

The Sun-Climate Effect: The Winter Gatekeeper Hypothesis

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Abbreviations

97CS: 1997–1998 climate shift

$\delta^{18}\text{O}$: Change in oxygen isotope 18, expressed as ‰

μm : One millionth of a meter

- A -

a: Anni. Years taking 1950 as the reference present date

Aa index: The antipodal amplitude geomagnetic index

AAM: Atmospheric angular momentum

ACE: Abrupt climatic event

AD: Anno Domini. Number of years since the beginning of the Christian era in the Gregorian calendar

AGW: Anthropogenic global warming.

AMO: Atlantic Multidecadal Oscillation.

AMOC: Atlantic Meridional Overturning Circulation.

AO: Arctic oscillation

AOO: Arctic Ocean Oscillation index

AR: Assessment report published by the IPCC

ASR: Absorbed short-wave radiation.

- B -

BC: Before Christ. Label to indicate a number of years before the beginning of the Christian era in the Gregorian calendar

BDC: Brewer–Dobson circulation

BO: Biennial Oscillation of the polar vortex

BP: Before present. Number of years before 1950 in the Gregorian calendar

- C -

c.: Circa, approximately.

CMIP: Coupled model intercomparison project

CO₂: Carbon dioxide

- D -

D: Deuterium (hydrogen isotope 3)

- E -

ECMWF: European Center for Medium-range Weather Forecast

ENSO: El Niño/Southern Oscillation

EPICA: European Project for Ice Coring in Antarctica

EUMETSAT: European Organisation for the Exploitation of Meteorological Satellites

- G -

Ga: Giga anni. Number of 10⁹ years before the present

GCM: General circulation model

GHE: Greenhouse effect

GHG: Greenhouse gas

GISP2: Greenland Ice Sheet Project 2

GSAT: Global surface average temperature

- H -

HadCRUT: Hadley Climate Research Unit temperature

- I -

IERS: International Earth Rotation and Reference Systems Service

IPCC: Intergovernmental Panel on Climate Change

IR: Infrared radiation

ISGI: International Service of Geomagnetic Indices

ITCZ: Intertropical Convergence Zone

- K -

ka: Kilo anni. Number of 10³ years from the present

KNMI: Koninklijk Nederlands Meteorologisch Instituut

kyr: Kilo years, thousands of years

- L -

LGM: Last Glacial Maximum

LIA: Little Ice Age

LIG: Latitudinal insolation gradient

LOD: Length of day.

LTG: Latitudinal temperature gradient

LWR: Longwave radiation

- M -

Ma: Mega anni. Number of 10⁶ years before the present

MGW: Modern Global Warming

MSM: Modern Solar Maximum

MT: meridional transport

MWP: Medieval Warm Period

Myr: Mega years, millions of years

- N -

NAO: North Atlantic Oscillation

NASA: National Aeronautics and Space Administration

NCEP/NCAR: National Center for Environmental Prediction/National Center for Atmospheric Research reanalysis

NH: Northern Hemisphere

NOAA: National Oceanic and Atmospheric Administration

NSIDC: National Snow and Ice Data Center

- O -

OHC: Ocean heat content

OLR: Outgoing long-wave radiation

ONI: Oceanic Niño Index

- P -

PDO: Pacific Decadal Oscillation

PV: Polar vortex

- Q -

QBO: Quasi-biennial oscillation
QBOe: Easterly orientation of the quasi-biennial oscillation
QBOw: Westerly orientation of the quasi-biennial oscillation

- R -

RCP: Representative concentration pathway
RF: Radiative forcing
RSR: Reflected shortwave radiation
RWP: Roman Warm Period

- S -

SC: solar cycle, referred only to specific numbered 11-year sunspot cycle occurrences
SGM: Solar grand minimum/minima
SH: Southern Hemisphere
SLR: Sea level rise
SN: International sunspot number
SPM: Summary for policymakers
SR: Short-wave radiation

SST: Sea-surface temperature
SSW: Sudden stratospheric warming

- T -

TSI: Total solar irradiance
ToA: top of the atmosphere
TOR: Total outgoing radiation

- U -

UV: Ultraviolet

- W -

WACC: warm Arctic/cold continents
WDC-SILSO: World Data Center-Sunspot Index and Long-term Solar Observations
WGK-h: Winter Gatekeeper hypothesis
WMO: World Meteorological Organization
WWV: Warm water volume

- Y -

yr: Years

GLOSSARY

¹⁴C: Unstable isotope of carbon having an atomic weight of 14, and a half-life of c. 5,700 years. It is produced by the effect of cosmic and solar high-energy radiation on atmospheric nitrogen. It is used for radiocarbon dating going back some 40 ka, and as a proxy for past solar activity. Its production is affected by solar magnetic activity and geomagnetic changes.

