



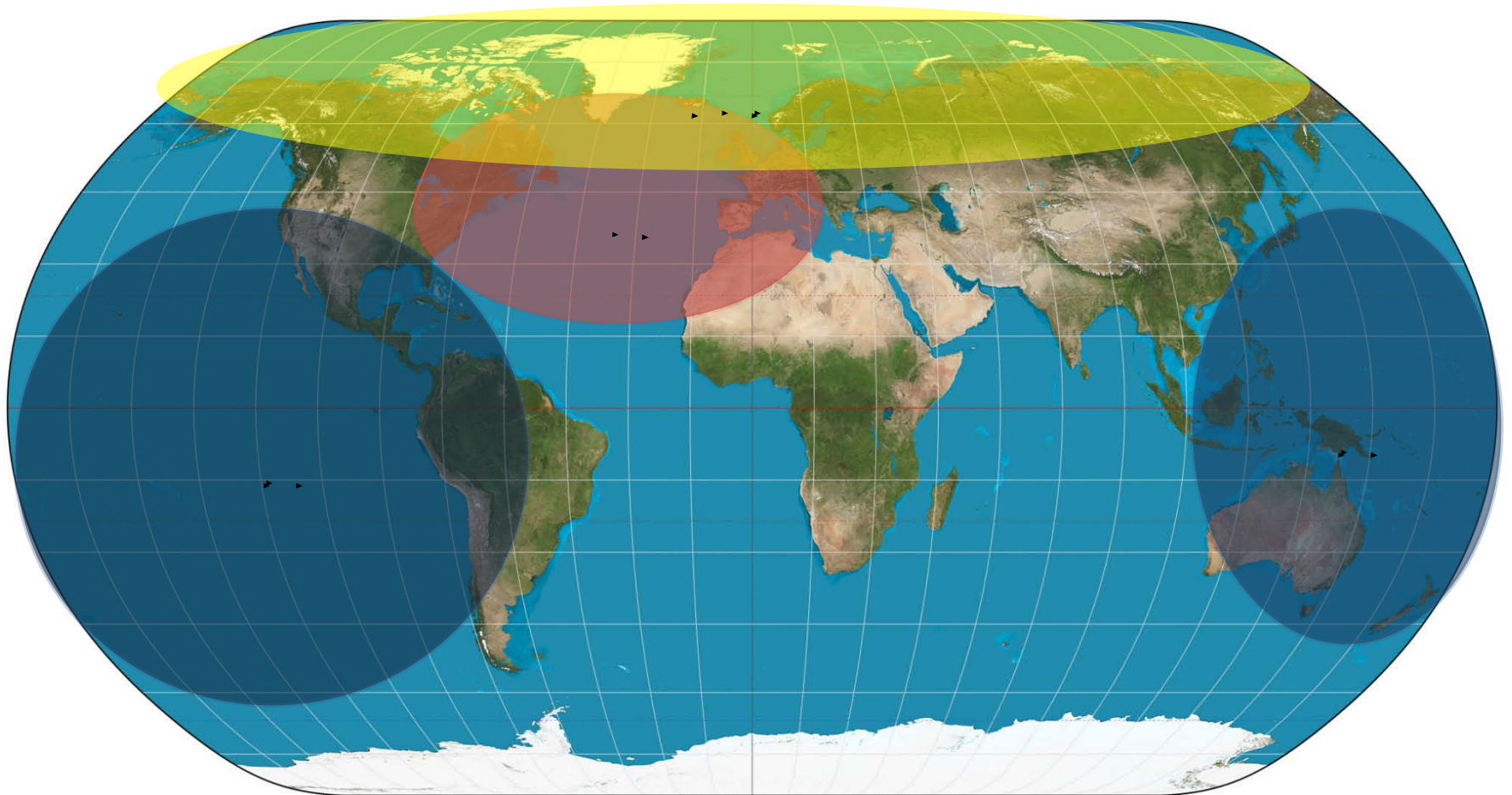
# **Solar activity correlation with NAO and ENSO**

Simeon Asenovski, Boian Kirov, Yana Asenovska





# The three indices we study and areas where they are defined



Possible solar effects:  
radiation at low latitudes  
solar wind disturbances at high latitudes



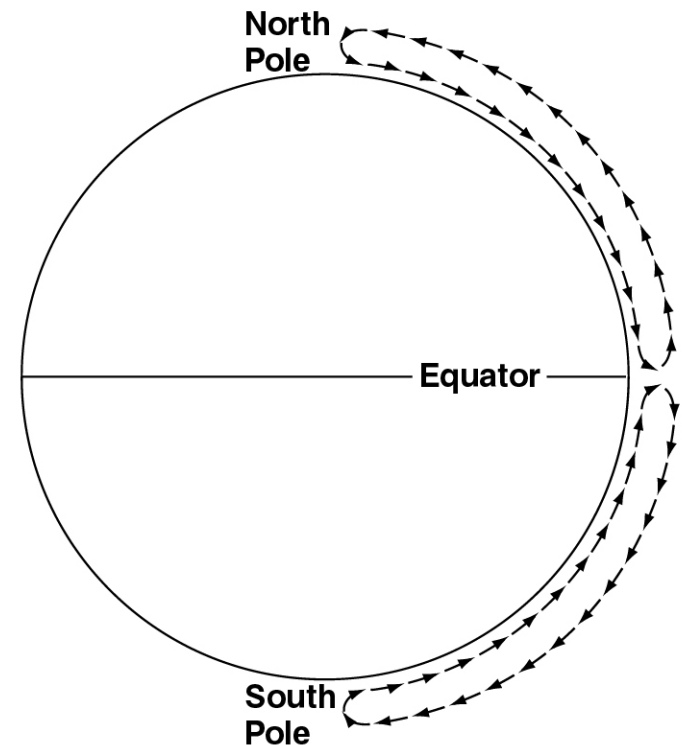
# Atmospheric circulation: the system of the large-scale atmospheric motions over the Earth

## If the Earth didn't rotate:

- heated air at the equator rises
- proceeds south and north toward the poles
- descends there
- returns to the equator.

=> 2-cell circulation (one in each hemisphere)

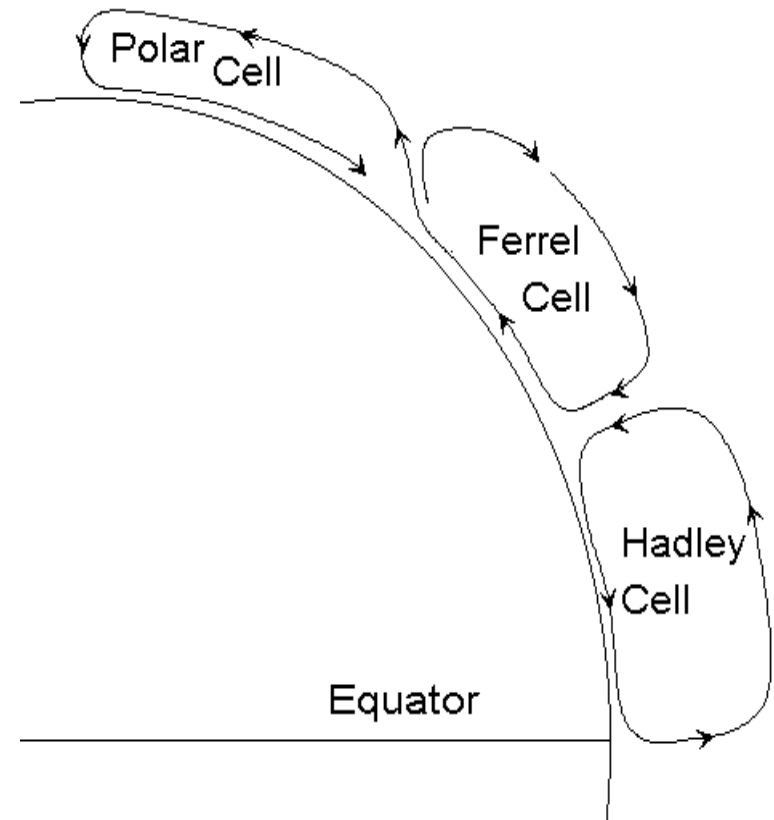
due to the differential heating of the Earth's surface

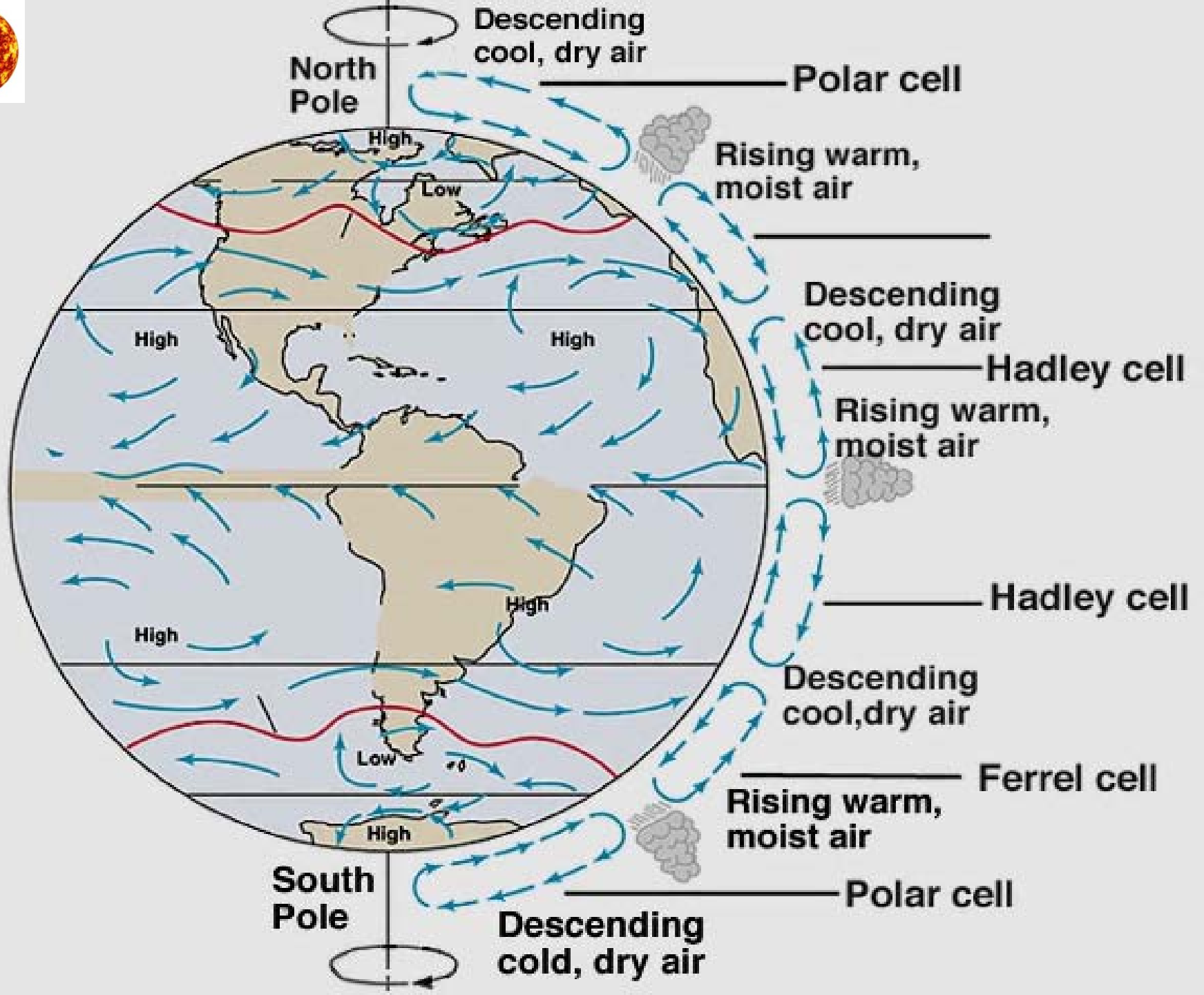




But the Earth does rotate...

