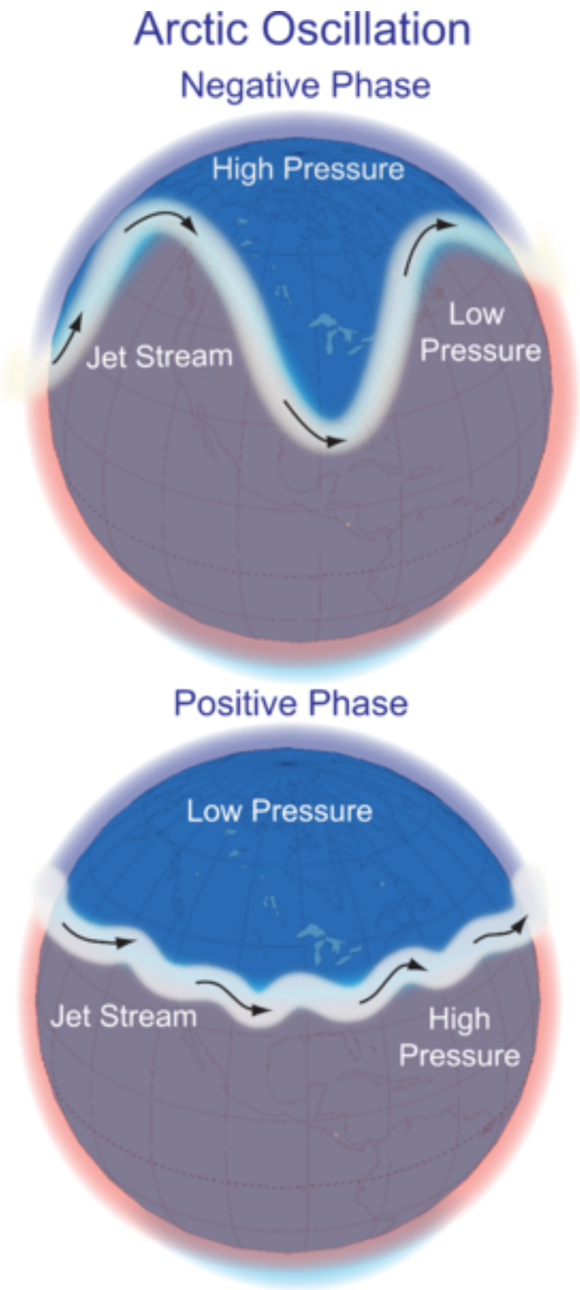
The AO regulates the **degree to which Arctic air penetrates into middle latitudes**. It is generally one of the **more predictable oscillations** (over short time scales).



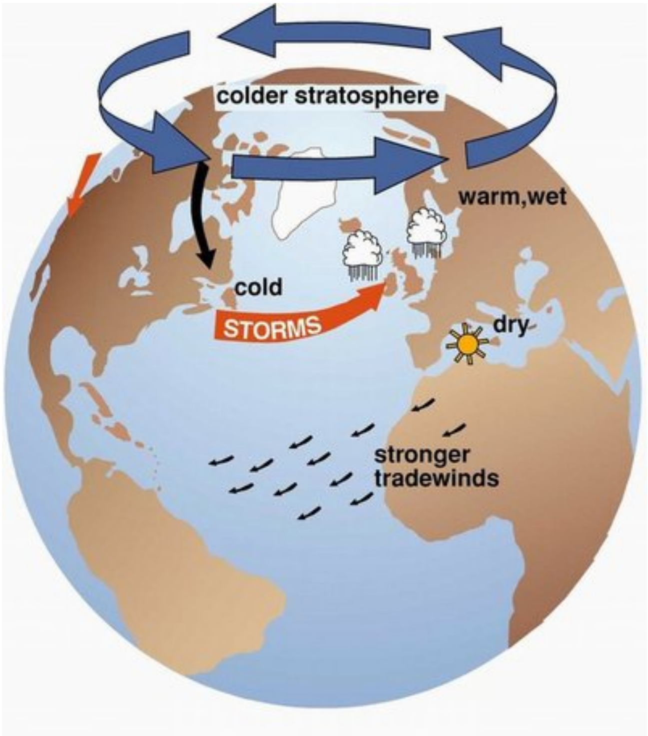
Arctic Oscillation (AO)

The **AO negative phase is** associated with transport of frigid winter air far south. When the AO reached a monthly mean value of -4.266 (February 2010), the mid-Atlantic region of the US received three separate historic snowstorms.

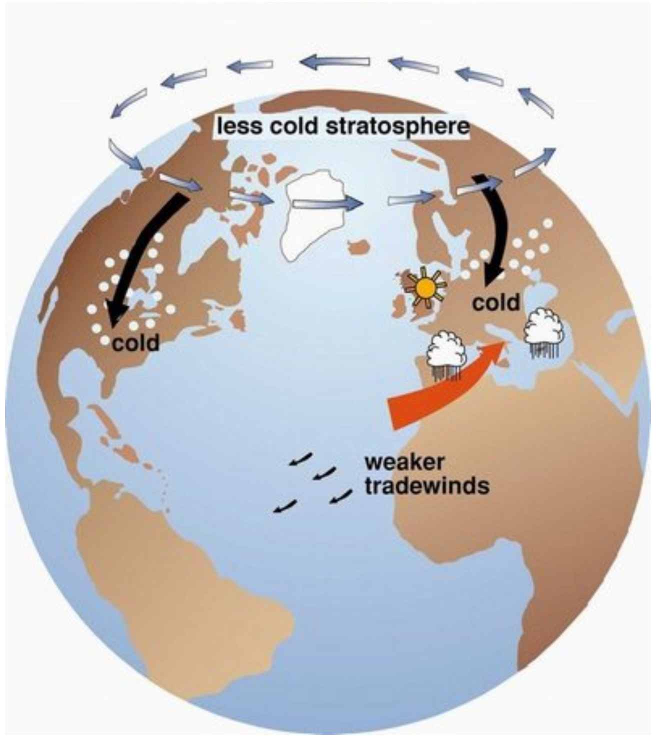
During **AO positive phase**, higher pressure in the midlatitudes drives ocean storms farther north and brings wetter weather to Alaska, Scotland and Scandinavia, and drier conditions to the western US and the Mediterranean. During this phase, frigid winter air does not extend as far into the middle of North America.



Arctic Oscillation (AO)



Arctic Oscillation
Positive Phase



Arctic Oscillation
Negative Phase

https://www.washington.edu/news/2001/06/01/uw-scientists-say-arctic-oscillation-might-carry-evidence-of-global-warming/

Arctic Oscillation (AO)