– A –

aa index: The antipodal amplitude geomagnetic index is a measure of the disturbance level of the Earth's magnetic field based on magnetometer observations at two nearly antipodal stations in the UK and Australia. It is the oldest geomagnetic index as it has been reconstructed back to 1868.

Abrupt climate change: A climate change characterized by a persistent alteration in one or more climate variables at a rate that is higher than what is observed 80% of the time, leading to a different climate state that can last decades or longer.

Abrupt climatic event (ACE): A period of centuries that displays significantly altered climate variables on a global or hemispheric scale, as a result of abrupt climate change, constituting a different climate state.

Advection: The transfer of some property of the atmosphere or ocean, like heat, moisture or salinity, by predominantly horizontal mass motions of water or air. In meteorology and oceanography it is the horizontal equivalent of the predominantly vertical convection.

Albedo: Is the fraction (percentage) of solar radiation that is reflected from a surface. Atmospheric albedo due to cloud cover is the largest contributor to Earth's albedo. Surface albedo is highest from ice and lowest generally from the ocean.

Angular momentum: A vector quantity determined by the rotational momentum of a rotating body or system, equivalent to the product of the angular velocity of the body or system and its moment of inertia with respect to the rotation axis. The direction of the vector is the rotation axis.

Anomaly: Referred to temperature indicates a scale, usually in Kelvin or Celsius degrees, where the zero value has been placed at the average temperature of a certain period of time, usually 30 years. The name is unfortunate, as it suggests that temperature changes are anomalous.

Anthropogenic Global Warming (AGW): Global warming resulting from past and present human activities.

Aphelion: The point in an orbit which is farthest from the sun. For the Earth it happens currently around the 5th of July.

Arctic Oscillation (AO): Also known as Northern Hemisphere Annular Mode, the AO is a mode of climate variability that affects the winds circulating counterclockwise around the Arctic. A positive AO is characterized by strong winds, a ring-like jet stream, low surface pressure in the Arctic, and cold masses of air confined to polar regions. A negative AO is characterized by weaker winds, a meandering jet stream, high surface pressure in the Arctic, and cold masses of air penetrating non-polar latitudes. The AO index is calculated by comparing the 20–90°N 1000 mBar geopotential height field to its main mode of variability for the 1979–2000 period.

Atlantic Meridional Overturning Circulation (AMOC): A system of surface and deep oceanic currents in the Atlantic Ocean responsible for the transport of heat, salt, carbon and nutrients. Surface currents transport heat and moisture northward from the tropics, while deep cold currents return the salt southward. Regions of overturning at both ends link both subsystems.

Atlantic Multidecadal Oscillation (AMO): A recurrent mode of climate variability in the North Atlantic associated to changes in sea surface temperature, changes in North American, European and North African precipitation, and the intensity of North Atlantic hurricanes. It is characterized by alternating phases of 20–40 years with a c. 0.6 °C amplitude in sea surface temperature.

– B –

Bjerknes compensation: The proposition by Jacob Bjerknes in 1964 that variability in latitudinal heat transport by the ocean is largely compensated by variability of the opposite sign in latitudinal heat transport by the atmosphere. Although not formally demonstrated due to difficulties in measuring heat transport by the ocean, it is generally accepted.

Bond event: Periods of increased ice-rafting activity in the North Atlantic during the Holocene identified by Gerard Bond in 1997. Their number and periodicity have been the subject of controversy, but their climatic importance is not, as they correlate to precipitation changes at both sides of the Atlantic, periods of weakness in the Asian Monsoon, and aridity events in the Middle East.