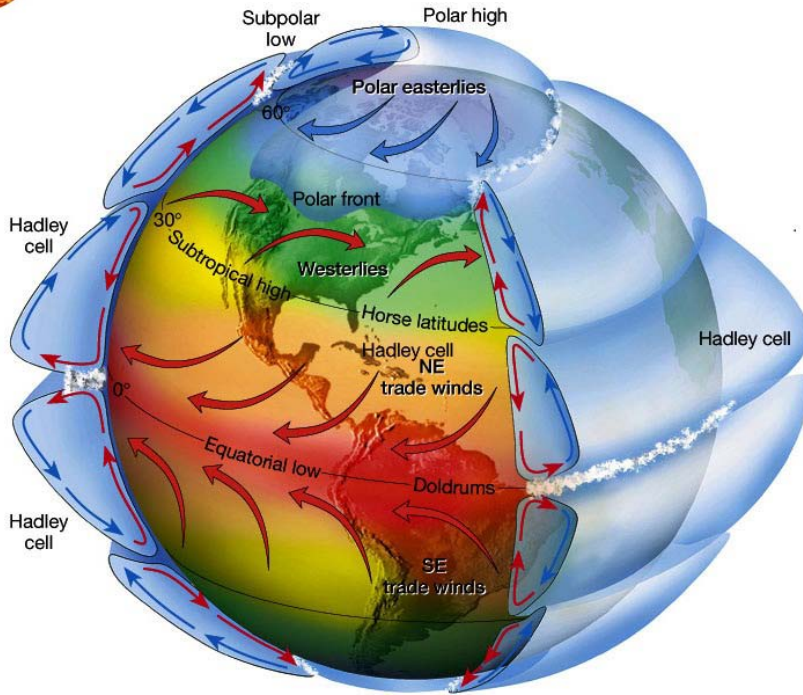
the Coriolis force  
deflects the flow  
forming 3 circulation  
cells in each  
hemisphere



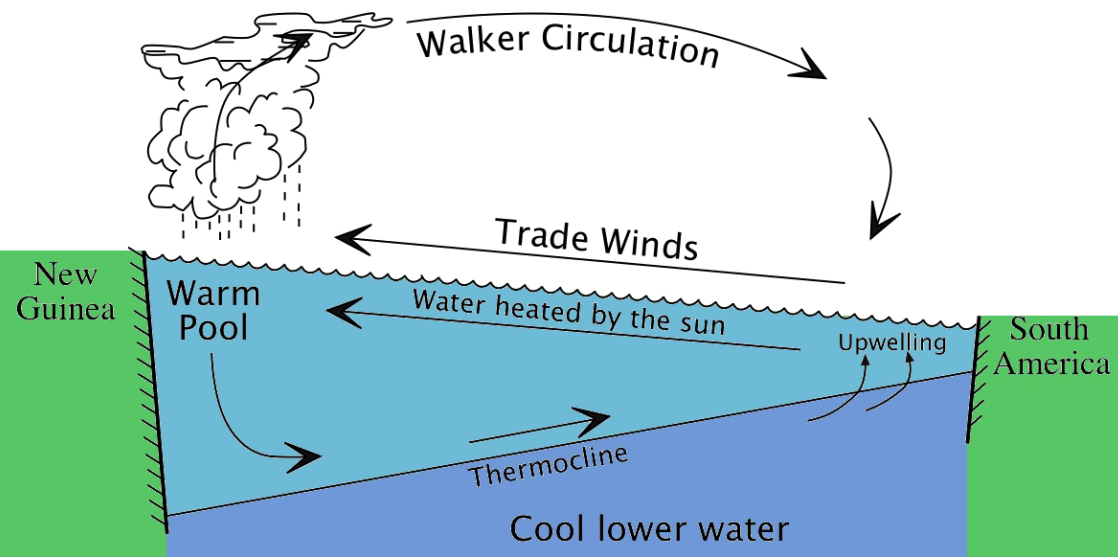




# Normal situation in Pacific Ocean



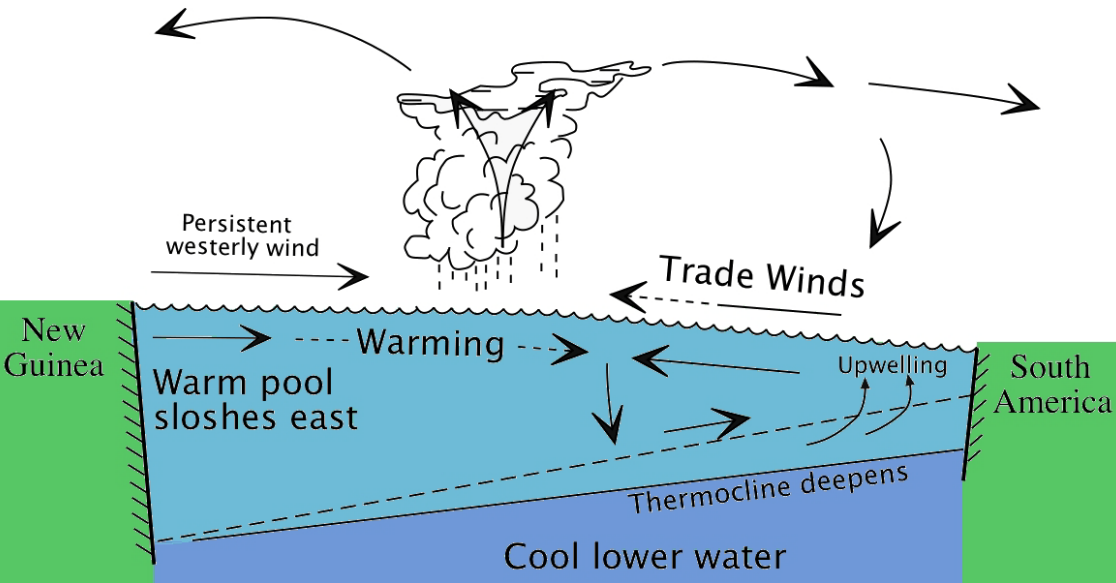
- Trade winds blow westward and push warm surface water towards Australia and New Guinea.
- Sea level in New Guinea is about 0.5 m higher than in Peru.
- Cold water wells up off South America's western coast.
- Upwelling of nutrient-rich cold water fosters marine productivity.





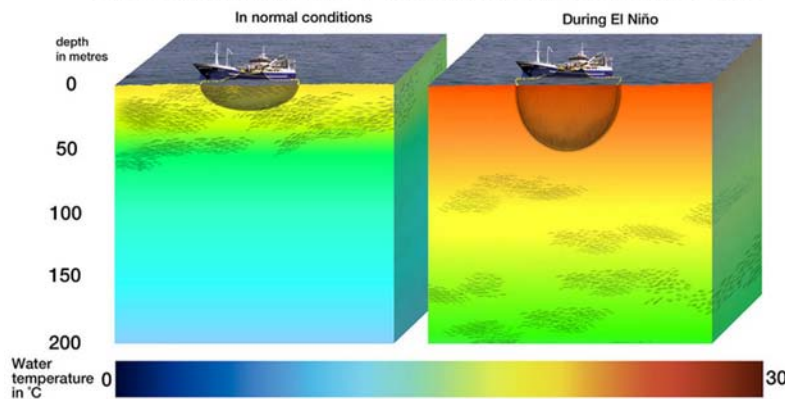


# El Niño in Pacific Ocean



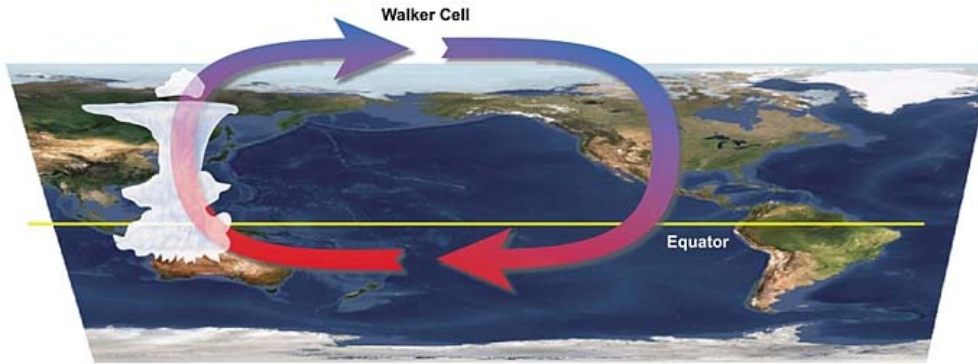
- Weak trade winds allow warm water to occupy much of the tropical Pacific Ocean
- Heavy rains move into the central Pacific Ocean, causing drought in Indonesia and Australia
- Rainfall follows the warm water eastward and can cause flooding in Peru and neighboring countries
- The upwelling of cold water along the coast of Peru weakens and supply of nutrient-rich water is cut off, disrupting local fishing activities

