

# Climate4you update June 2024



## Summary of observations until June 2024:

1: Observed average annual global air temperature change last 30 years is about  $+0.016^{\circ}\text{C}$  (UAH). If unchanged, additional average global air temperature increase by year 2100 will be about  $+1.2^{\circ}\text{C}$ .

2: Tide gauges along coasts indicate a typical global sea level increase of about 1-2 mm/yr. Coastal sea level change rate last 100 year has essentially been stable, but with periodic variations. If unchanged, global sea level at coasts will typically increase 8-16 cm by year 2100, although many locations in regions affected by glaciation 20,000 years ago, will experience a relative sea level drop.

3: Since 2004 the global oceans above 1900 m depth on average have warmed about  $0.037^{\circ}\text{C}$ . The maximum warming (about  $0.2^{\circ}\text{C}$ , 0-100 m depth) mainly affects oceans near Equator, where the incoming solar radiation is at maximum.

4: Sources and sinks for  $\text{CO}_2$  are many. However, changes in atmospheric  $\text{CO}_2$  follow changes in global air temperature, and changes in global air temperature follow changes in ocean surface temperature.

5: There was no perceptible effect on atmospheric  $\text{CO}_2$  due to the 2020-21 COVID-related drop in GHG emissions, underlining the fact that natural sinks and sources for atmospheric  $\text{CO}_2$  far outweigh human contributions. Therefore, any future reductions in the use of fossil fuels are unlikely to have any significant effect on the amount of atmospheric  $\text{CO}_2$ .

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General: This newsletter contains graphs and diagrams showing a selection of key meteorological variables, updated to the most recent past month, if possible. All temperatures are given in degrees Celsius.

Traditionally, a 30-year reference period is often used by various meteorological institutions for comparison purposes and are supposed to be updated through the end of each decade ending in zero (e.g., 1951-1980, 1961-1990, 1971-2000, etc.). The concept of a normal climate goes back to the first part of the 20th century. At that time, lasting to about 1960, it was generally believed that for all practical purpose's climate could be considered constant, no matter how obvious year-to-year fluctuations might have been. On this basis meteorologist decided to operate with an average or normal climate, defined by a 30-year period, called the normal period, assuming that it was of sufficient length to iron out all intervening variations.

In fact, using a 30-yr 'normal' period is rather unfortunate, as observations clearly demonstrate that various global climate parameters (see, e.g., page 20) are influenced by periodic changes of 50-70 years duration. The frequently used 30-yr reference period is roughly half this time interval and is therefore highly unsuited as reference period. In the maps on page 4, showing the geographical pattern of surface air temperature anomalies, the last previous 10 years are therefore used as reference period. This decadal approach corresponds well to the typical memory horizon for many people and is also adopted as reference period by other institutions, e.g., the Danish Meteorological Institute (DMI).

In many diagrams shown in this newsletter the thin line represents the monthly global average value, and the thick line indicate a simple running 37-month average, nearly corresponding to a three-year average. The year 1979 has been chosen as starting point in many diagrams, as this approximately corresponds to both the beginning of satellite observations and the onset of the late 20<sup>th</sup> century warming period. However, most of the data series have a longer record length, which may be inspected in greater detail on [www.climate4you.com](http://www.climate4you.com).

### June 2024 surface air temperature

General: For June 2024, the GISS data portal provided AIRS interpolated surface air data, based on satellite observations (p.4-5). According to the GISS and NCDC records, the June global temperature anomaly was slightly higher than the May anomaly. The UAH lower troposphere satellite series show the June temperature anomaly to be lower than in May. The AIRS v6 June global average temperature anomaly compared to the average for the last 10 years shows little change (diagrams p.4-5). All the above air temperature records are registering the declining El Niño episode in the Pacific Ocean (p.25).