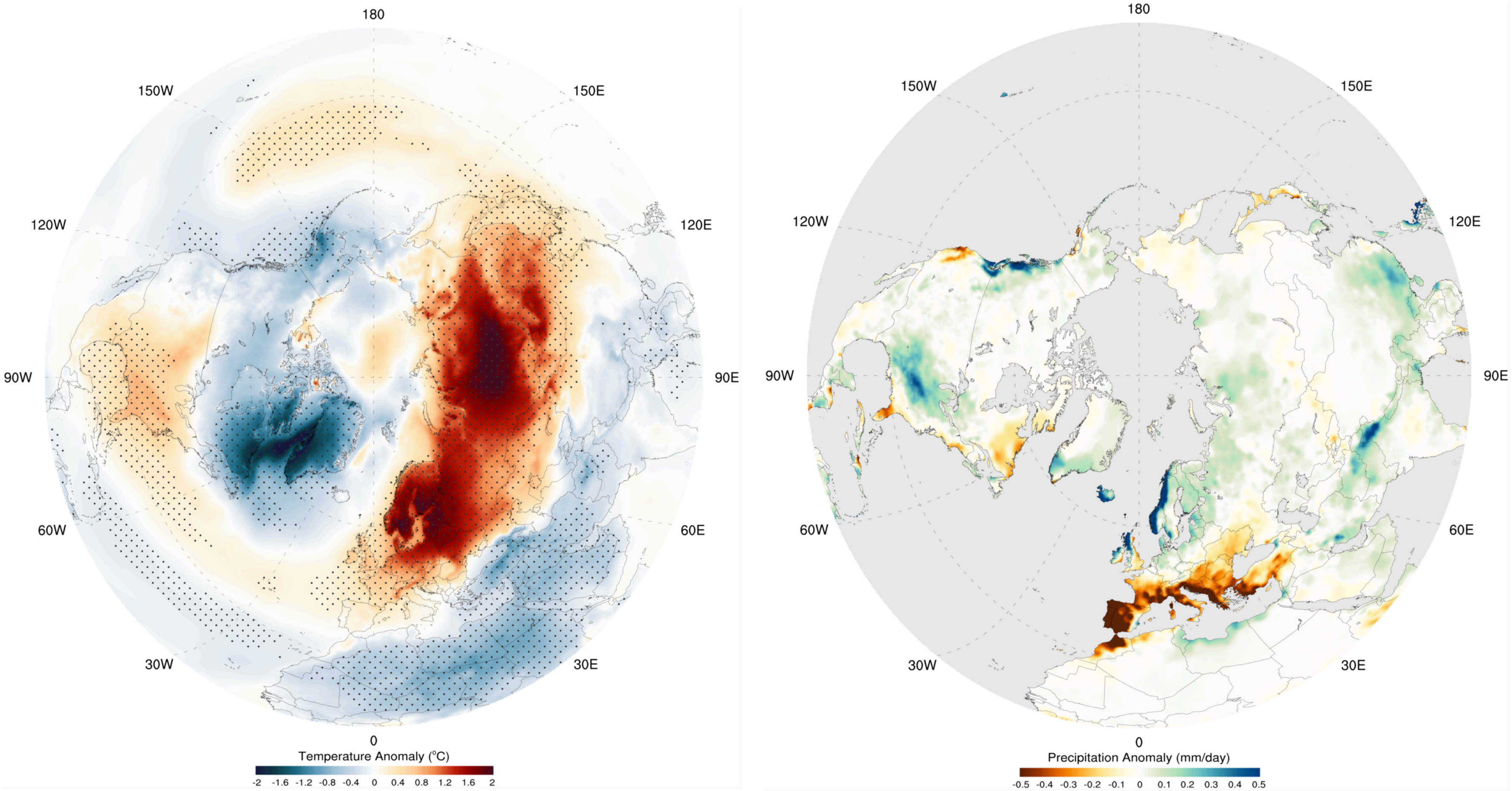


Figure: (Left) DJFM temperature anomalies and (Right) DJFM precipitation anomalies associated with the positive mode of the AO (Source: Wikipedia)

Arctic Oscillation (AO)

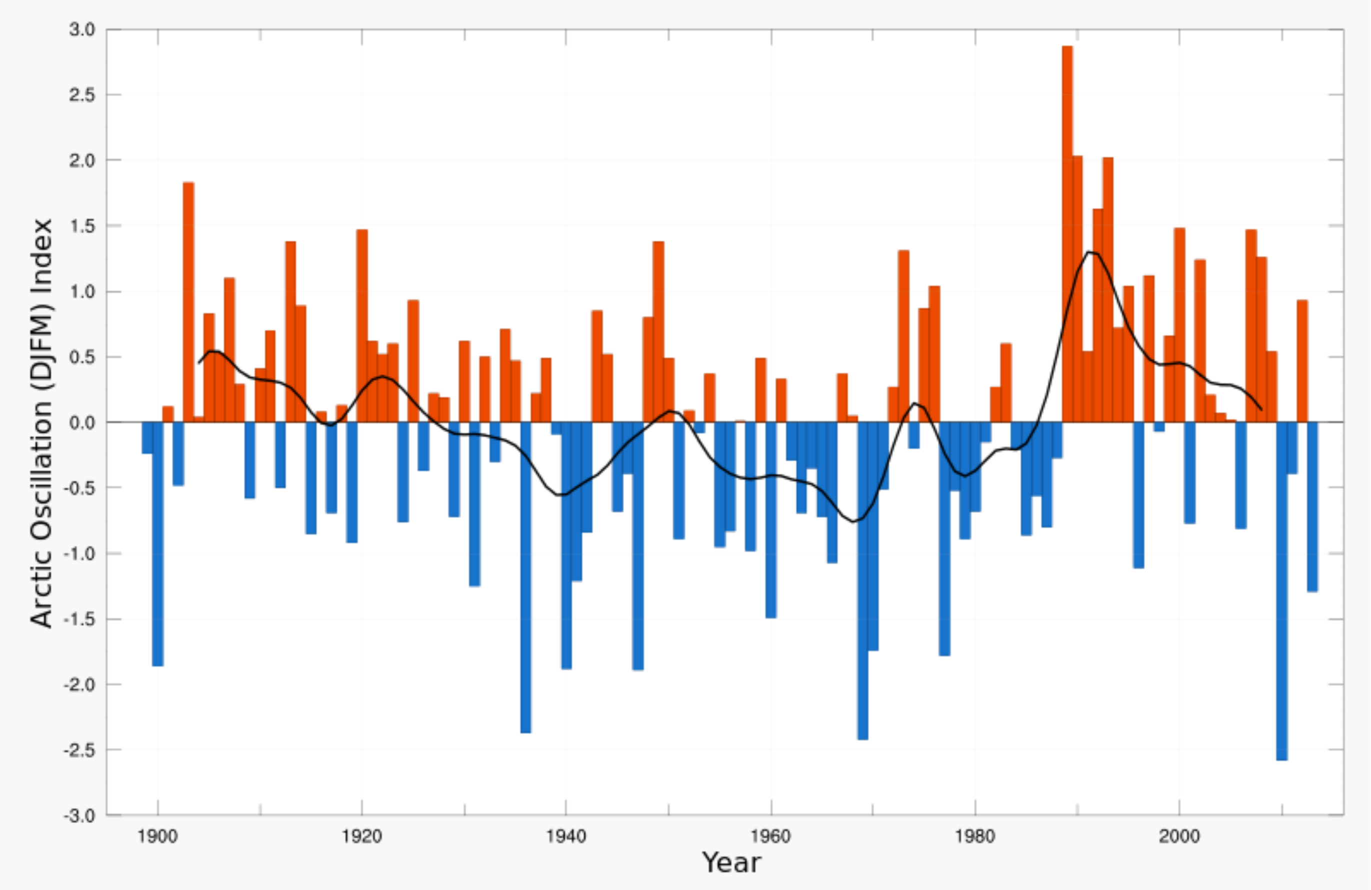


Figure: Arctic Oscillation (AO) time series for the extended DJFM winter season 1899-2010. (Source: Wikipedia)

Arctic Oscillation (AO)