How water temperature influences fishing for small pelagics

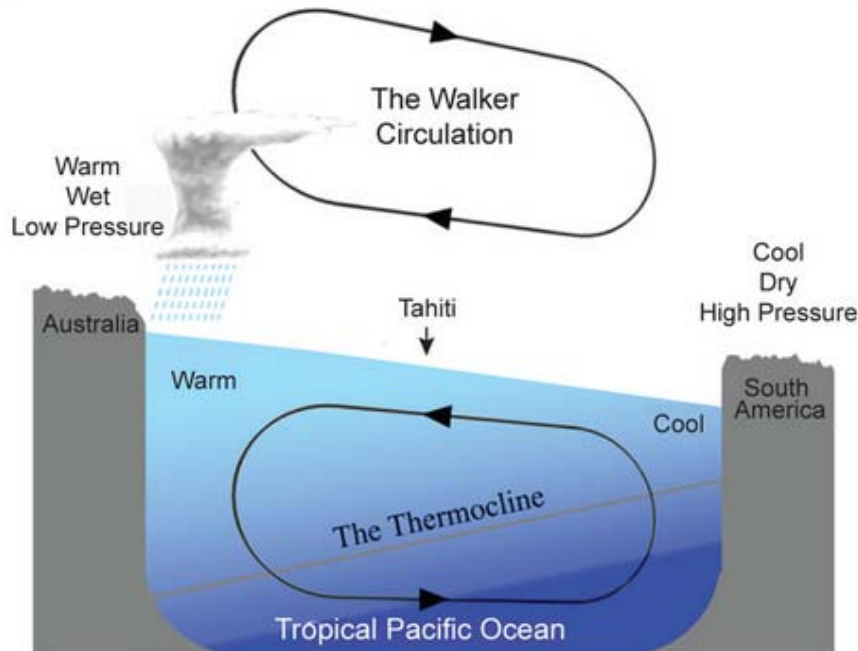




# La Niña in Pacific Ocean



## Walker Circulation and the La Niña phase of ENSO



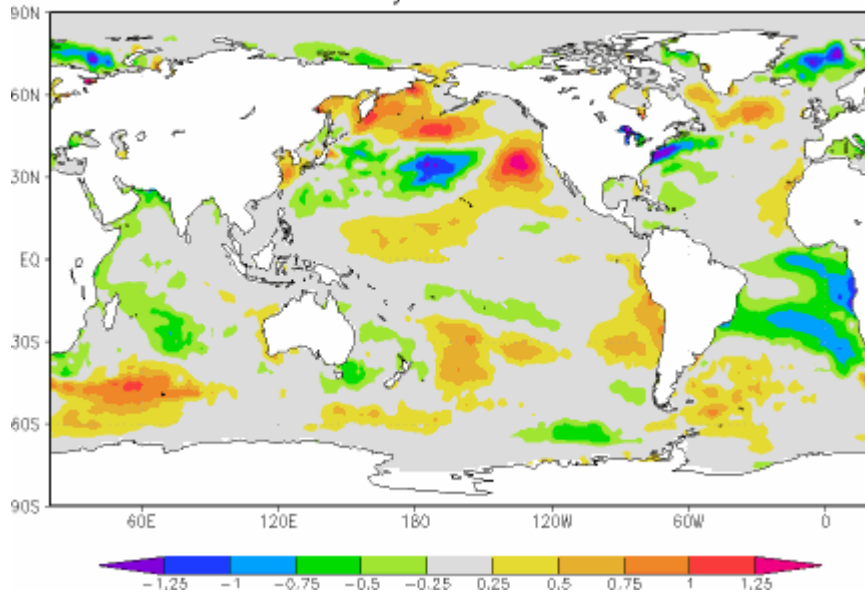
- The trade winds intensify and stack the warm surface water in the west even more than in normal years
- The waters near Australia are often 1,5 m higher than the ocean surface in the east during La Niña episodes
- The area of intense rainfall is dragged back toward Australia
- Upwelling of nutrient-rich cold water fosters marine productivity.



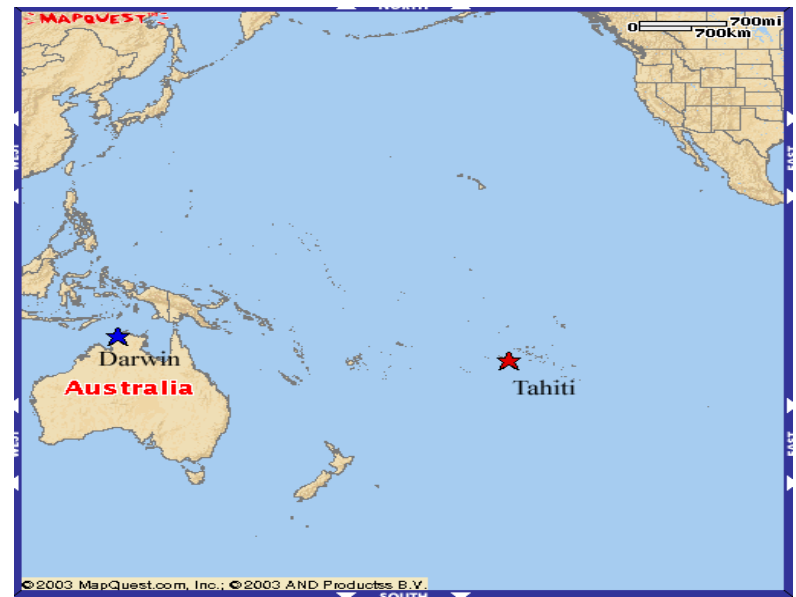
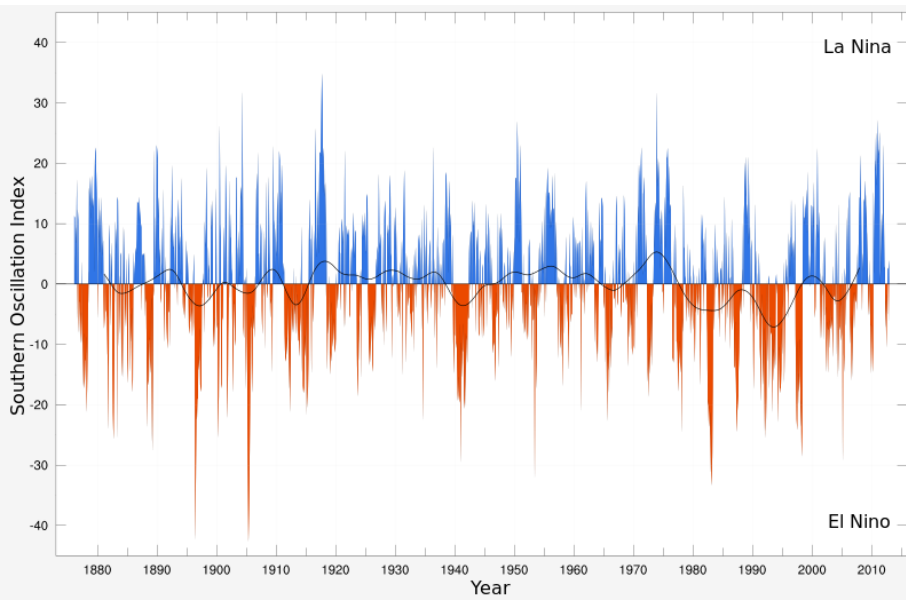


# El Niño Southern Oscillation

sst-clim8209 Aug-Jul1997  
Reynolds v2 SST

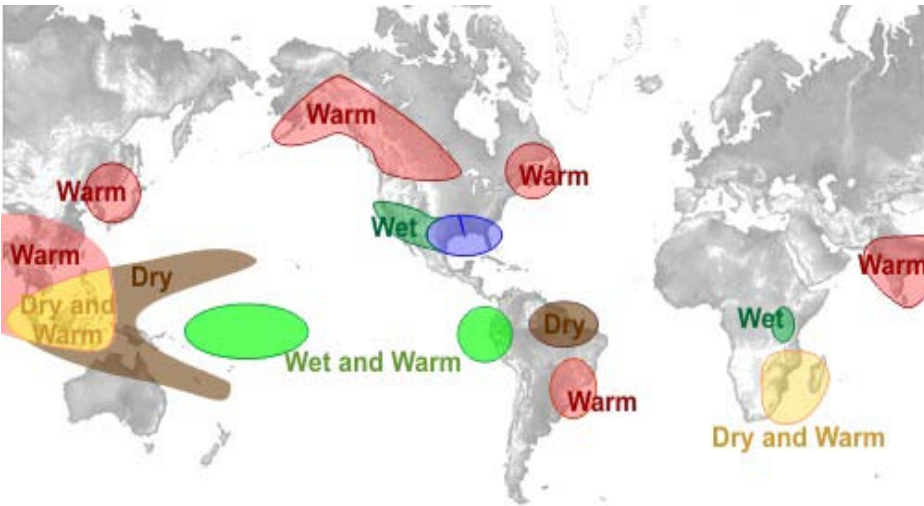


- oscillation in surface air pressure between the tropical eastern and the western Pacific Ocean waters
- The strength of the Southern Oscillation is measured by the **Southern Oscillation Index (SOI)** - fluctuations in the surface air pressure difference between Tahiti and Darwin, Australia or by the **Cold Tongue Index (CTI)** – water temperature in the Eastern Pacific.

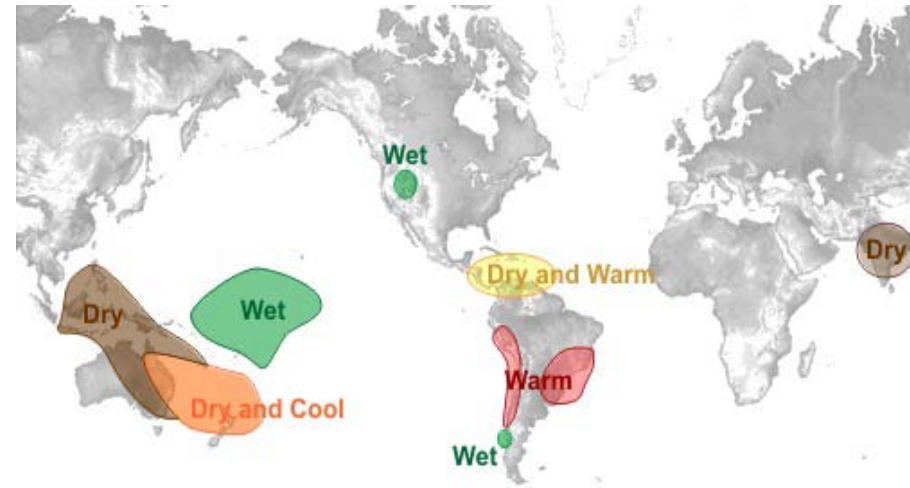




# The Effects of El Niño and La Niña



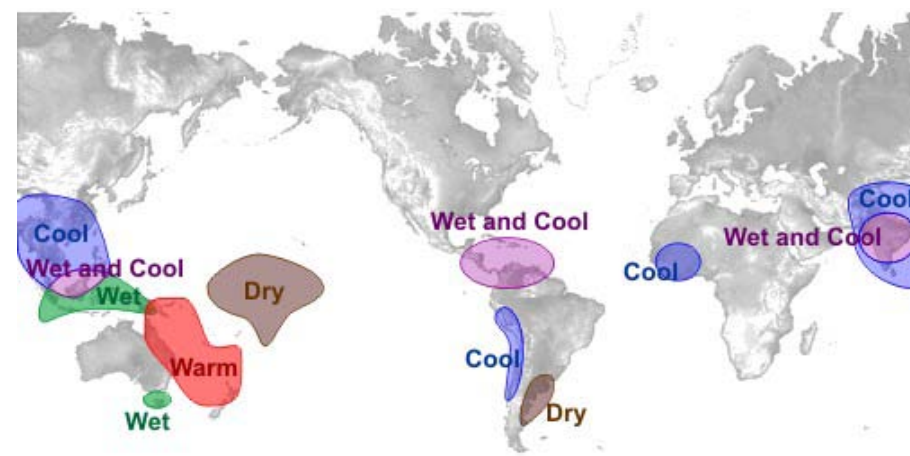
El Niño effect during December through February