BP: Before Present. Label to indicate a number of years before 1950 in the Gregorian calendar. This scale is common in Geology, and 1950 was selected because radiocarbon dating was developed in the early 1950s and used to date materials prior to that date.

Bray solar cycle: A solar activity periodicity of c. 2500-year period first described by Roger Bray in 1968 and linked to a climate periodicity of the same period and phase.

– C –

Cal (years): Calibrated years, also calendar years. Dating obtained from converting radiocarbon years to calendar years.

Climate change: A change in climate identified by statistically significant changes in its climatological variables that persist for an extended period, typically decades or longer. By this definition climate is always changing.

Climate sensitivity: See equilibrium climate sensitivity.

Climate: General pattern of weather conditions for an area. Climate is statistically defined in terms of the mean and variability of relevant climatological variables over a period of time ranging from months to thousands or millions of years.

CMIP: Coupled Model Intercomparison Project. A collaborative framework designed to improve knowledge for global coupled ocean–atmosphere general circulation models. Organized in 1995 by the Working Group on Coupled Modelling of the World Climate Research Programme. Its most recently completed phase of the project (2014–2020) is phase 6.

CO₂ hypothesis: Hypothesis proposing that the amount of CO₂ in Earth's atmosphere is the main factor governing the temperature of its surface, and that changes in CO₂ levels caused most large climate changes in the past and are responsible for present global warming.

Conduction: Thermal conduction is the transfer of heat between particles through collisions. The flow of energy is spontaneous from a hotter to a colder body and its rate depends on the temperature gradient and the properties of the conductive medium.

Convection: The transfer of some property of the atmosphere or ocean, like heat, moisture or salinity, by predominantly vertical mass motions of water or air. In meteorology and oceanography it is the vertical equivalent of the predominantly horizontal advection.

Cosmogenic isotopes: Unstable isotopes produced naturally by the effect of cosmic radiation on Earth's atmosphere. The main ones are ¹⁴C and ¹⁰Be.

– D –

Dansgaard–Oeschger event (D–O): A glacial-period abrupt climate event centered in the North Atlantic–Nordic Seas region characterized by abrupt warming, measured at 7–13 °C in Greenland ice cores, over a period of seven decades, followed by a slower return to glacial conditions over several centuries to a few millennia. Their effect is hemispheric and they are tied to Antarctic isotope maxima to produce a global climate feature that is well registered in global methane levels.

Dark Ages Cold Period (DACP): A climate interval after the Roman Warm Period and before the Medieval Warm Period characterized by cooling. It is usually dated c. AD 400–900.

de Vries solar cycle: A solar activity periodicity of c. 210-year period named after Hessel de Vries, who in 1958 identified two maxima in ¹⁴C production near AD 1500 and 1700.

– E –

Early Twentieth Century Warming (ETCW): The period of global warming between 1910 and 1945, that was of comparable magnitude (0.5 °C versus 0.6 °C) to the Late Twentieth Century Warming (LTCW) between 1975–2000, despite a much lower increase in atmospheric CO₂ levels.

Earth System Model: A model that incorporates biogeochemistry and the carbon cycle, and from an emissions pathway produces a model of resulting CO₂ atmospheric levels.

Easterlies: Prevailing pattern of surface winds from the east toward the west. At the Hadley cell they are known as trade winds, and at the Polar cell as polar easterlies.

Eccentricity: In astrodynamics eccentricity is a measure of the ellipticity of an orbit, with a value between zero for a circular orbit and one for a parabola.

Eddy: Fluid current with a different direction to the general flow. They are responsible for most of the energy and angular momentum transfer within the fluid. The size and number of eddies is a measure of turbulence. Examples of atmospheric eddies are hurricanes, cyclones and anticyclones, and Rossby waves. Oceanic eddies are responsible for upwelling and downwelling.

Eddy solar cycle: A solar activity periodicity of c. 1000-year period named after John A. Eddy, who described it in 1976.

El Niño/Southern Oscillation (ENSO): Irregularly periodic oscillation of 2–5 years in sea surface temperatures and predominant winds strength over the tropical eastern Pacific Ocean, that affects the weather of much of the world.

El Niño: The warm phase of the El Niño Southern Oscillation (ENSO) associated to warm surface waters in the Central–East Pacific Ocean and a weakening or reversal of the easterly trade winds.