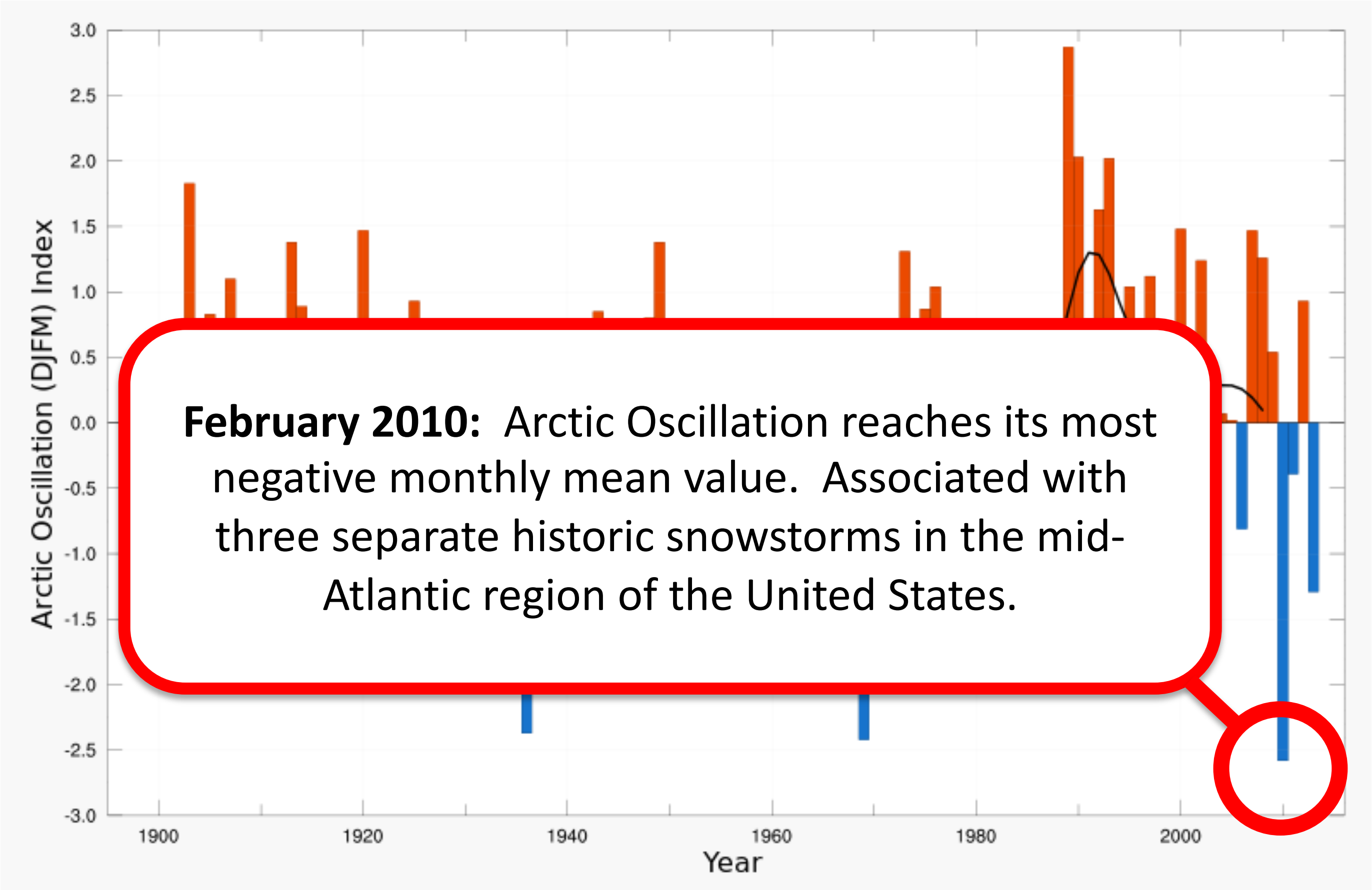
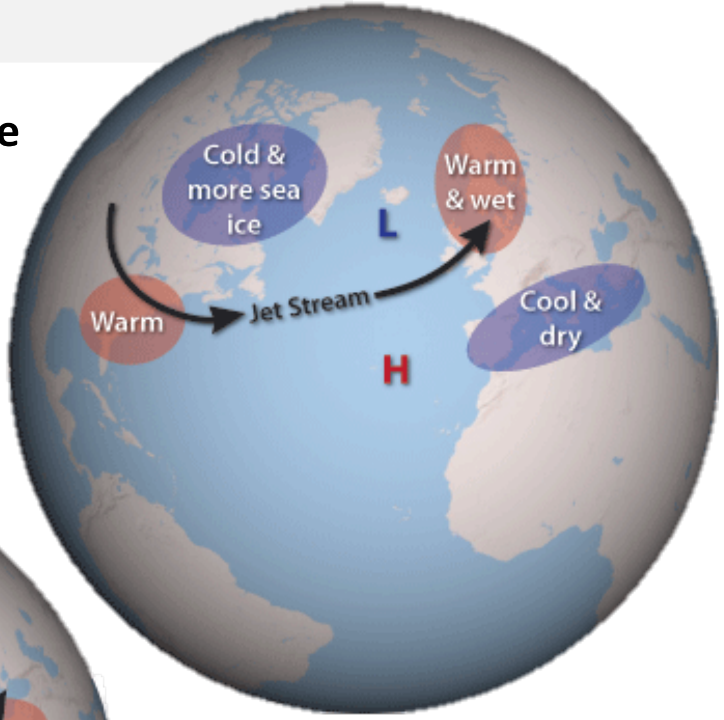


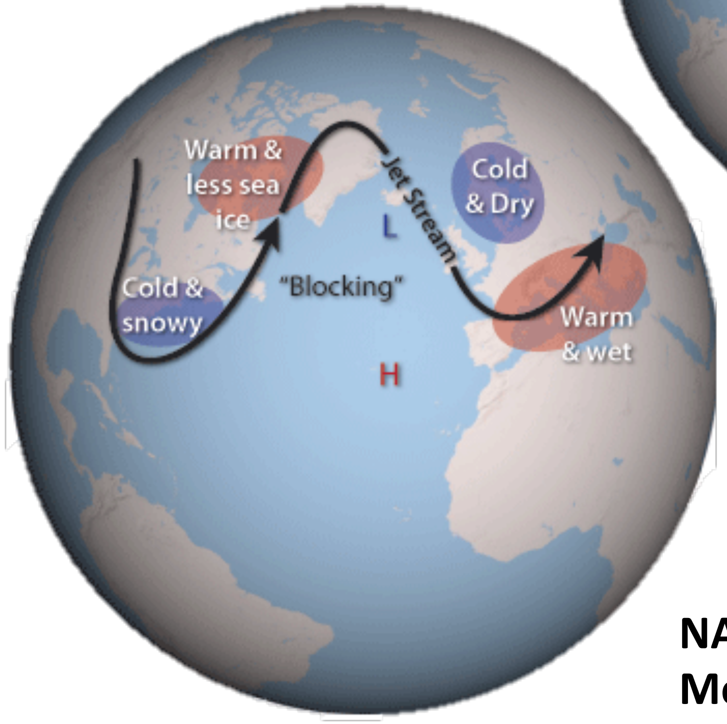
Figure: Arctic Oscillation (AO) time series for the extended DJFM winter season 1899-2010. (Source: Wikipedia)

North Atlantic Oscillation (NAO)

Definition: The **North Atlantic Oscillation** is a weather phenomenon in the North Atlantic Ocean of fluctuations in the difference of atmospheric pressure at sea level between the Icelandic Low and the Azores High.

NAO Positive Mode





NAO Negative Mode

Figure: North Atlantic Oscillation (top) positive mode and (bottom) negative mode.

The NAO is the dominant mode of winter climate variability in the North Atlantic.

The NAO is closely related to the Arctic Oscillation (note the similar behavior of the polar jet), but is more regionally focused over the North Atlantic.

North Atlantic Oscillation (NAO)