El Niño effect during June through August



La Niña effect during December through February

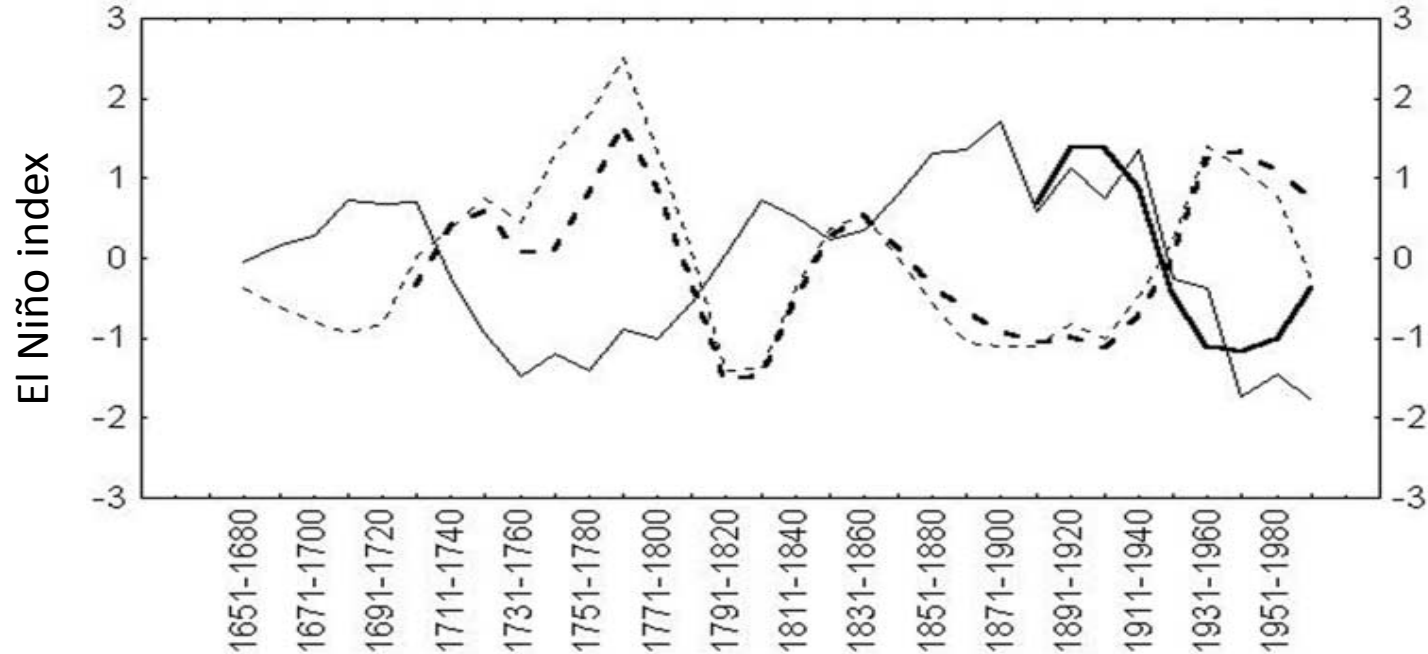


La Niña effect during June through August



# Long-term relations of ENSO and Solar activity

- ✓ The dependence of ENSO on solar activity with a correlation coefficient of -0.76.
- ✓ Higher solar activity - weaker and less frequent El Niño

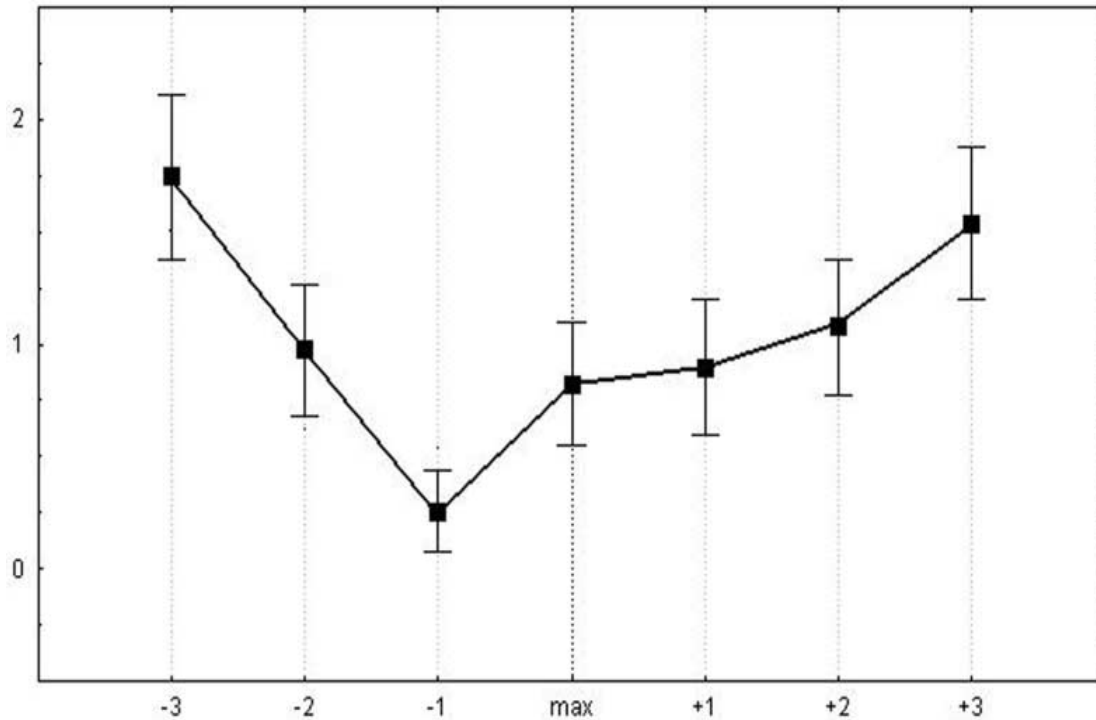


Comparison between El Niño and solar activity: Quinn's El Niño index (Quinn et al., 1987) – thin solid line and Cold Tongue Index (CTI) – thick solid line; the grouped sunspot numbers  $R_g$  – thin broken line and international sunspot numbers – thick broken line, in units of standard deviations, 30-year averages, detrended.





# ENSO and solar activity in the 11-year sunspot cycle

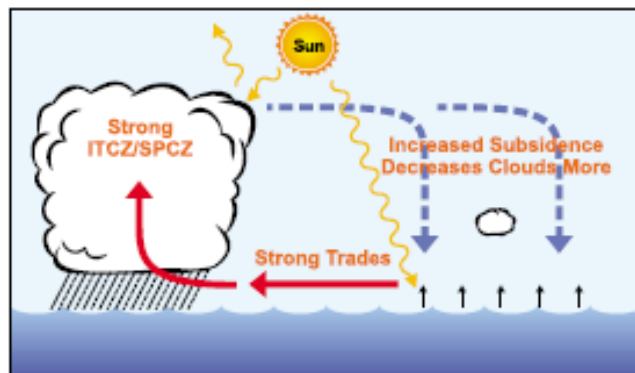
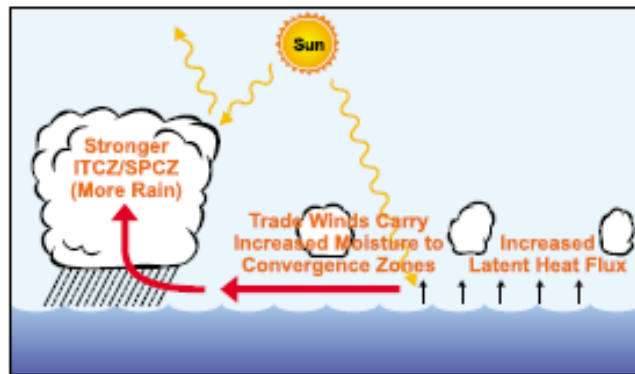
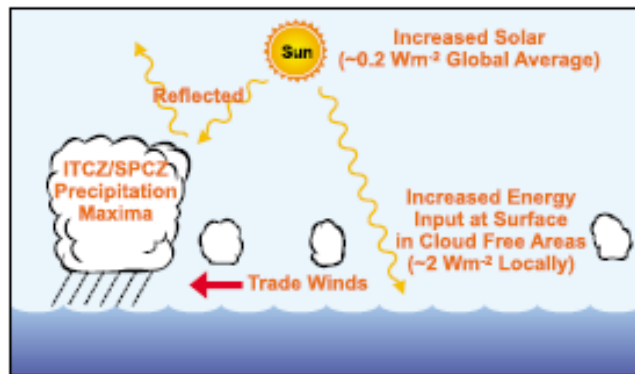


Superposed method analysis of El Niño intensity relative to sunspot maximum in the 11-year solar cycle (dotted vertical line).

- A clearly expressed minimum is observed one year before solar maximum.
- The statistical significance is evaluated with Student's t-criterion, and it better than 99% with  $t = 3,62$  for 74 degrees of freedom.
- The same behavior is seen when we compare not the intensity but the cases of occurrence of El Niño.



# Explanation: the bottom-up mechanism



**Increased solar forcing** during high solar activity on cloud-free eastern Pacific ocean  
**increased evaporation** ⇒ decreased sea surface temperature there  
⇒ **increased trade winds** and **increased moisture** carried to the west  
⇒ **intensified precipitation** and **upward vertical motions** into precipitation zones  
⇒ **stronger Hadley and Walker circulations**  
⇒ **stronger subsidence** in the east  
⇒ further reduced clouds and further increased solar forcing... and so on

van Loon, Meehl, Cubasch





## Comments

- ENSO long-term variation is closely related to the secular solar activity variations
- Both the intensity and occurrence frequency of El Nino are low at secular solar maximum and high at secular solar minimum
- In the 11-year solar cycle, El Nino has a statistically significant minimum one year before solar activity maximum
- Whatever factors drive El Nino, the conditions in solar max are more unfavorable for its occurrence



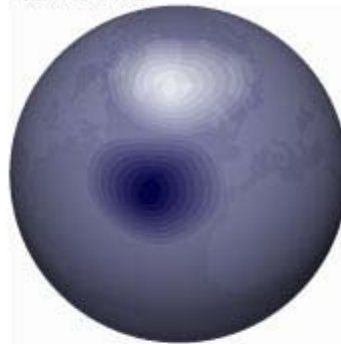


# North Atlantic Oscillation (NAO)

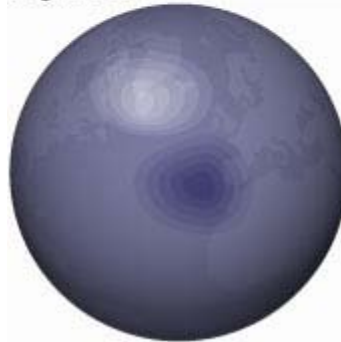
Difference between the normalized pressure in two atmospheric “centers of action”: **Azores High** and **Iceland Low**