Enthalpy: Enthalpy comprises a system's internal energy, plus the amount of work required to establish its volume and pressure. It is the preferred expression of energy changes in many scientific disciplines as changes in enthalpy equal the energy transfer through heat and work when there is no transfer of matter at constant pressure.

Equable climate problem: Refers to the inability by climate models to reproduce past hothouse climates of the Earth (e.g. Early Eocene, Cretaceous), characterized by reduced equator to pole temperature difference, warm polar regions with a reduced seasonality and ice free conditions at both poles, without resorting to unrealistic greenhouse gas concentrations or altered physical parameters.

Equilibrium Climate Sensitivity (ECS): The amount of warming produced by a doubling of atmospheric CO₂ levels after the oceans have had time to equilibrate.

– F –

- Feedback:** A feedback occurs when part of the output from a system is added or subtracted to the input modifying the result. Amplifying feedbacks are positive and dampening feedbacks negative. Systems dominated by negative feedbacks are inherently stable and systems where positive feedbacks predominate are unstable.
- Ferrel Cell:** Part of the atmospheric circulation pattern proposed by William Ferrel in 1856 to explain prevailing wind patterns between latitudes 35–60° in both hemispheres. Part of the ascending air at 60° diverges at high altitude westward and towards the equator meeting an opposite circulation from the Hadley cell at 30° latitude. There it subsides and strengthens the high pressure ridges beneath. Then the air flows eastward and northward near the surface. The Ferrel cell is driven by the existence of the Hadley and Polar cells, as it lacks a powerful heat source or sink. Due to this it is a weaker cell with more mixed winds, and its characteristic surface winds are called prevailing westerlies. The Ferrel cell is not a very good representation of reality as at 10-km height strong westerlies are usually found.
- Feynman solar cycle:** A solar activity periodicity of c. 100-year period named after Joan Feynman, who described it in 1982 based on solar wind and geomagnetic activity.
- Forcing:** Any process or perturbation that drives climate change.

– G –

- Ga:** Giga anni (10⁹ years), a unit of time to indicate age in billions of years from the present, taking 1950 as the reference present date.
- General circulation model (GCM):** Numerical models representing physical processes in the atmosphere, ocean, cryosphere and land surface.
- Geopotential height:** It is the actual height of a pressure surface above mean sea-level, and is related to the density of the air below. A low geopotential height indicates the presence of cold dense air masses below, while a high geopotential height indicates the opposite. It is measured in meters relative to a given pressure. On a weather map height contours connect points of equal geopotential height.
- Glacial period:** An interval of time within an ice age when surface temperature is several degrees lower than present, and polar and mountain ice sheets are much more extensive, covering large parts of the northern hemisphere.
- Greenhouse effect (GHE):** It is the difference between the temperature at which a planet must emit infrared radiation to balance the absorbed solar radiation and the temperature at its surface. It is primarily due to atmospheric greenhouse gases that absorb and emit infrared radiation. Due to the GHE, the Earth is 33°C warmer than it would be with an atmosphere transparent to infrared radiation, or no atmosphere.
- Greenhouse gas (GHG):** A gas that absorbs and emits energy within the thermal infrared part of the spectrum. The main GHGs in Earth's atmosphere are water vapor (H₂O_v), carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), ozone (O₃), chlorofluorocarbons (CFCs), and hydrofluorocarbons (HFCs). In climatology the term might refer only to non-condensing greenhouse gases, excluding water vapor.
- Greenhouse theory:** Theory describing how the surface temperature of a planet, with an atmosphere containing greenhouse gases, is determined by the balance between the absorbed solar radiation and the emitted infrared radiation. Due to the presence of greenhouse gases, infrared radiation emission to space takes place mostly from the atmosphere instead of the surface, and the temperature of the surface becomes warmer. Changes in the amount of greenhouse gases cause an imbalance between absorbed and emitted energy, due to a change in the height of infrared radiation emission. The balance is restored by a change in the surface and atmosphere temperature, causing a change in climate.
- Greenland Ice Sheet Project 2 (GISP2):** A 1998–1993 drilling project at the Greenland ice sheet summit, and the ice core that it produced.