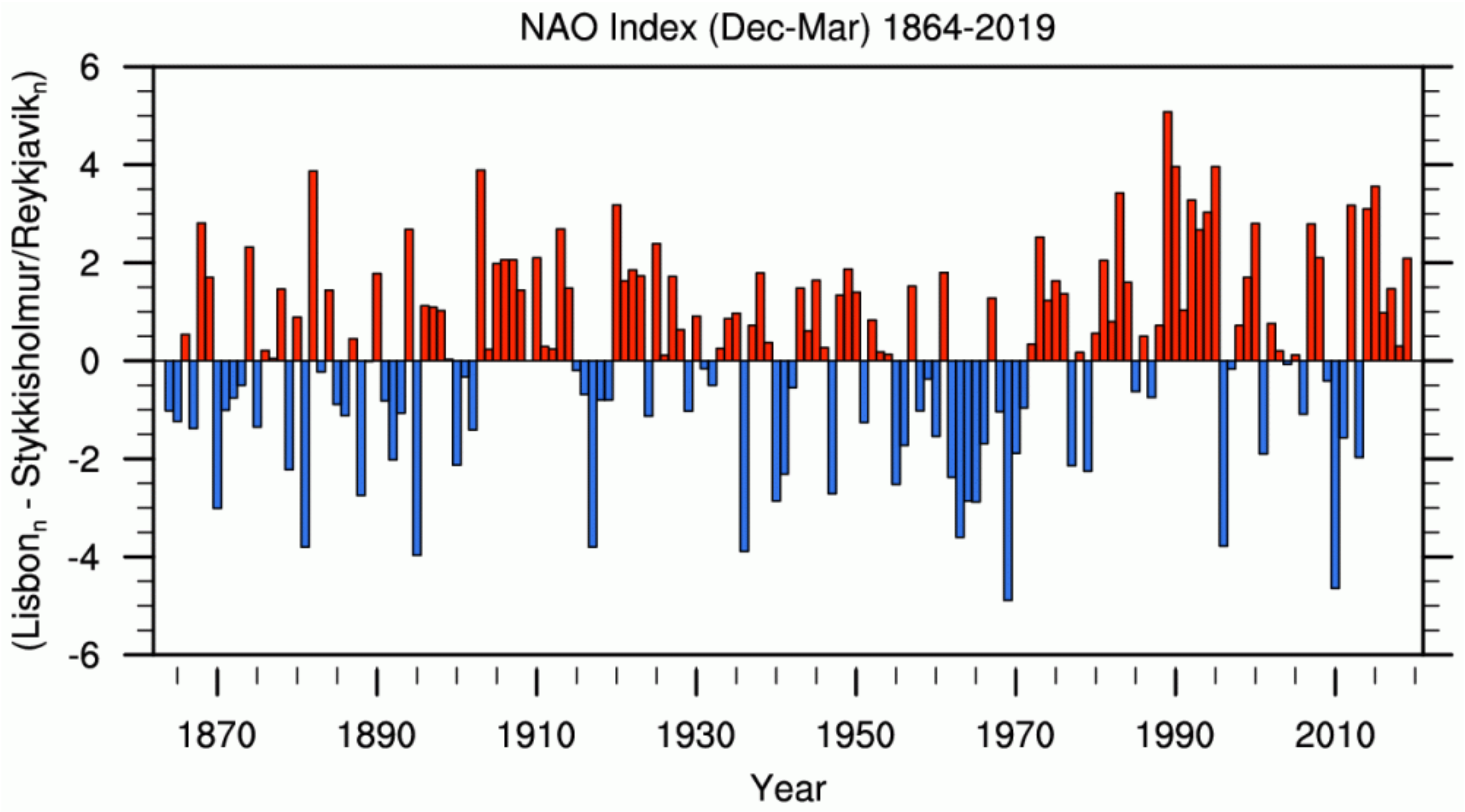


Figure: North Atlantic Oscillation (NAO) time series for the extended DJFM winter season 1864-2019. (Source: NCAR Research Data Archive)

Atlantic Multidecadal Oscillation (AMO)

Definition: The **Atlantic Multidecadal Oscillation** is a mode of variability occurring in the North Atlantic Ocean that is expressed in the sea surface temperature (SST) field. The period of the AMO is about 50-90 years (with 25-50 years for each component of the cycle).

- Identified by Schlesinger and Ramankutty (1994).
- Some controversy about its real amplitude and if methods for extracting the natural climate signal are valid. Estimates peg the magnitude of the oscillation at ± 0.5°C.
- Correlated to air temperatures and rainfall over much of the Northern Hemisphere. Also associated with frequency of North American droughts (warm phase corresponds to more frequent and prolonged droughts) and the severity of Atlantic hurricanes.
- In models, AMO-like variability is associated with small changes in the North Atlantic branch of the Thermohaline circulation.

Atlantic Multidecadal Oscillation (AMO)

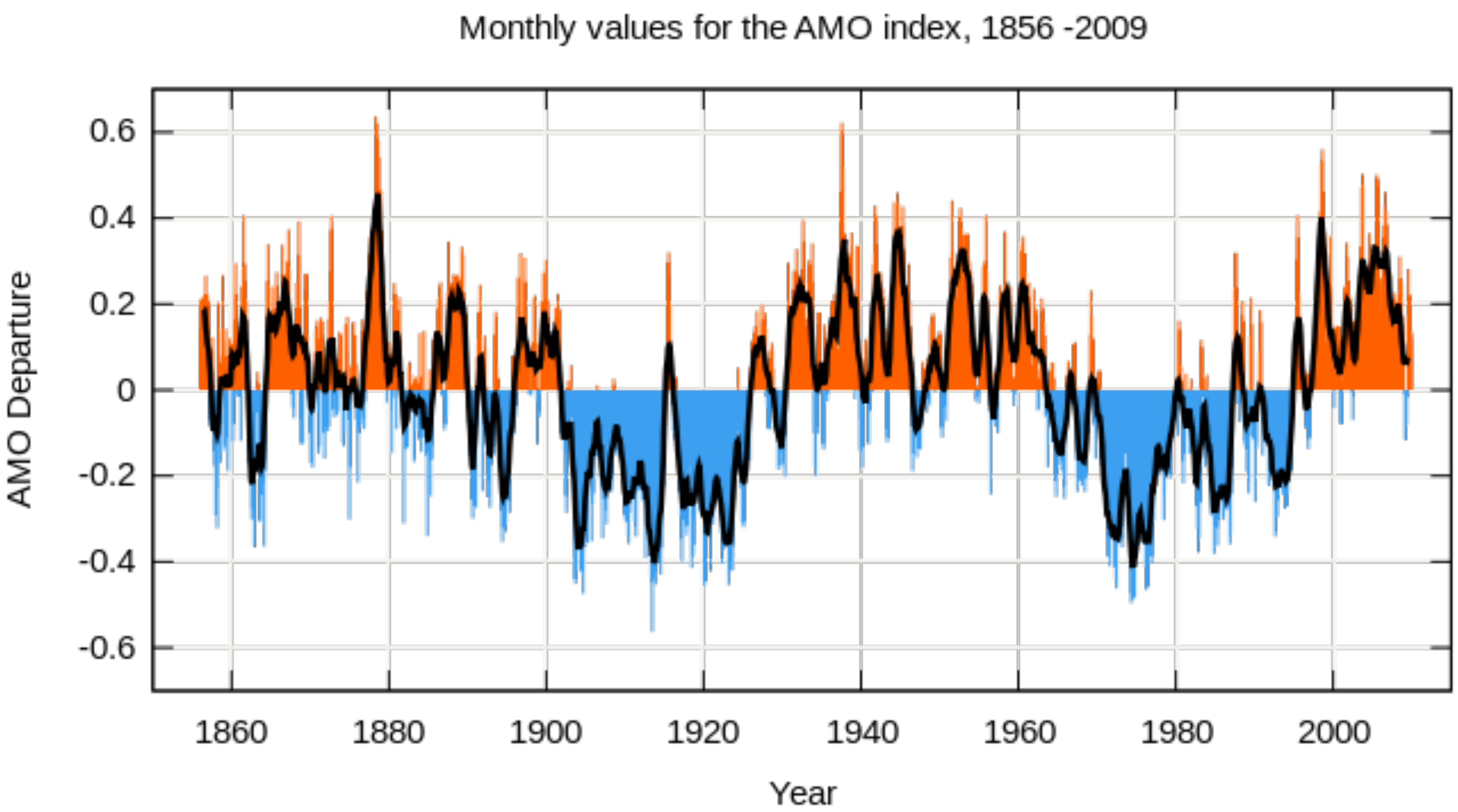


Figure: Monthly values of the AMO index (1856-2009), corresponding to the observed sea surface temperature (SST) departure from the long-term mean and subtracting the signal of anthropogenic forcing. (Source: Wikipedia)

Atlantic Multidecadal Oscillation (AMO)