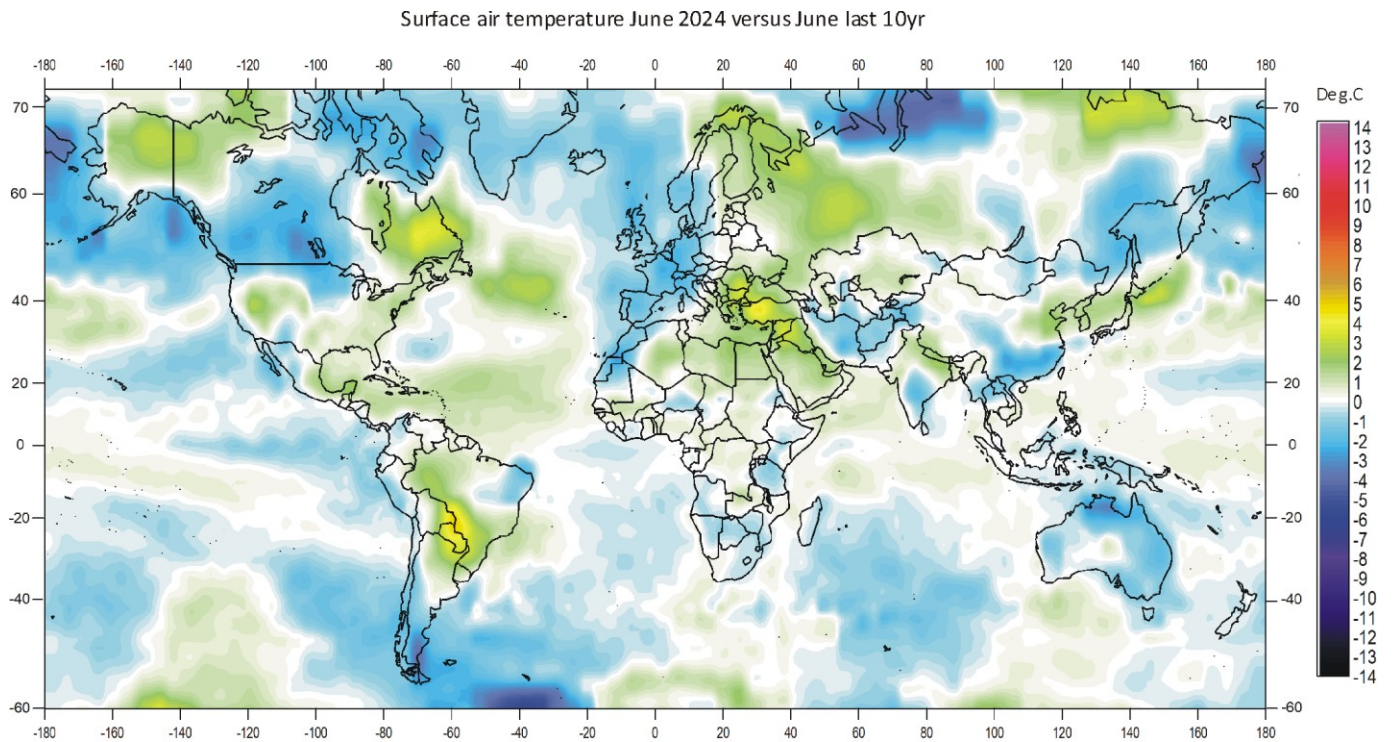
The Northern Hemisphere surface temperature anomaly pattern (p.4) was characterised by regional contrasts, mainly controlled by the dominant jet stream position. Especially eastern Europe and western Russia were warm relative to the average for the last 10 years. In contrast, western Europe, and much of Canada were relatively cold. Ocean wise, much of the North Atlantic was relatively warm, while the Greenland and Norwegian Seas were cold. The Pacific Ocean was relatively cold, except for a region centred around 40°N. PDO (p.20) remains negative. Arctic Ocean surface air temperatures were above the 10-yr average.

Near the Equator temperatures were generally above the 10-year average, but less so than in the previous months. Apparently, ocean heat released during the previous warm El Niño episode is still affecting many Equatorial regions.