– H –

- HadCRUT:** A global surface temperature dataset produced by the Hadley Centre of the UK Met Office and the Climatic Research Unit of the University of East Anglia. Current version is HadCRUT5.
- Hadley Cell:** Part of the atmospheric circulation pattern proposed by George Hadley in 1735 to explain prevailing wind patterns near the equator (trade winds). High insolation in the equatorial band causes warm air to rise. At high altitude the warm air moves poleward and deviates eastward by the Coriolis force. Upon reaching 30° latitude the air sinks and closes the loop by moving equatorward and westward at the surface creating the trade winds (easterlies).
- Hale solar cycle:** A solar magnetic cycle of c. 22 years discovered by George Ellery Hale in 1919, that comprises two 11-year sunspot cycles, during which the polarity of the solar magnetic polar fields and the polarity of the sunspot pairs reverses twice.
- Heinrich event (HE):** Recurrent climate event during the glacial period responsible for the deposition of a very prominent layer of ice-rafted debris at the bottom of the North Atlantic Ocean. They were discovered by Hartmut Heinrich in 1988. Heinrich events constitute periods of very intense iceberg activity indicative of a massive collapse at the Atlantic borders of the ice sheets. They coincide with colder periods in Greenland and warming periods in Antarctica. There are six of them between 60 and 17 ka, with the Younger Dryas possibly constituting the most recent one.
- Hiatus:** In climatology, each period of time during the instrumental era of temperature measurements (since 1850) when little or no warming has taken place. Hiatuses appear to be the low phase of a c. 65-yr periodicity. The first hiatus took

place between 1879 and 1909. The second hiatus happened between 1944 and 1974. The third hiatus started around 1998 and is still ongoing.

Holocene: The current interglacial and geological epoch. The base of the Holocene has been stratigraphically defined at 11,700 B2K (11,650 BP) by the International Union of Geological Sciences.

Holocene Climatic Optimum (HCO): A period within the Holocene when the highest global average temperatures were reached. Although its temporal span varied between different regions, globally it can be considered to have taken place roughly between 9600 and 5500 BP.

Holton–Tan Effect: A phenomenon in which the strength of northern stratospheric winter polar vortex synchronizes with the equatorial quasi-biennial oscillation. The vortex becomes stronger and colder when the QBO is in its westerly phase and weaker and warmer when it is in its easterly phase.

– I –

Ice Age: Any geological period of the Earth history characterized by the presence of large continental ice sheets. We are currently in the Quaternary Ice Age, as both Greenland and Antarctica are covered by ice sheets. Within an ice age there are alternating colder glacial periods, or stadials, and warmer interglacials, or interstadials. Historically and popularly the term ice age is used as a synonym for glacial periods, generating confusion.

Ice-rafted debris (IRD): Deposits of material, usually of petrological origin, found at the bottom of a water body that have been transported by ice. During the Pleistocene the transport of sediments by icebergs to areas of high iceberg melting rates was a primary mechanism of sediment transport. The mineralogical nature of the sediments allows to trace the regional origin of the icebergs responsible for the transport.

Indo–Pacific Warm Pool (IPWP): A large area ($>30 \times 10^6$ km²) in the tropical western Pacific Ocean and eastern Indian Ocean of c. 7% of the planet surface that is permanently above 28 °C. The high temperature causes deep convection, producing clouds that rise to 15 km high, and result in significant atmospheric circulation effects. It is an important component of the global climate system.

Infrared radiation (IR): Radiation with a wavelength between 0.75–1000 μm. The relevant IR for climate is the thermal infrared, between 3–15 μm.

Interferometry: A technique based on the superposition of electromagnetic waves in order to extract information from their interference. In radio astronomy, very-long-baseline interferometry allows the precise timing of the arrival of a signal from a very distant source with atomic clocks at faraway radiotelescopes for imaging remote cosmic radio sources and astrometry. When used in reverse it allows the precise measurement of changes in Earth's rotation speed and the mapping of tectonic movements.

Intergovernmental Panel on Climate Change (IPCC): The United Nations body in charge of producing reports assessing the published science on climate change.