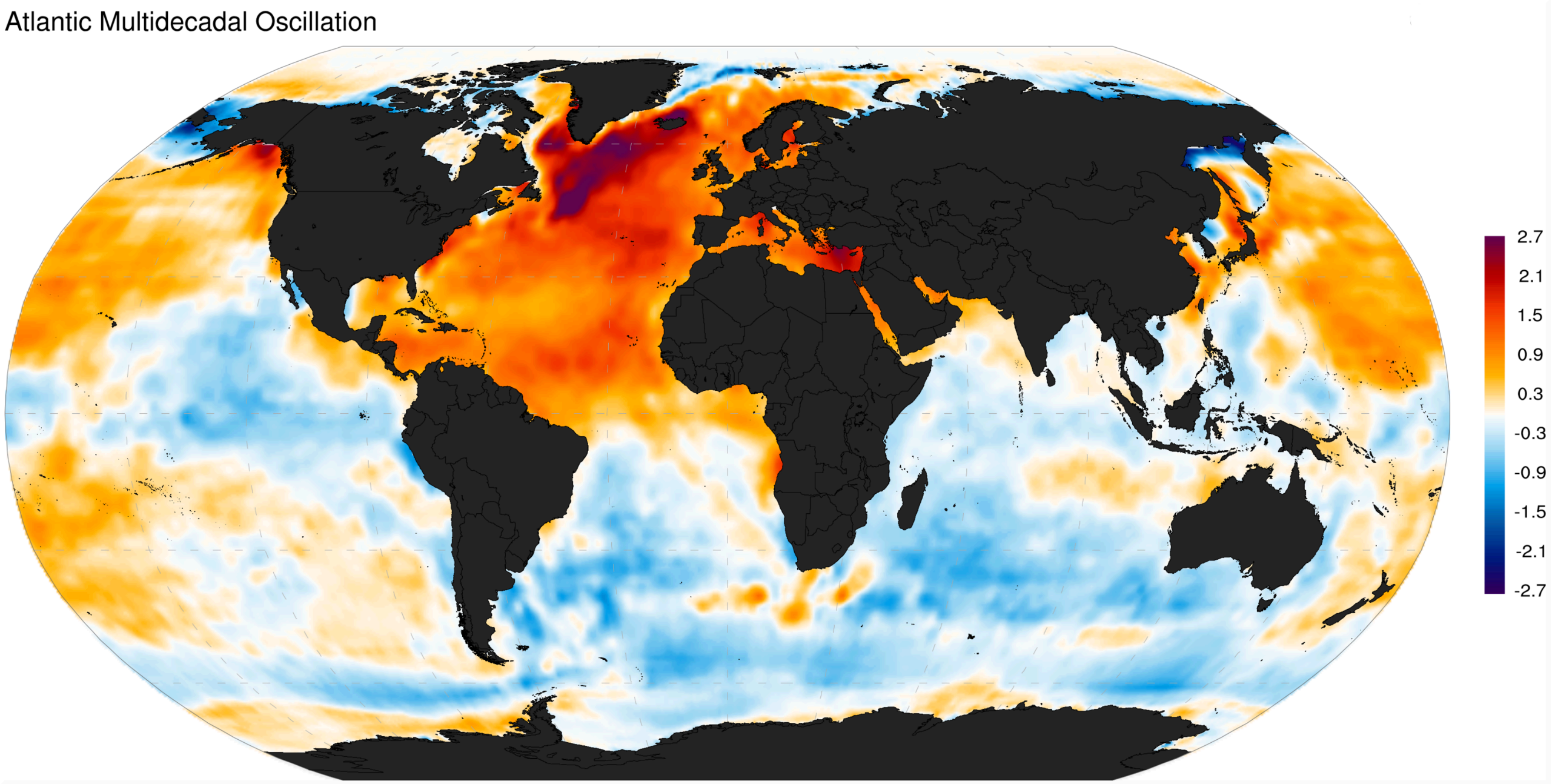


Figure: Spatial sea-surface temperature pattern associated with the AMO. (Source: Wikipedia)

Atlantic Multidecadal Oscillation (AMO)

There is significant correlation between AMO and rainfall in Florida.

Lake Okeechobee, which regulates Florida’s water supply, changes by 40% between AMO extremes.

Warm phase of AMO associated with more rainfall in Florida; cold phase associated with less rainfall and droughts.

Pacific Decadal Oscillation (PDO)

Definition: The **Pacific Decadal Oscillation (PDO)** is a robust, recurring pattern of ocean-atmosphere climate variability centered over the mid-latitude Pacific basin.

Pacific decadal oscillation (PDO) named by Steven Hare (1997).

During a “warm” phase, west Pacific becomes cool and part of the Eastern ocean warms (opposite pattern during a “cool” phase). Typical phases shift occurs on time scale of 20-30 years.

It is associated with the sum of several processes with different dynamical origins, but caused by interaction of tropic and extra-tropical forcing.

Pacific Decadal Oscillation (PDO)

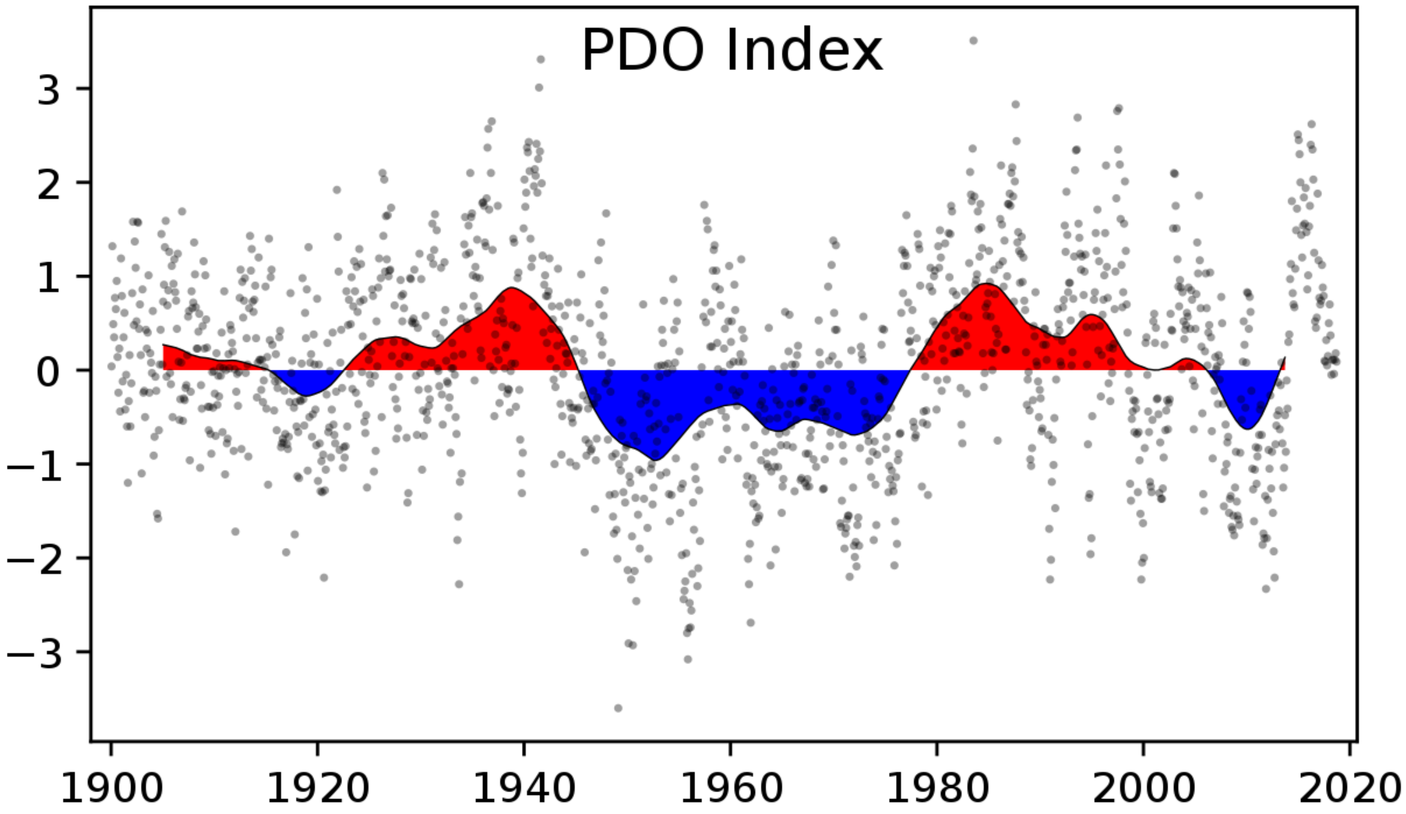


Figure: Observed monthly values for the PDO (1900-2019, dots) and 10-year averages