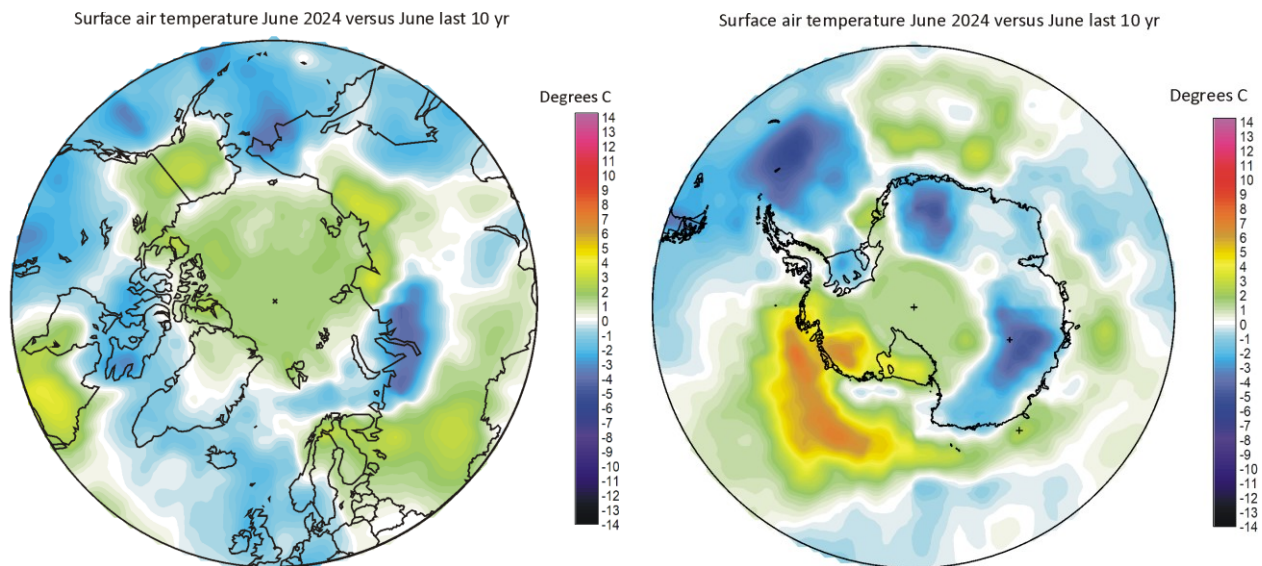
Southern Hemisphere temperatures were near or below the 10-yr average for June (approaching southern hemisphere winter). Australia, New Zealand and southern South America were relatively cold. In contrast, central South America was relatively warm. East Antarctic had temperatures below the 10-yr average, while much of West Antarctica was relatively warm. A warm ocean region beyond the coast of West Antarctica first time visible in the January 2024 anomaly pattern, has intensified further, and now represents the highest positive global surface air temperature anomaly in June 2024.