Determines the winter temperatures over big parts of the Northern hemisphere

Positive NAO



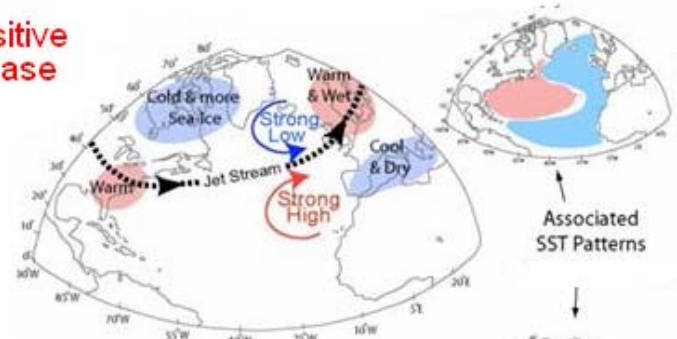
Negative NAO



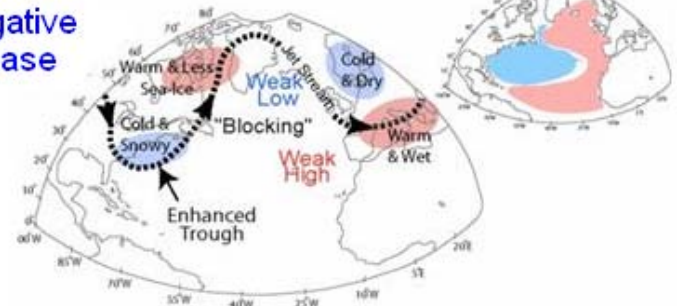
Atmospheric Pressure



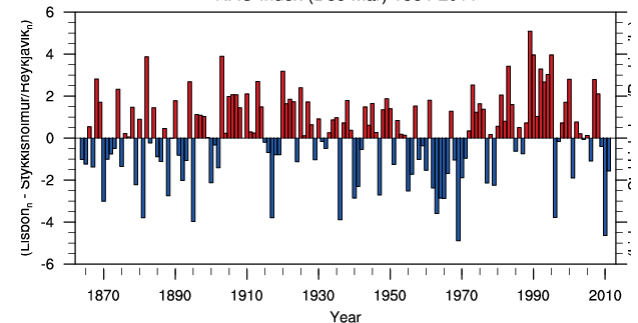
positive phase



negative phase



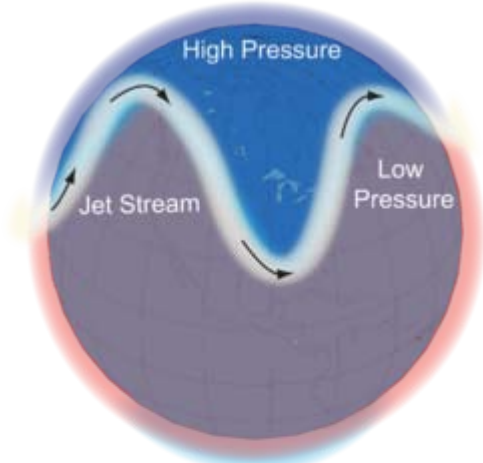
NAO Index (Dec-Mar) 1864-2011



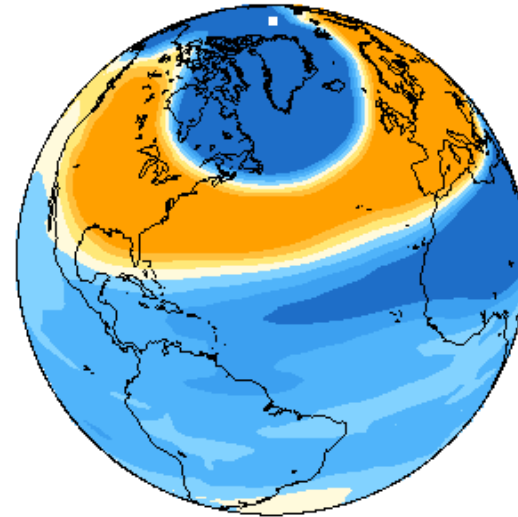
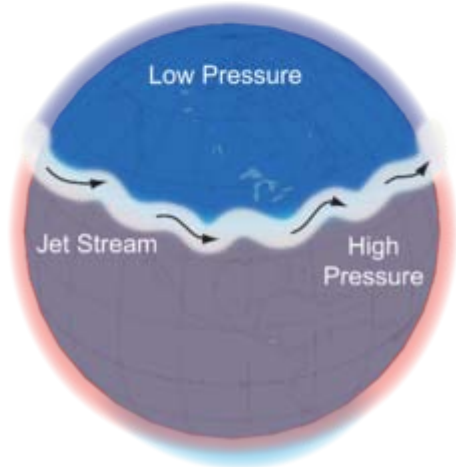


# What is NAM?

Arctic Oscillation  
Negative Phase



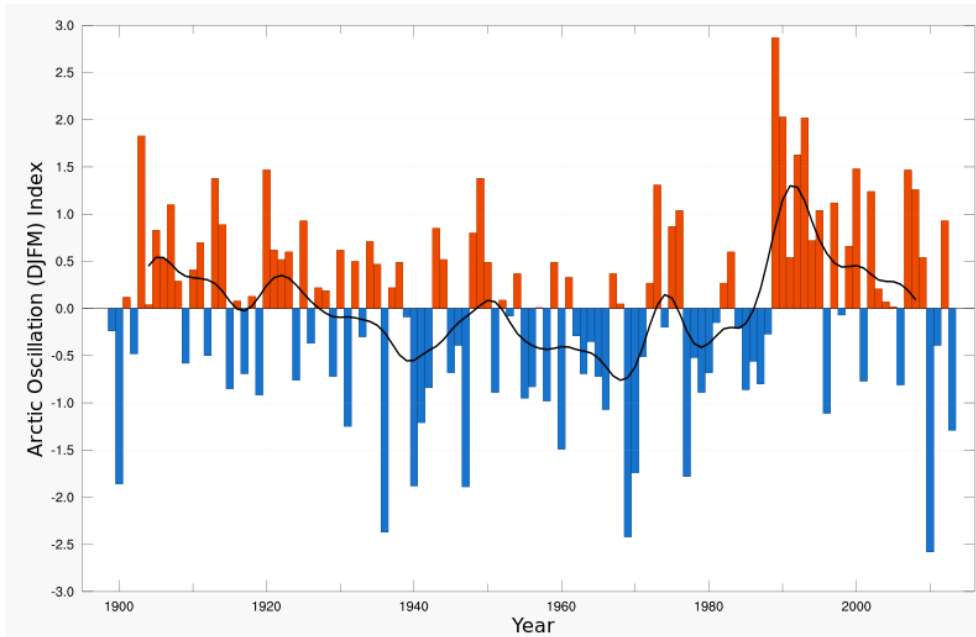
Positive Phase



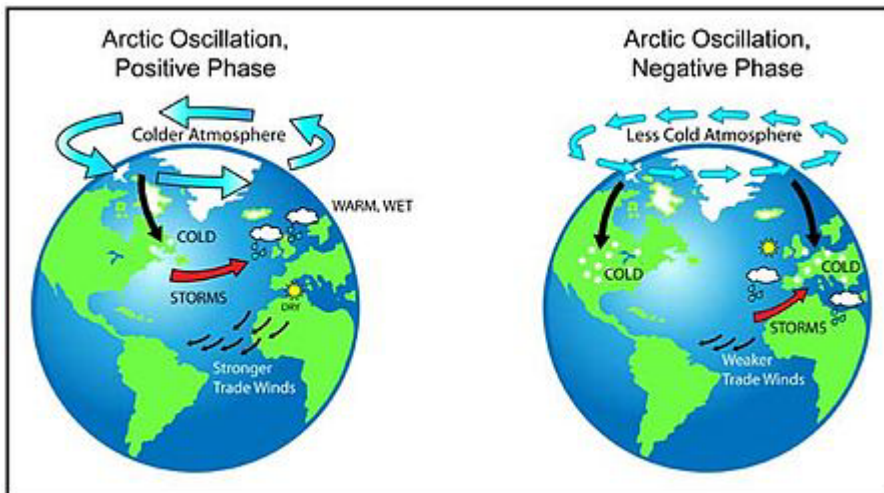
- Northern Hemisphere Annular Mode (NAM) or Arctic Oscillation
- Same as NAO index on the surface
- Symmetrical structure at high altitudes



# What is NAM?



- NAM index (which varies over time with no particular periodicity) is defined as the difference in atmospheric pressure between high (above 60N) and middle (around 45N) northern latitudes at pressure levels from 1000hPa to 10hPa
- Positive NAM - surface pressure is low in the polar region and keeping cold Arctic air locked in the polar region.
- Negative NAM - high pressure in the polar region, weaker zonal winds, and greater movement of polar air into middle latitudes.



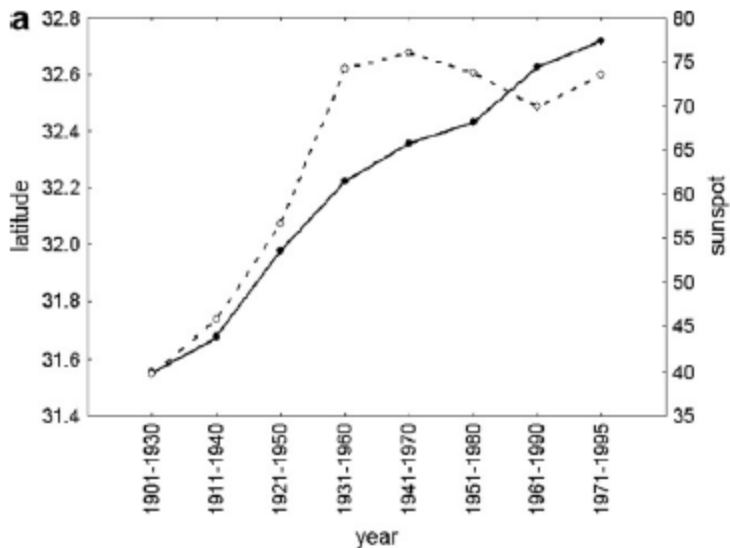
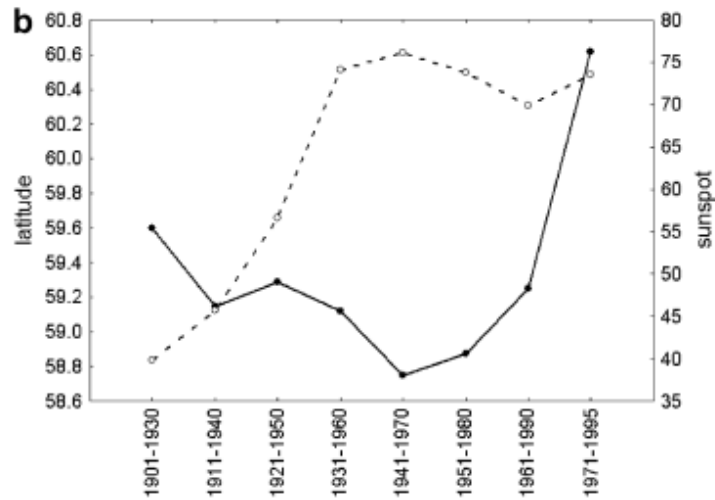
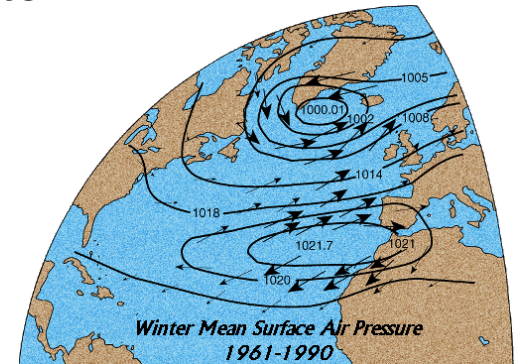