Pacific Decadal Oscillation (PDO) SSTs

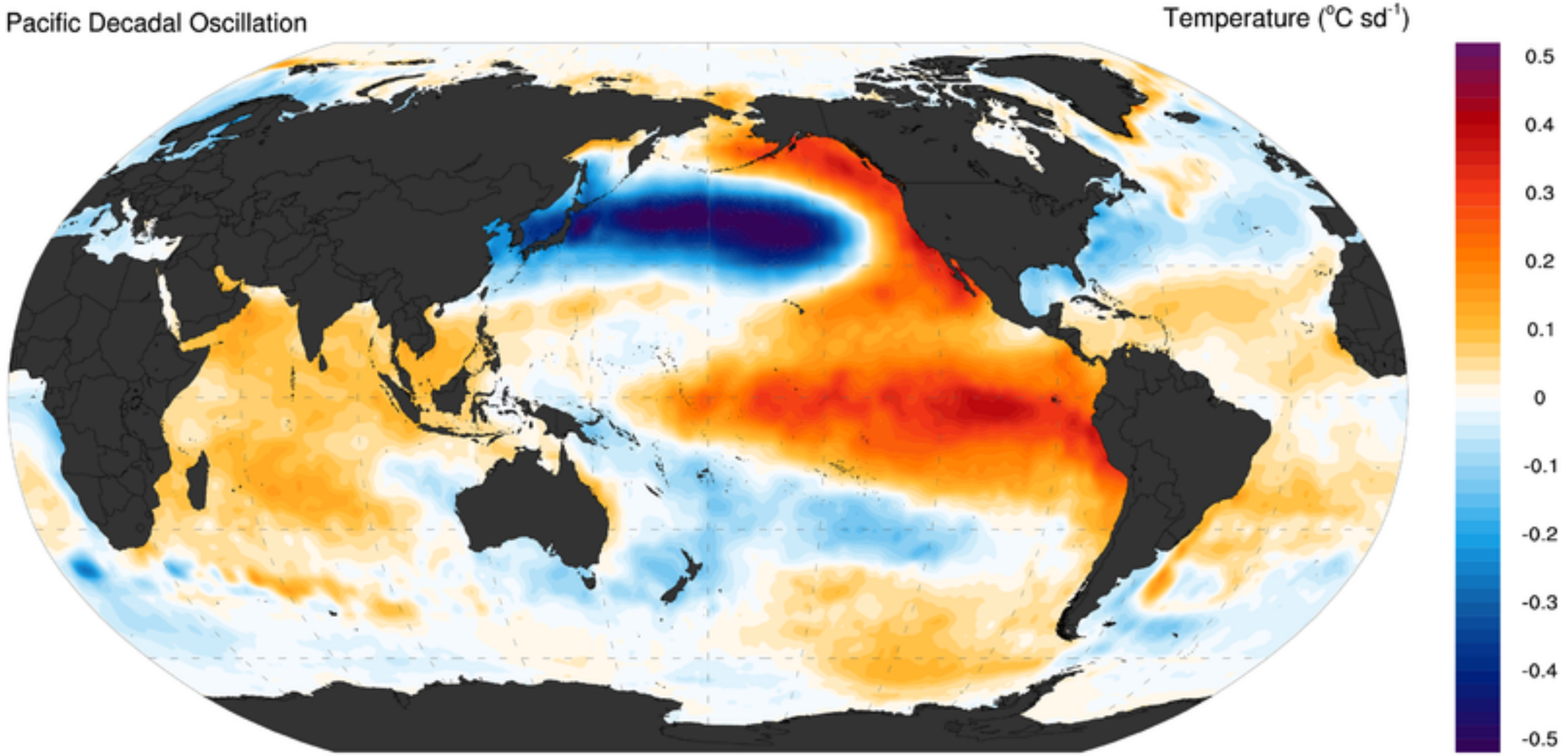


Figure: Pacific Decadal Oscillation (PDO) positive phase global pattern (sea surface temperature anomaly shown).

Pacific Decadal Oscillation (PDO) Impacts

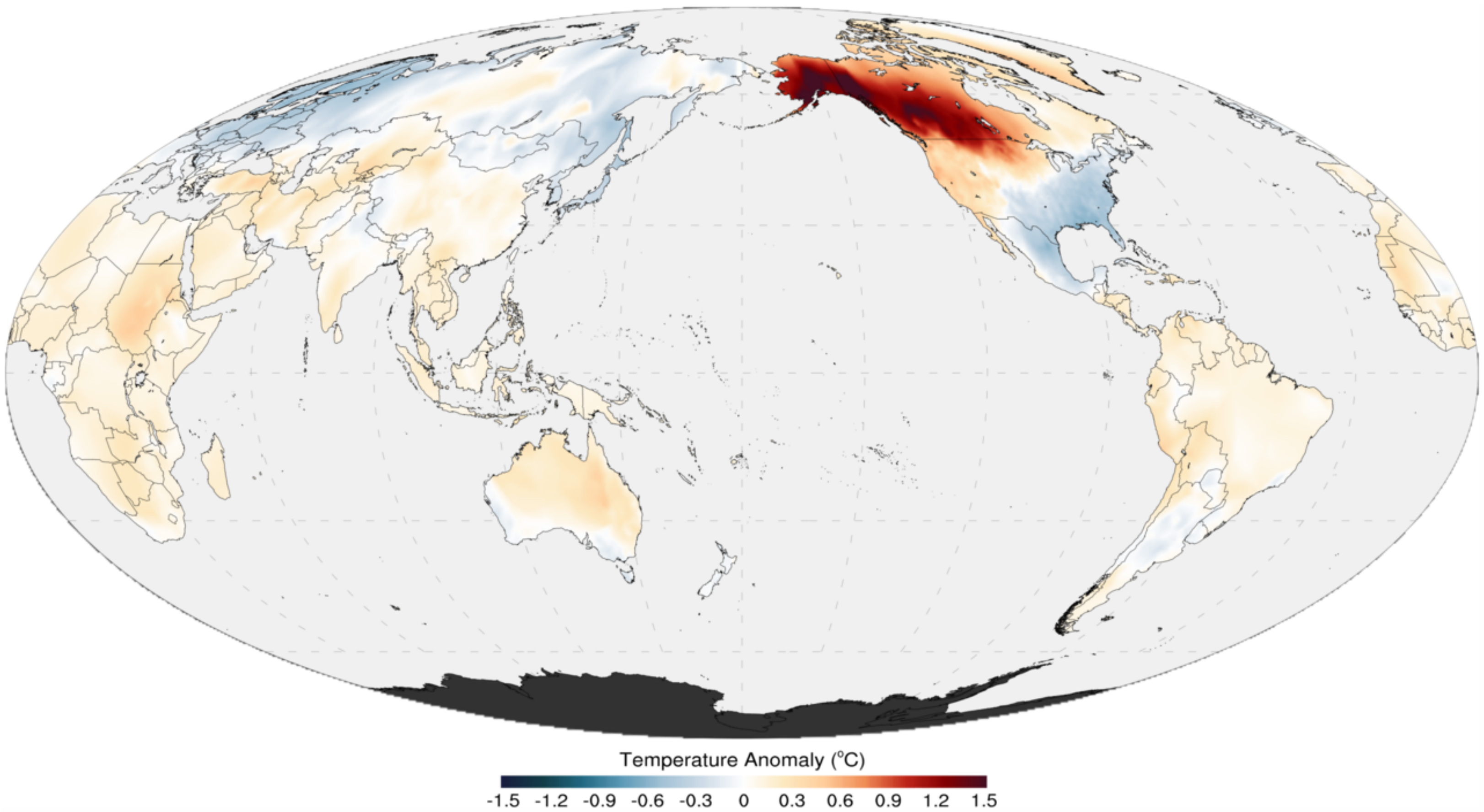


Figure: Pacific Decadal Oscillation (PDO) positive phase 2m temperature anomaly during DJFM.