## June 2024 global surface air temperature overview versus average June last 10 years



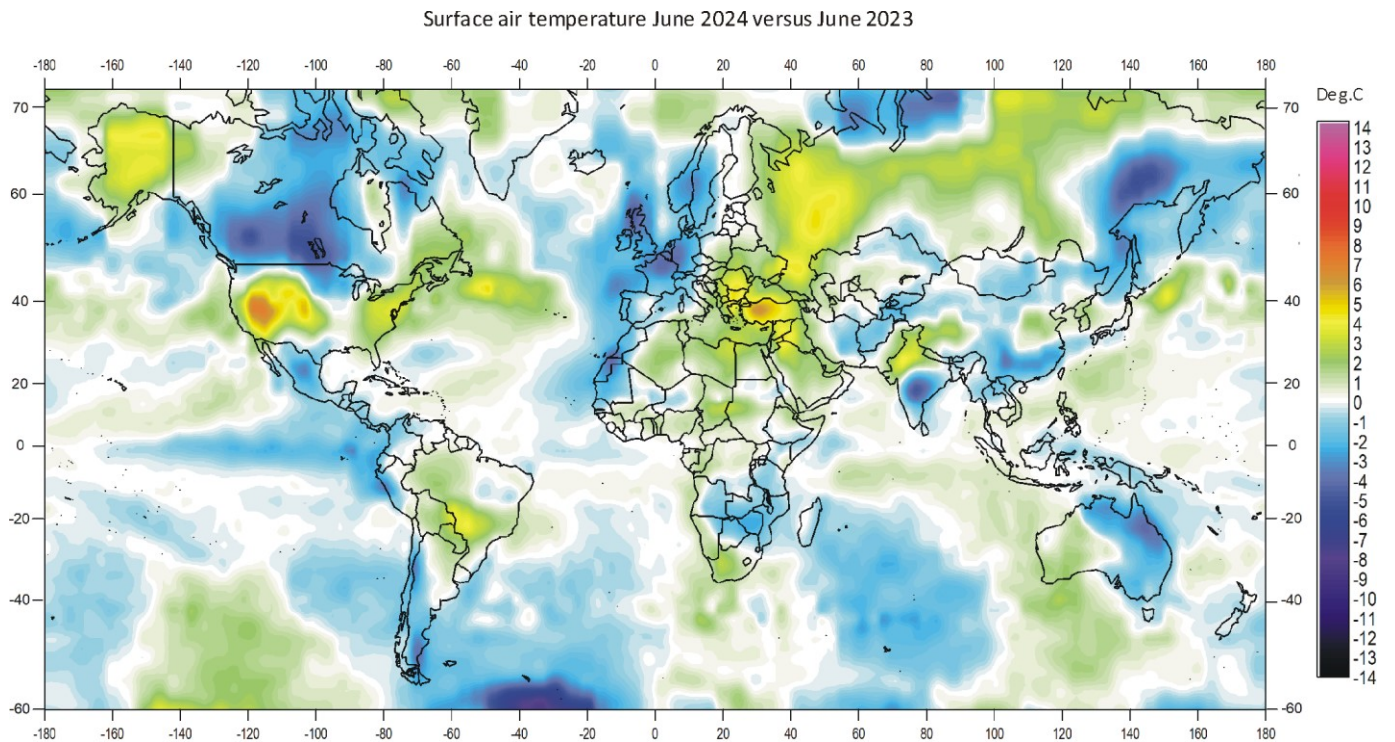
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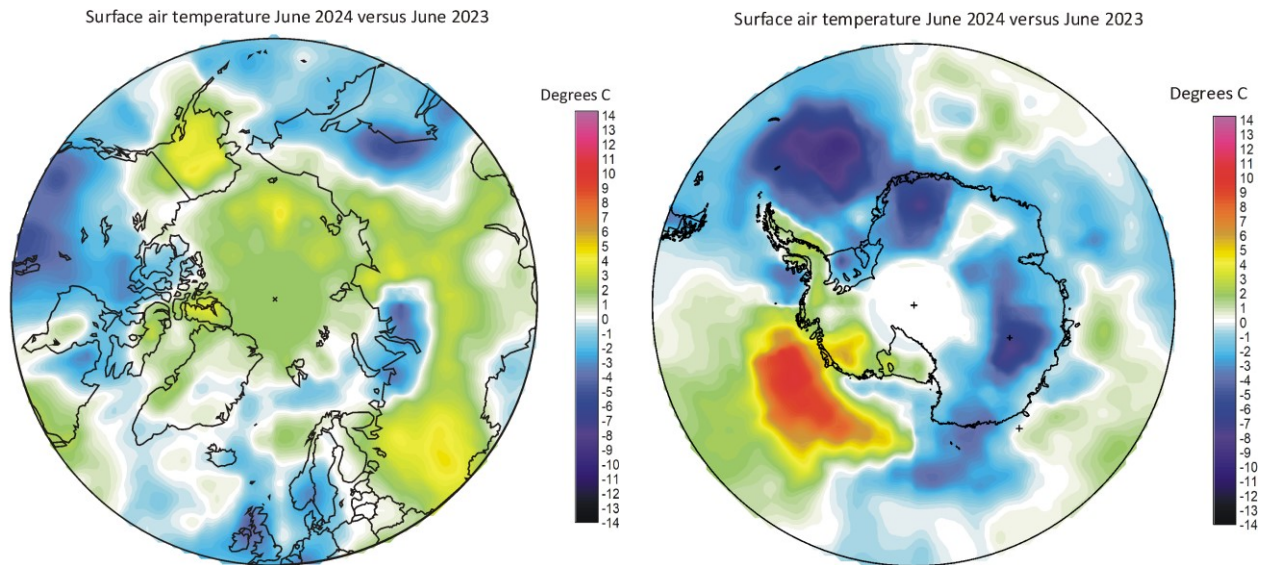
June 2024 surface air temperature compared to the average of June over the last 10 years. Green-yellow-red colours indicate areas with higher temperature than the 10-year average, while blue colours indicate lower than average temperatures. Data source: Remote Sensed Surface Temperature Anomaly, AIRS/Aqua L3 Monthly Standard Physical Retrieval 1-degree x 1-degree V006 (<https://airs.jpl.nasa.gov/>), obtained from the GISS data portal ([https://data.giss.nasa.gov/gistemp/maps/index\\_v4.html](https://data.giss.nasa.gov/gistemp/maps/index_v4.html)).