Intertropical Convergence Zone (ITCZ): Is the climatic equator of the planet, the area encircling the Earth where the northeast and southeast trade winds converge, producing what is known by sailors as the calms. It is formed by high tropical insolation driving warm, moist air convection, forming the ascending branch of the Hadley cell. As the air ascends it cools down forming a band of clouds and thunderstorms that encircle the globe near the Equator. The ITCZ location varies through the seasons, moving North from January to July and South from July to January, following the band of maximal solar flux. Tropical monsoons are linked to the position of the ITCZ, and long-term changes in its position due to changes in insolation derived from precessional and obliquity changes have a very important effect on paleoclimate evolution.

– L –

La Niña: The cold phase of the El Niño Southern Oscillation (ENSO) associated to cold surface waters in the Central–East Pacific Ocean and a strengthening of the easterly trade winds.

Last Glacial Maximum (LGM): The time during the last glacial period when ice sheets were at their greatest extent. It is defined based on sea level being 125 meters below current level between 26.5 and 19.0 ka.

Late Cenozoic Ice Age: The present ice age, that started at 33.9 Ma at the Eocene–Oligocene Boundary with the beginning of Antarctic glaciation. It spans the second half of the Cenozoic Era.

Late Twentieth Century Warming (LTCW): The period of global warming between 1975 and 2000, that was of comparable magnitude (0.6 °C versus 0.5 °C) to the Early Twentieth Century Warming (ETCW) between 1910–1945, despite a much higher increase in atmospheric CO₂ levels.

Latitudinal insolation gradient (LIG): The gradient determined by the angle of incidence of solar radiation in the amount of energy received from the sun in a period of time at the planet's surface (for example, kWh/m²/day), that changes with latitude. This gradient acts on the climate system through differential solar heating, which determines the Earth's latitudinal temperature gradient that drives the atmospheric and ocean circulation and creates the different climatic zones. The LIG changes with the seasons and on longer timescales with changes in obliquity and precession.

Latitudinal temperature gradient (LTG): The surface temperature gradient, determined mainly by differential solar heating, that changes with latitude, and by the efficiency of the heat transport from the tropics to the poles. The LTG drives the atmospheric and ocean circulation and creates the different climatic zones. The LTG changes with the seasons and on longer timescales with changes in obliquity and precession, but unlike the LIG it also changes when there is a

latitudinal change in surface temperatures, like with Arctic warming amplification. The LTG is a central property of the planet's climate system.

Length of day (LOD): A measure of day-length fluctuations determined by the difference between the astronomically determined duration of the day and 86,400 International System seconds.

Little Ice Age (LIA): A climate interval after the Medieval Warm Period characterized by cooling and mountain glaciers expansion. There is no agreement on the LIA timespan. In this book the LIA is considered to start after the 1257 Samalas eruption and end after the effects of the 1835 Cosigüina eruption were over, spanning 1258–1840.

Low gradient paradox: The physical paradox posed by equable climates with warm poles requiring enhanced meridional fluxes of heat to sustain mild high latitude temperatures while keeping low latitudes from becoming exceedingly warm and the turbulence theory standpoint that the meridional heat flux is proportional to the meridional temperature gradient.

Lunisolar: Caused by both the sun and the moon.

– M –

Medieval Warm Period (MWP): A climate interval after the Dark Ages Cold Period and before the Little Ice Age characterized by warming and mountain glaciers contraction. It is usually dated c. AD 950–1250.

Milankovitch Theory: The theory proposed by Milutin Milanković in 1920 to explain the alternation of interglacial and glacial periods during the Pleistocene as a result of long-period changes in the orbit of the Earth caused by the gravitational pull of the sun, the moon and the planets. It was demonstrated in 1976 that Pleistocene climate proxies follow the orbital frequencies proposed by Milanković.

Modern Global Warming (MGW): The period of warming of c. 300 years from the bottom of the Little Ice Age between 1650–1700 to the present.

Modern Solar Maximum (MSM): The period 1935–2004, defined by solar cycles 17–23, constituting the longest period in the sunspot record of above average decadal solar activity.

– N –

Neoglacial Period: The period of the Holocene between c. 5200–400 BP characterized by an increase in global glacier advances and a decrease in global temperature. It is thought to have been driven by the decrease in Earth's obliquity and in northern summer insolation due to precession.