# Solar activity and the latitudes of the North Atlantic centers of action

with increasing solar activity Iceland low to the south

Azores high moves to the north

The two centers of action come closer



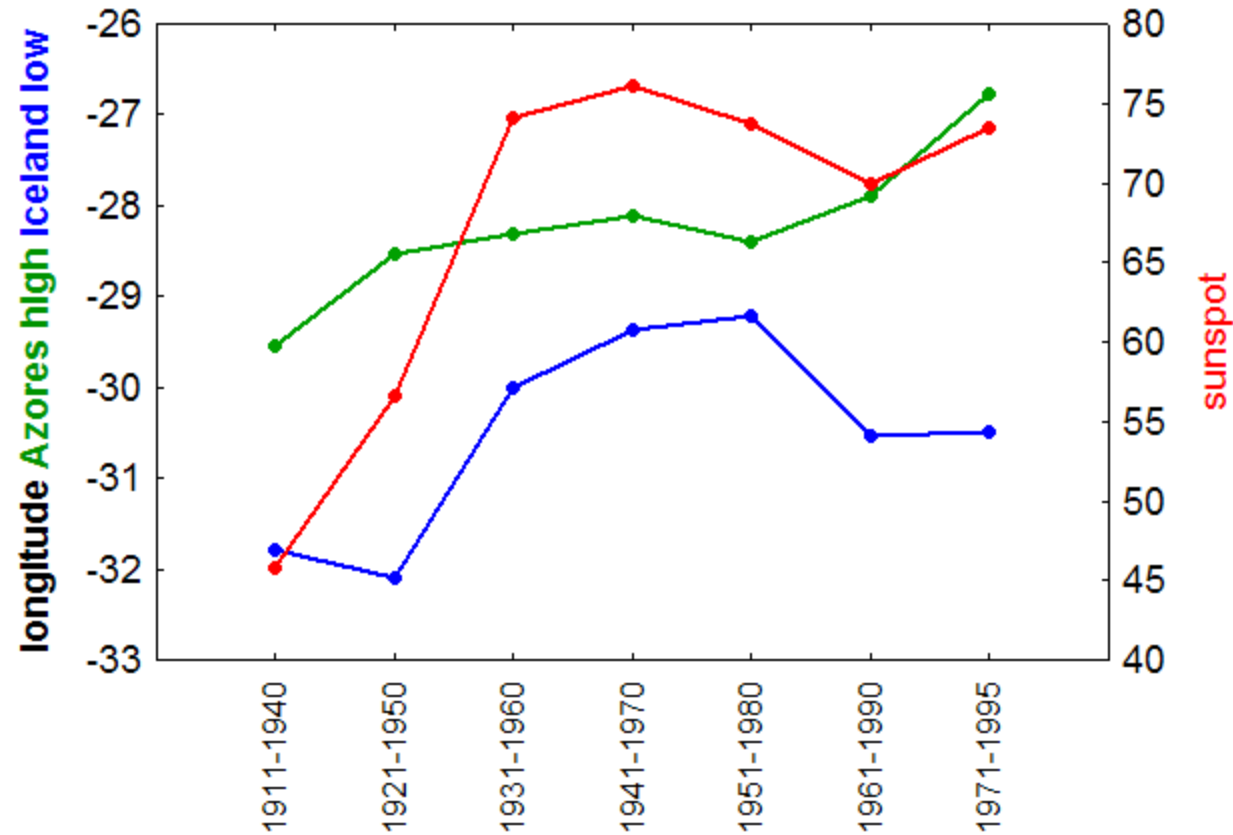
Solid lines: long-term variations in the latitude of the (a) Azores High and (b) Icelandic Low dashed line: long-term variations in sunspot number (Kirov and Georgieva, 2002)







# Solar activity and the longitudes of the North Atlantic centers of action



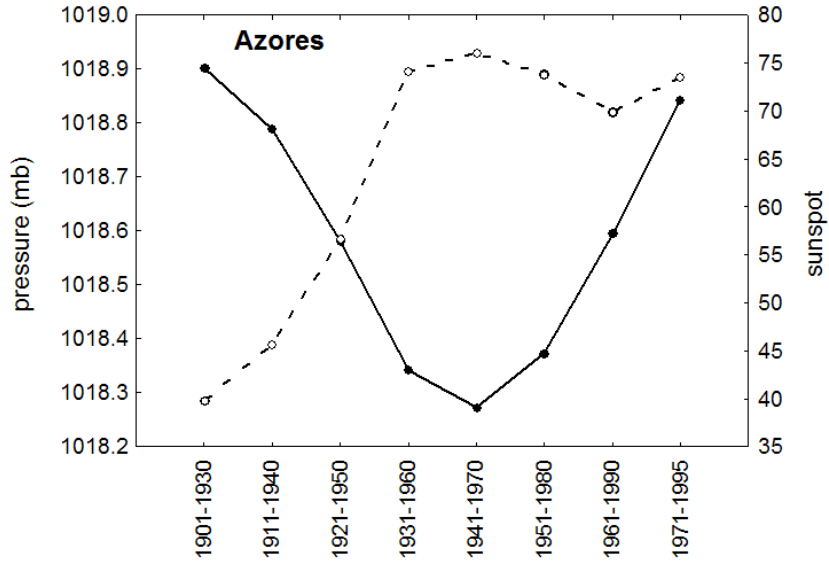
With increasing solar activity  
Iceland low moves to the East

Much smaller effect on the Azores high



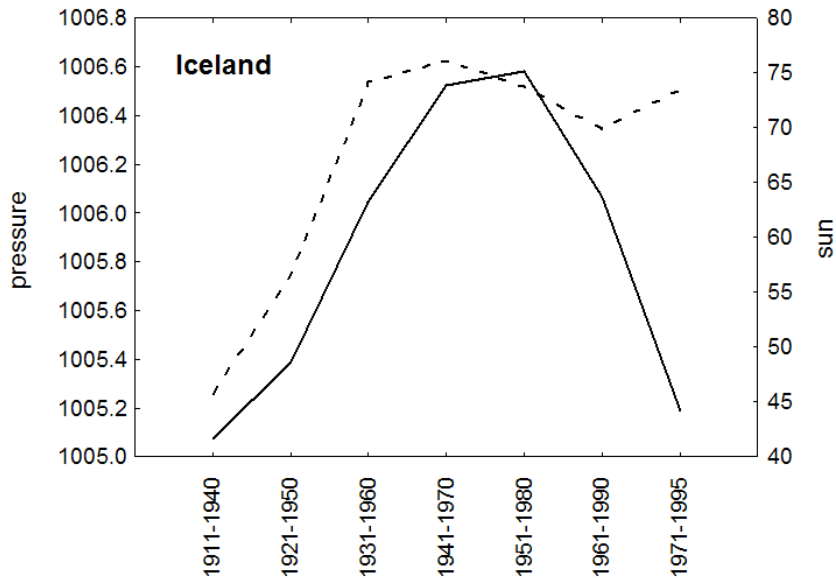


# Solar activity and the pressure in the North Atlantic centers of action



With increasing solar activity the pressure in Azores high decreases

the pressure in the Iceland low increases

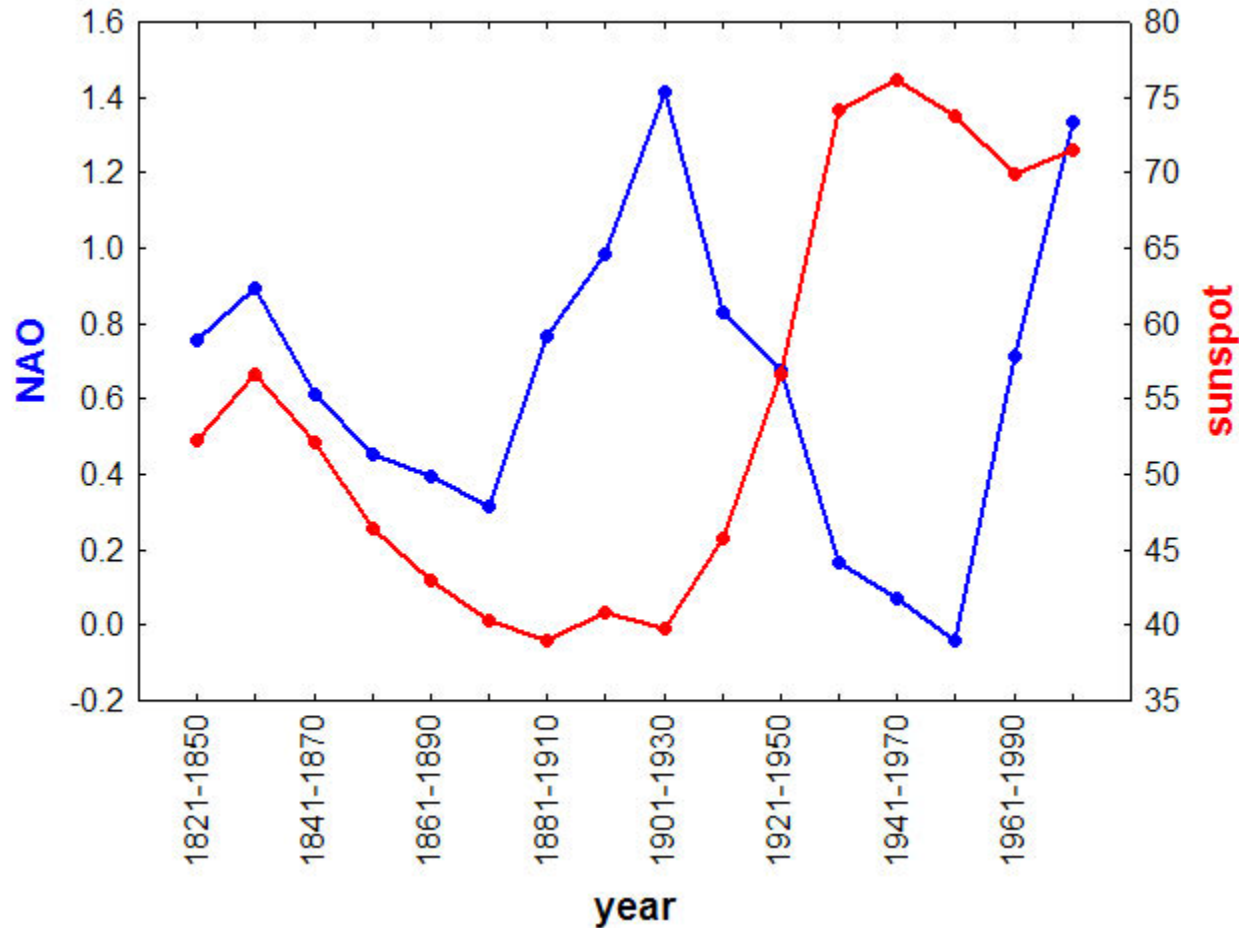


The pressure difference decreases





# NAO and Solar activity

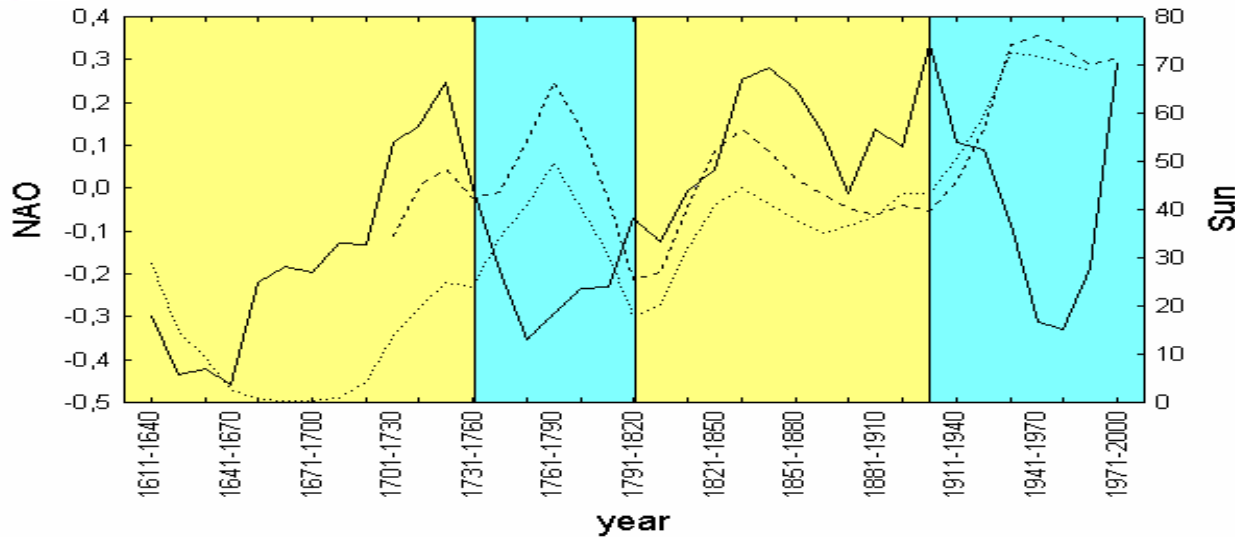


✓ long-term variations of NAO are negatively correlated to sunspot activity of the solar activity **but only in the XX century**