Pacific Decadal Oscillation (PDO) Impacts

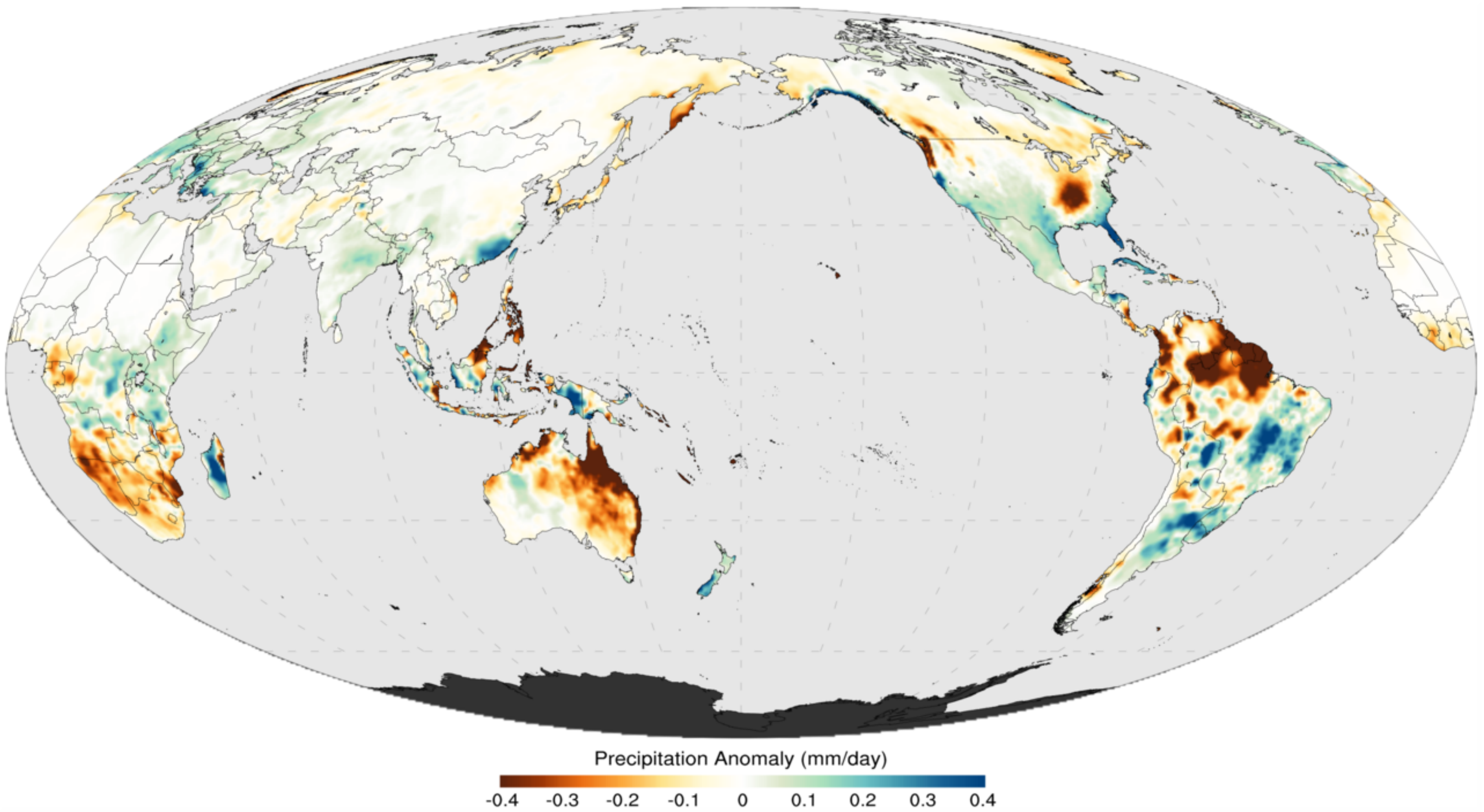


Figure: Pacific Decadal Oscillation (PDO) positive phase precipitation anomaly during DJFM.

Indian Ocean Dipole (IOD)

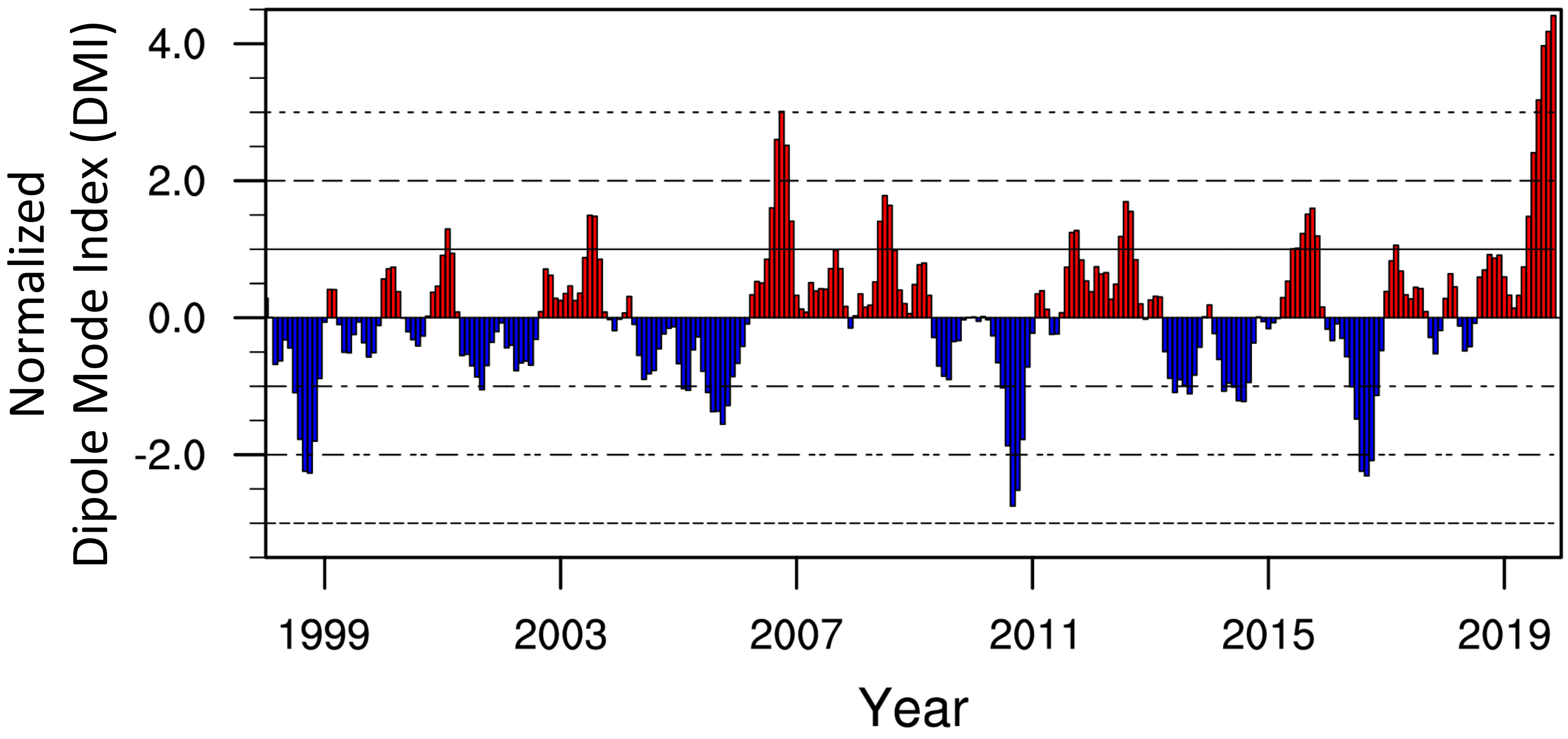
Definition: The **Indian Ocean Dipole (IOD)**, also known as the Indian Niño, is an irregular oscillation of sea surface temperatures.

During the positive phase, the western Indian Ocean becomes warmer than the eastern part of the ocean. This pattern is reversed in the negative phase.

Average of four positive-negative IOD events occur during each 30-year period, with each lasting around six months.

Known to affect the strength of monsoons over the Indian subcontinent, and rainfall over Australia and East Africa.

Indian Ocean Dipole (IOD)



The strong positive IOD was associated with the devastating 2019-2020 Australian bushfires. Simultaneously heavy flooding occurred in East Africa.