Neoglaciation: The increasing trend in global glacier advances after the Holocene Climatic Optimum identified and named by François Matthes in the 1940s.

Nodal precession: It is the precession of the orbital plane of a satellite around the rotational axis of the main body. In the case of the Moon it is the time it takes the ascending node to move through 360° relative to the vernal equinox. It is about 18.6 years.

North Atlantic Oscillation (NAO): A north–south dipole of atmospheric pressure mode of variability over the North Atlantic that displays prominent climatic teleconnections. One center of the dipole is located over Greenland and the other center of opposite sign is located in the Central North Atlantic between 35–40°N. The North Atlantic Oscillation (NAO) index is constructed from the pressure difference between the Icelandic Low and the Azores High. The oscillation switches between a positive mode with strong Icelandic Low and Azores High and a negative mode with weak Icelandic Low and Azores High. Strong NAO positive phases display above-average temperature in the Eastern US and Northern Europe and below-average temperature in Greenland and often in Southern Europe and the Middle East. They are also associated with above-average winter precipitation over Northern Europe and Scandinavia, and below-average winter precipitation over Southern and Central Europe. Opposite patterns of temperature and precipitation anomalies are typically observed during strong NAO negative phases.

– O –

Obliquity: The angle between the earth's orbital plane (ecliptic) and equatorial plane, also called axial tilt. It can change between 22.1° and 24.5°, and currently is equal to 23°26' (23.44°) and decreasing. It is the main Milankovitch parameter for orbital forcing of climate, responsible for the spacing and occurrence of interglacials.

Oceanic Niño index (ONI): NOAA's El Niño/Southern Oscillation index based on sea-surface temperature in the Niño 3.4 region (5°N–5°S, 120–170°W).

Orbital tuning: The process of adjusting the time scale of a geologic or climate record so that the observed fluctuations correspond to calculated orbital changes. Overtuning can result if the features in the record do not correspond to the chosen orbital changes, leading to circular reasoning.

– P –

Pacific Decadal Oscillation (PDO): A climatic mode of variability in the North Pacific with ample teleconnections. It is defined as the leading pattern of sea surface temperature anomalies in the North Pacific basin. It is strongly influenced by ENSO and represents a long-term envelop of ENSO variability. Its phases can last decades and when positive present negative SST anomalies in central and western North Pacific and positive SST anomalies in the eastern North Pacific and the opposite when positive. A weak mirror image of these anomalies occur across the South Pacific.

Pause: See hiatus.

Pentadecadal solar cycle: A statistically weak reduction in solar activity every c. 50 years that is supported by cosmogenic ¹⁰Be frequency analysis in the annually resolved DYE-3 Antarctic ice core.

Perihelion: The point in an orbit which is closest to the sun. For the Earth it happens currently around the 4th of January.

Petrological tracer: A mineral sediment whose origin can be traced to geological formations within a certain region.

Pleistocene Glaciation: Also known as Quaternary Glaciation, it comprises the last 2.59 Myr within the Late Cenozoic Ice Age when ice-sheets in the Northern Hemisphere began to grow outside Greenland at intervals. The 2.59 Ma boundary was chosen as a convenient point within a period of global cooling with major cooling phases between 2.8–2.4 Ma and cold evidence at mid-latitudes at the time of the Isthmus of Panama closure.

Polar Cell: Part of the atmospheric circulation pattern. Very cold air at high altitude in polar regions sinks creating a high pressure area and moving equatorward and westward at surface (polar easterlies) towards the 60° parallel, where it meets opposite warmer more humid winds from the Ferrel cell. The air ascends and diverges, with part of it moving polarward and eastward at high altitude to close the loop.

Polar vortex: A large region of low pressure cold air rotating cyclonically (clockwise in the Southern Hemisphere, counter-clockwise in the Northern Hemisphere) around both poles that manifests both in the troposphere and stratosphere. The stratospheric polar vortex is an Autumn-Spring phenomenon, while the tropospheric polar vortex usually persists, albeit weakened, during the Summer.

Precession: In a rotating body or system, precession is the comparatively slow (with respect to the rotation speed) change in the orientation of the rotating axis. Earth's axial precession is responsible for the slow displacement of the equinoxes (and seasons) along its orbit, with very important climatic repercussions, constituting one of Milankovitch orbital forcings. Earth's orbit around the sun also has a rotation axis that presents precession (apsidal precession), modifying the frequencies of the precession of the equinoxes.