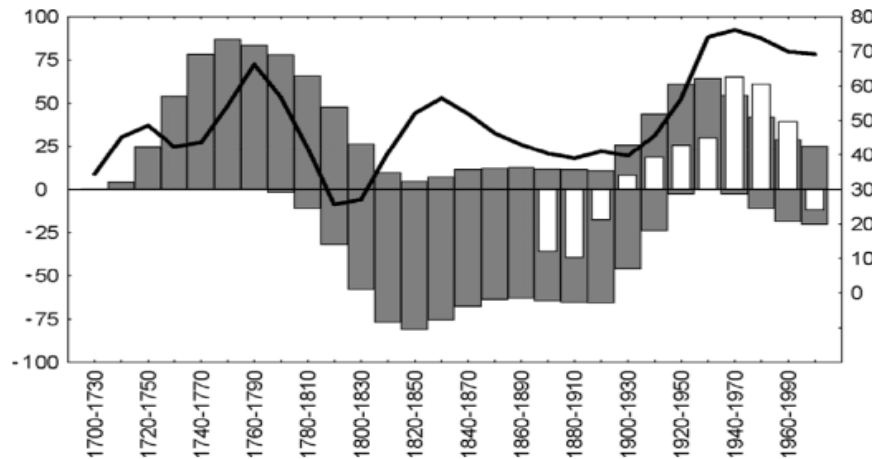




# NAO and Solar activity



✓ positive and negative correlations between the longer-term variations of NAO (back to 1611) and solar activity

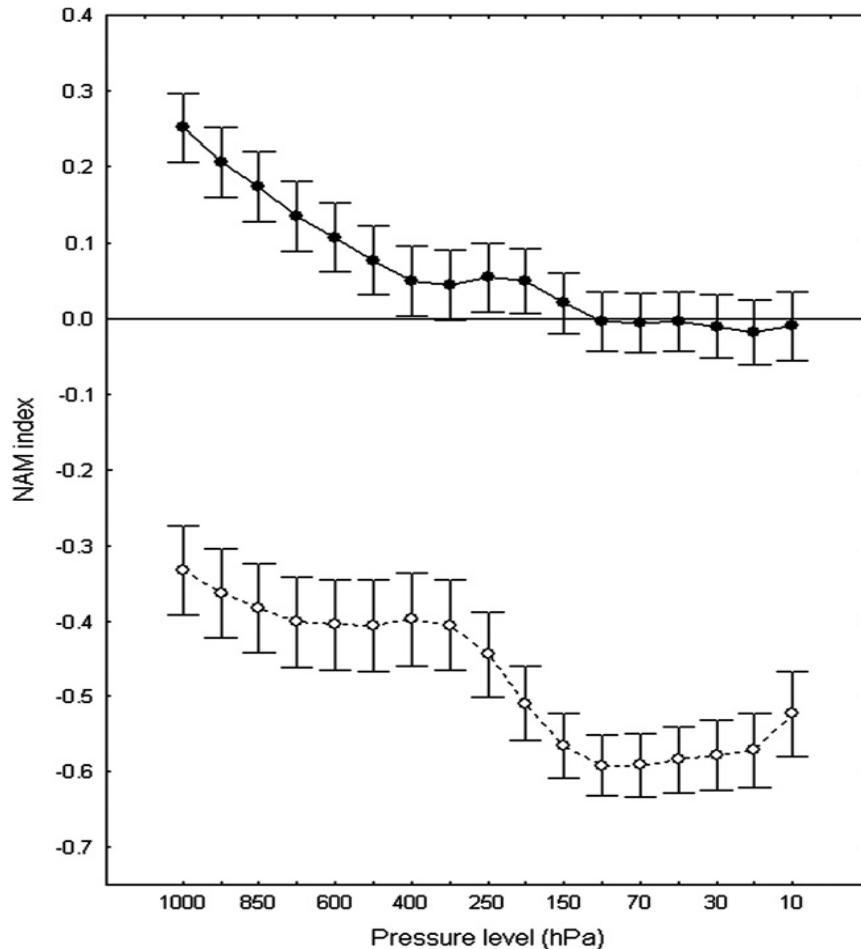
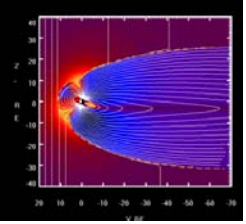


✓ positive and negative correlations between the solar activity and surface air temperature

Percentage of meteorological stations (grey bars) measuring positive (along the positive y-axis) or negative (along the negative y-axis) correlations in the 11 year sunspot cycle between solar activity and surface air temperature; secular sunspot cycle (solid line); north-south solar activity asymmetry,  $A = (SN - SS)/(SN+SS)$  (white bars)



# Geomagnetic activity, solar radiation and NAM index



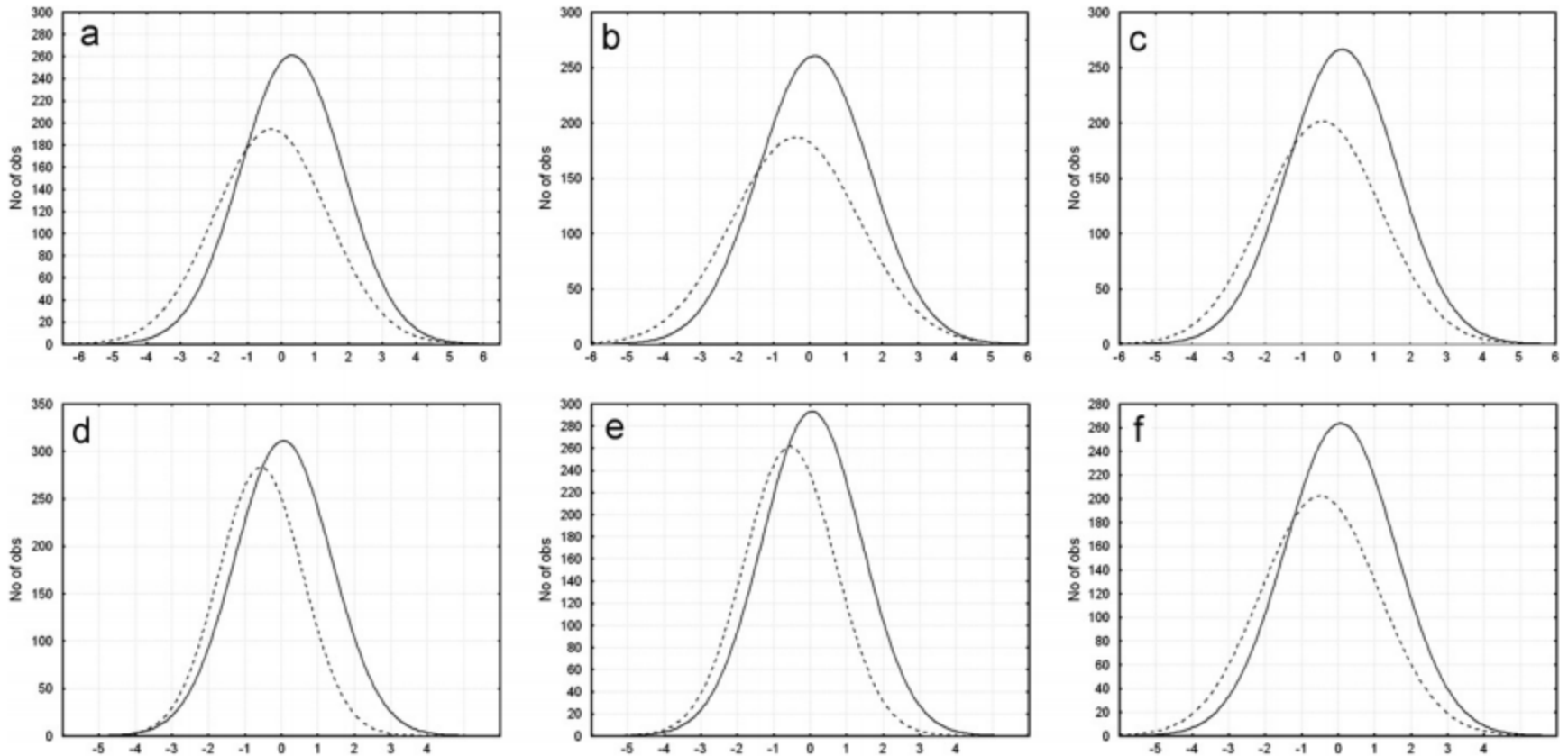
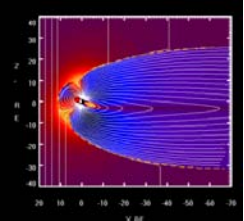
- At all altitudes, the winter NAM-index is on the average higher for high aa-index, low F10.7, and lower for low aa-index, high F10.7
- The differences are higher with increasing pressure levels—closer to the surface.

NAM index at levels from 1000 to 10 hPa for: high aa-index, low F10.7 (full circles, solid line) and high F10.7, low aa-index (open circles, dashed line), together with their error bars





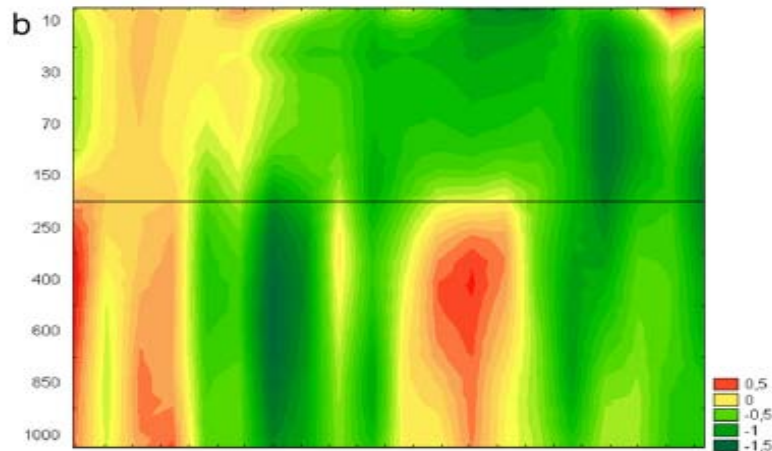
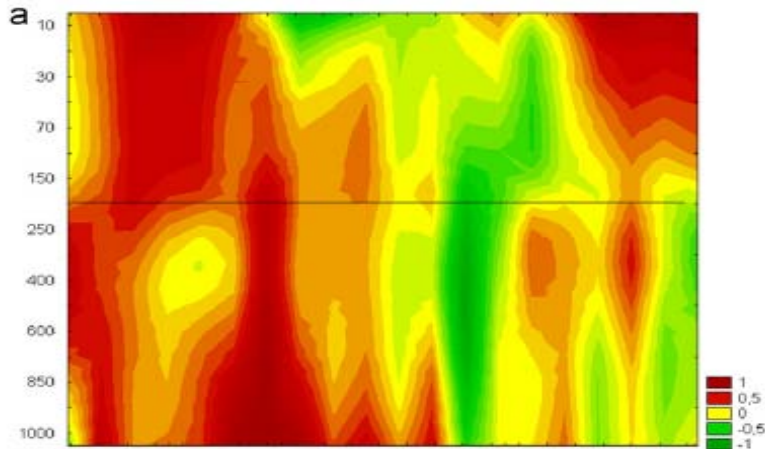
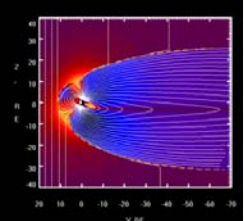
# Geomagnetic activity, solar radiation and NAM index



Histograms of the NAM-index values for high aa-index, low F10.7 (solid line) and high F10.7, low aa-index (dashed line) at (a) 1000hPa, (b) 500hPa, (c) 250hPa, (d) 100hPa, (e) 50hPa and (f) 10hPa.