Indian Ocean Dipole (IOD)

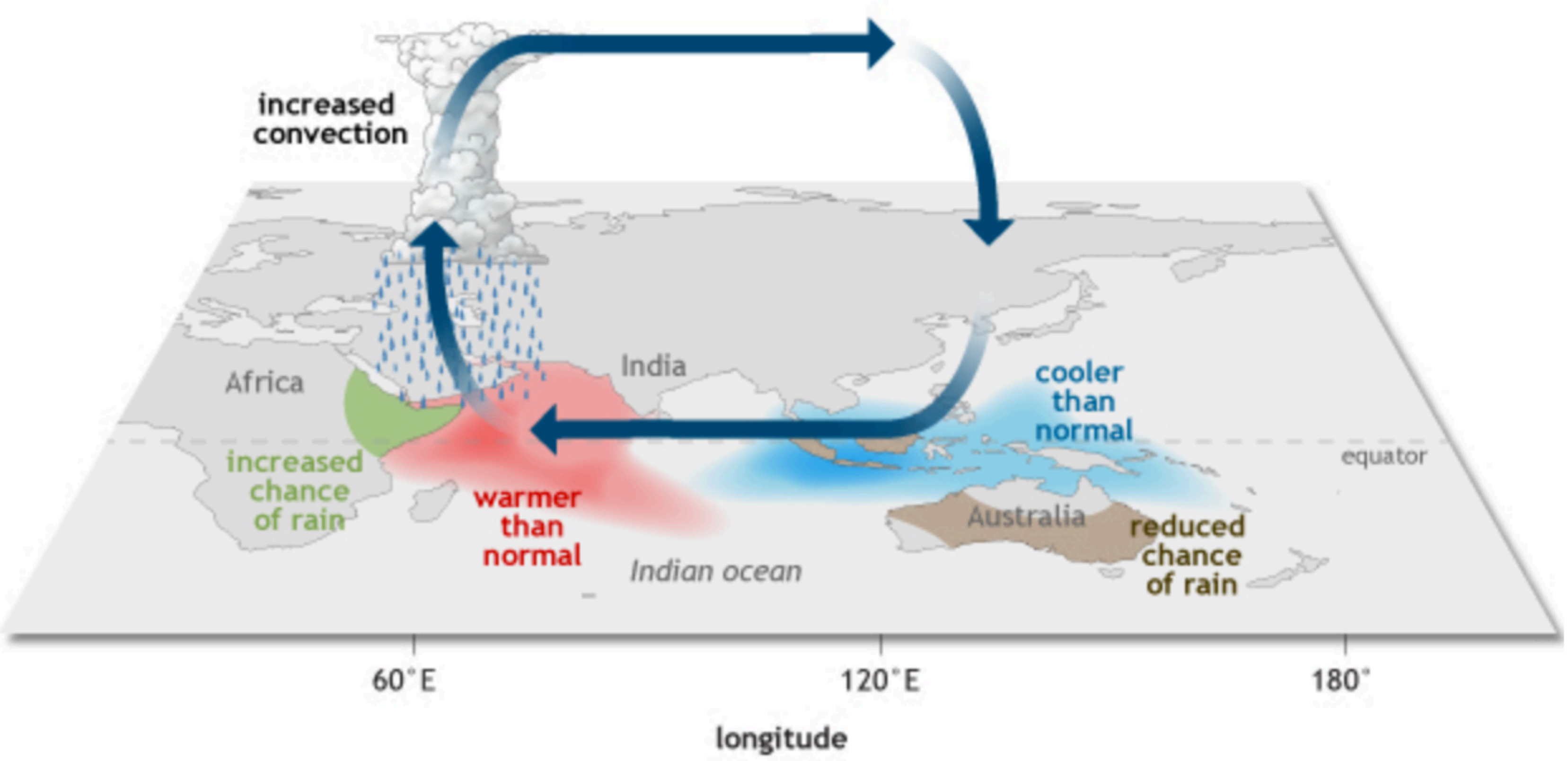


Figure: Indian Ocean Dipole positive phase. Precipitation and temperature are enhanced in the west and suppressed in the east. (Source: NOAA)

Indian Ocean Dipole (IOD)

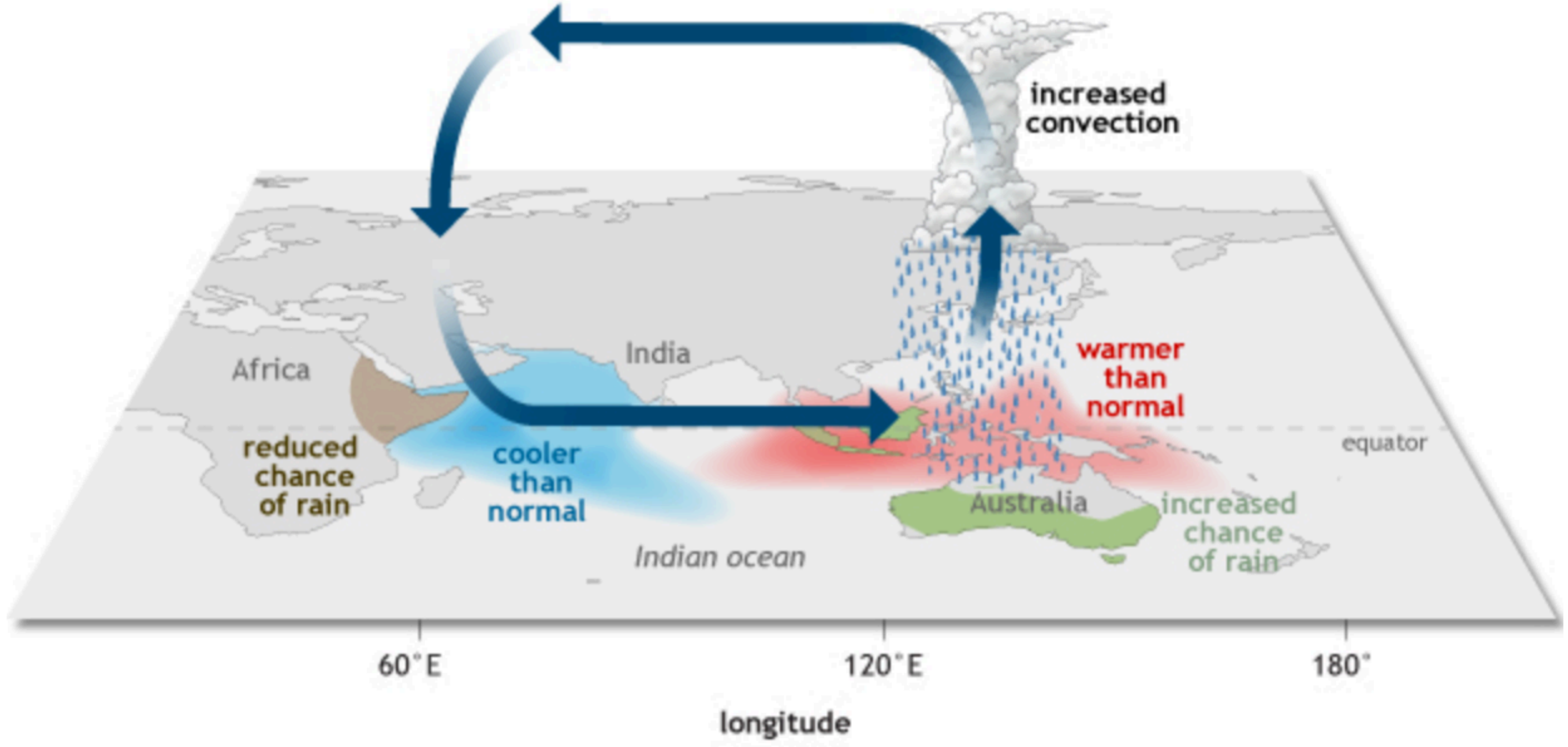


Figure: Indian Ocean Dipole negative phase. Precipitation and temperature are enhanced in the east and suppressed in the west. (Source: NOAA)

ATM 241 Climate Dynamics
Lecture 11
Climate Oscillations

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Thank You!