– Q –

Quasi-Biennial Oscillation (QBO): Is a quasi-periodic oscillation in the strong stratospheric winds that circle the planet high above the equator, descending about 1 km per month. The new belt that develops above the old one has an opposite orientation. At a given height (measured at 30 hPa) westerlies and easterlies alternate every c. 14 months. The amplitude of the easterly phase (QBOe, negative values of wind speed) is about twice as strong as that of the westerly phase (QBOw, positive values of wind speed), and lasts a little longer, but climatically low speed easterly winds (–5–0 m/s) behave as westerly winds. The QBO has important repercussions on the northern hemisphere climate, particularly during winters, affecting the strength of the Polar Vortex and the Jet Stream.

Quaternary: The current and most recent of the three periods of the Cenozoic Era that spans the last 2.59 Myr and is divided into two epochs: the Pleistocene (2.59 Ma to 11.7 ka) and the Holocene (11.7 ka to today).

Quaternary Glaciation: See Pleistocene Glaciation.

– R –

Radiative forcing (RF): The net change in the energy balance of the Earth system due to some imposed perturbation.

Representative concentration pathway (RCP): A greenhouse gas concentration trajectory adopted by the IPCC for its Assessment Reports for the purpose of modelling climate change.

Roman Warm Period (RWP): A very long climate interval after the 2.8 Ka event and before the Dark Ages Cold Period characterized by warming and mountain glaciers contraction. Some authors date it at 2500–1600 BP (550 BC – AD 350), while others restrict it to 250 BC – AD 350. Historical and climatic evidence suggests the Roman Warm Period could have been as warm or warmer than the present.

Rossby wave: also planetary wave, is a kind of inertial wave generated in rotating planets due to differences in the Coriolis effect with latitude. Atmospheric Rossby waves are huge meanders in high-altitude winds with wavelengths of several hundreds of kilometers. Oceanic Rossby waves are much smaller and generally associated to the thermocline.

– S –

Schwabe solar cycle: A solar activity periodicity of c. 11-year period named after Samuel Heinrich Schwabe, who described it in 1843. It is traditionally measured by counting the number of sunspots in the sun.

Seasonality: The variation between the seasons. In paleoclimatology the difference between the seasons has changed over time with changes in precessional-linked insolation. Currently northern hemisphere winters are warmer and summers cooler than they were during the Early Holocene, displaying a decrease in seasonality over time.

Stadium wave hypothesis: The hypothesis proposed by Marcia Glaze Wyatt in 2012 of a multidecadally varying climate signal that propagates across the Northern Hemisphere within a network sequence of synchronized ocean, atmosphere, and sea-ice indices. All indices vary at the same timescale of c. 64 years peak-to-peak throughout 20th century with one index leading the next in a consistently ordered lead-lag fashion.

Stefan–Boltzmann equation: Equation describing the Stefan–Boltzmann law that relates the energy radiated by a body to its temperature.

Summary for policymakers (SPM): Summary of the IPCC reports intended to aid policymakers. The form is approved line by line by governments.

– T –

Thermohaline circulation (THC): Also called the Great Ocean Conveyor Belt. The main component of general oceanic circulation below the surface and at depth controlled by differences in temperature and salinity. Cold, salty water sinks mainly in the polar regions and outside the Mediterranean and spreads slowly into the rest of the oceans before resurfacing at multiple places as cold, less saline, rich in nutrients water that is warmed and increases in salinity as it moves towards the sinking areas. In the process it transports huge amounts of heat, nutrients and ions over vast distances. It is responsible for part of the heat transport from the equator towards the poles, and it links both poles by the polar see-saw.

Total solar irradiance (TSI): The total amount of solar radiation in W/m^2 received outside the Earth's atmosphere on a surface normal to the incident radiation, and at the Earth's mean distance from the Sun. It can only be measured reliably from satellites and the record extends back only to 1978. The solar cycle variation of TSI is of the order of 0.1%.

– W –

Westerlies: Dominant pattern of surface winds from the west toward the east. At the Ferrel cell they are known as prevailing westerlies.