# Geomagnetic activity, solar radiation and NAM index



- NAM-index is on the average positive for high geomagnetic activity, low irradiance
- Negative for low geomagnetic activity, high irradiance

Composites of time-height development of the NAM for the 11 winters of high aa-index and low F10.7 (a), and the 9 winters of high F10.7 and low aa-index (b). The horizontal line denotes the approximate altitude of the tropopause.

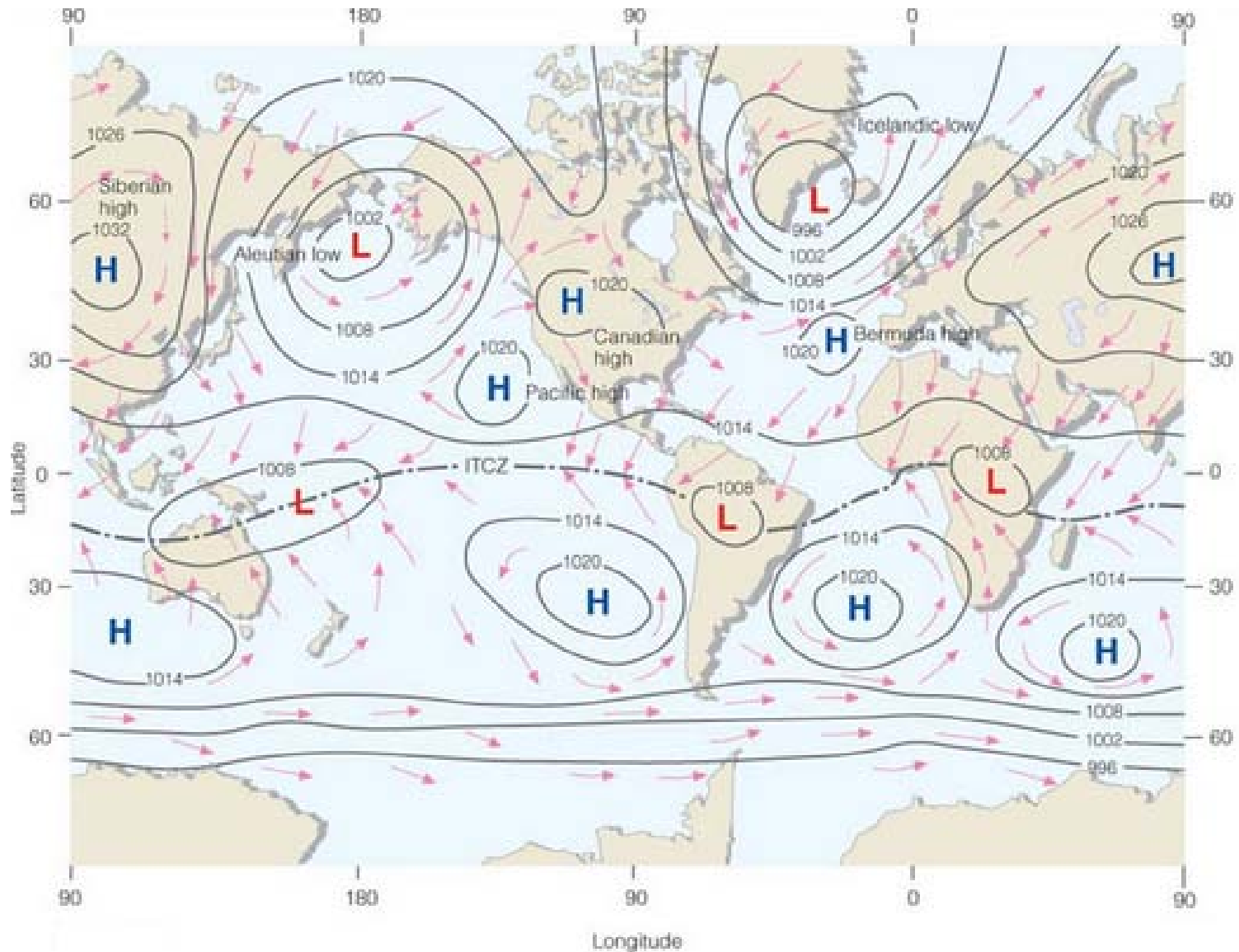


## comments

- The correlation between solar activity and NAO changes in consecutive 100-year solar cycles
- Solar irradiance and geomagnetic activity have opposite effects on NAO
- The changing correlation between solar activity and NAO may be due to changing relative influence of different solar drivers.

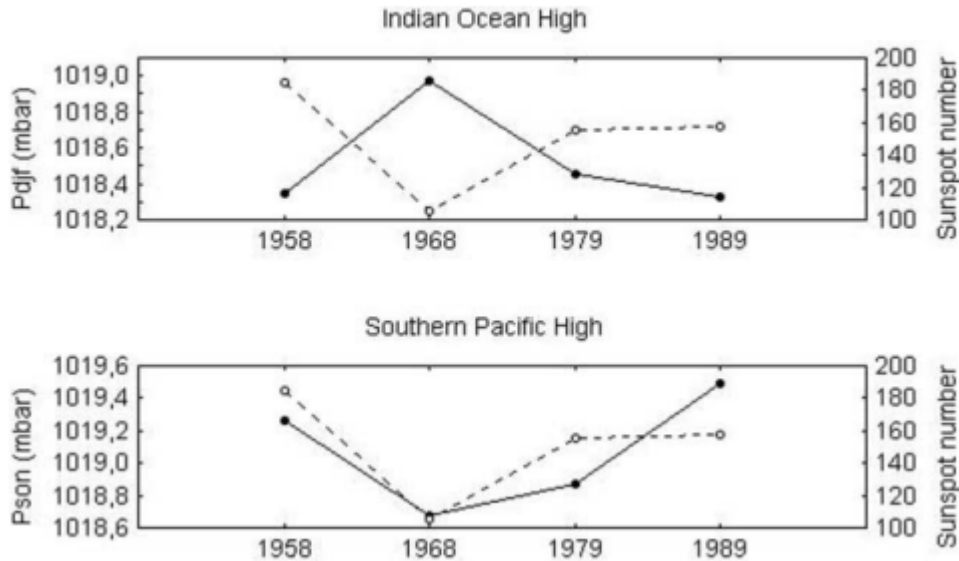


# Effects on other atmospheric center of actions





# Solar activity and Southern Hemisphere center of action



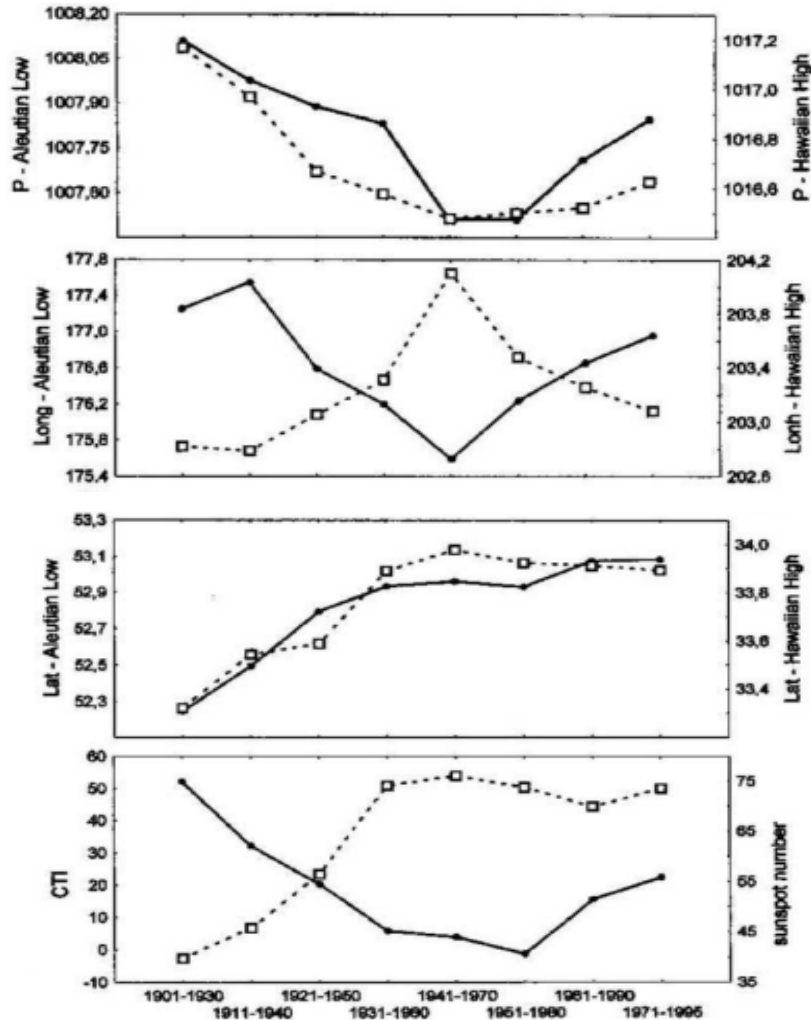
- The pressure in the Indian Ocean High (west of the Date line, 77.5E, 31.2S) is inversely related to solar activity, with  $r = -0.80$  for the “winter” months (December to January) – top panel.
- The pressure is in phase with solar activity to the east of the Date line, in the Southern Pacific High (117W, 31.4S) – bottom panel

Solar activity in four consecutive 11-year cycles maxima (broken line) and average pressure anomalies (solid line) from December to February – P<sub>djf</sub> – in the Indian Ocean High, top panel, and from September to November – P<sub>son</sub> – in the Southern Pacific High, bottom panel.





# Solar activity and Northern Pacific center of action



- The pressure in both of them decreases with increasing solar activity
- The longitude of the Aleutian Low decreases with increasing solar activity, i.e. it moves to the West and of the Hawaiian High increases, it moves to the East – the second panel
- The displacements in longitudinal location of both centers are about three times greater than their standard deviations
- From minimum to maximum solar activity in the secular solar cycle both Northern Pacific centers of action move towards the Pole

Long-term variations of the Aleutian Low (solid line) and Hawaiian High (broken line). From top to bottom: pressure, longitude, latitude; Bottom panel: Cold Tongue Index (CTI) – solid line, and solar activity – broken line.