## June 2024 global surface air temperature compared to June 2023



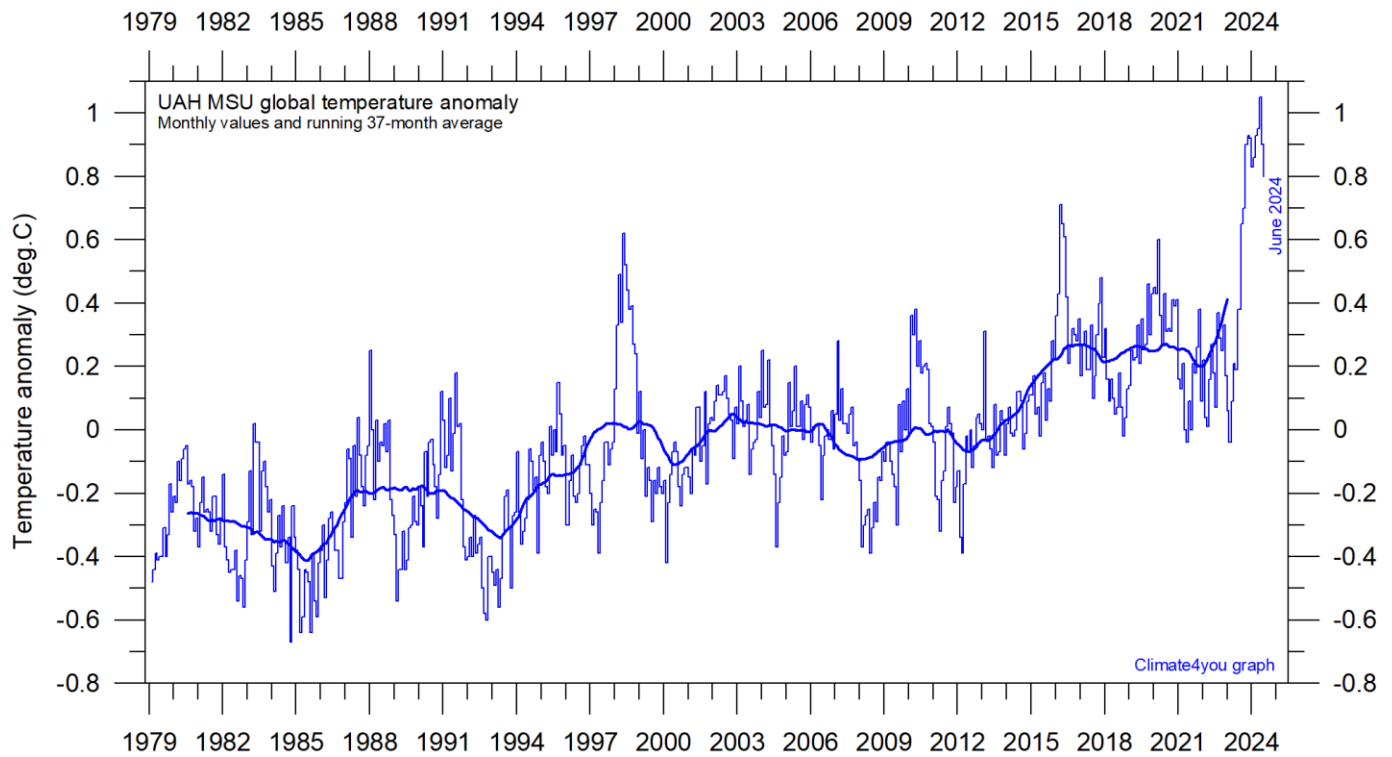
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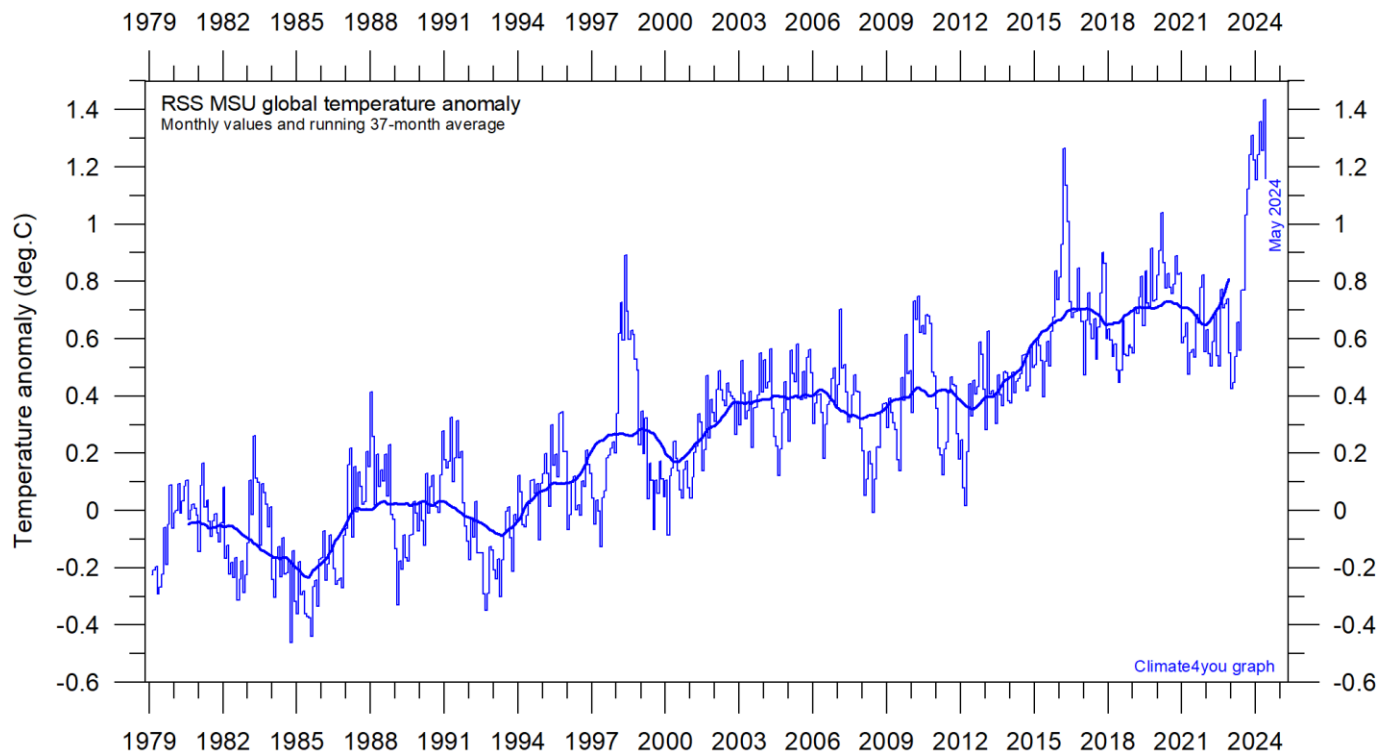
June 2024 surface air temperature compared to June 2023. Green-yellow-red colours indicate regions where the present month was warmer than last year, while blue colours indicate regions where the present month was cooler than last year. Variations in monthly temperature from one year to the next has no tangible climatic importance but may nevertheless be interesting to study. Data source: Remote Sensed Surface Temperature Anomaly, AIRS/Aqua L3 Monthly Standard Physical Retrieval 1-degree x 1-degree V006 (<https://airs.jpl.nasa.gov/>), obtained from the GISS data portal ([https://data.giss.nasa.gov/gistemp/maps/index\\_v4.html](https://data.giss.nasa.gov/gistemp/maps/index_v4.html)).

## Temperature quality class 1: Lower troposphere temperature from satellites, updated to June 2024

(see page 9 for definition of classes)



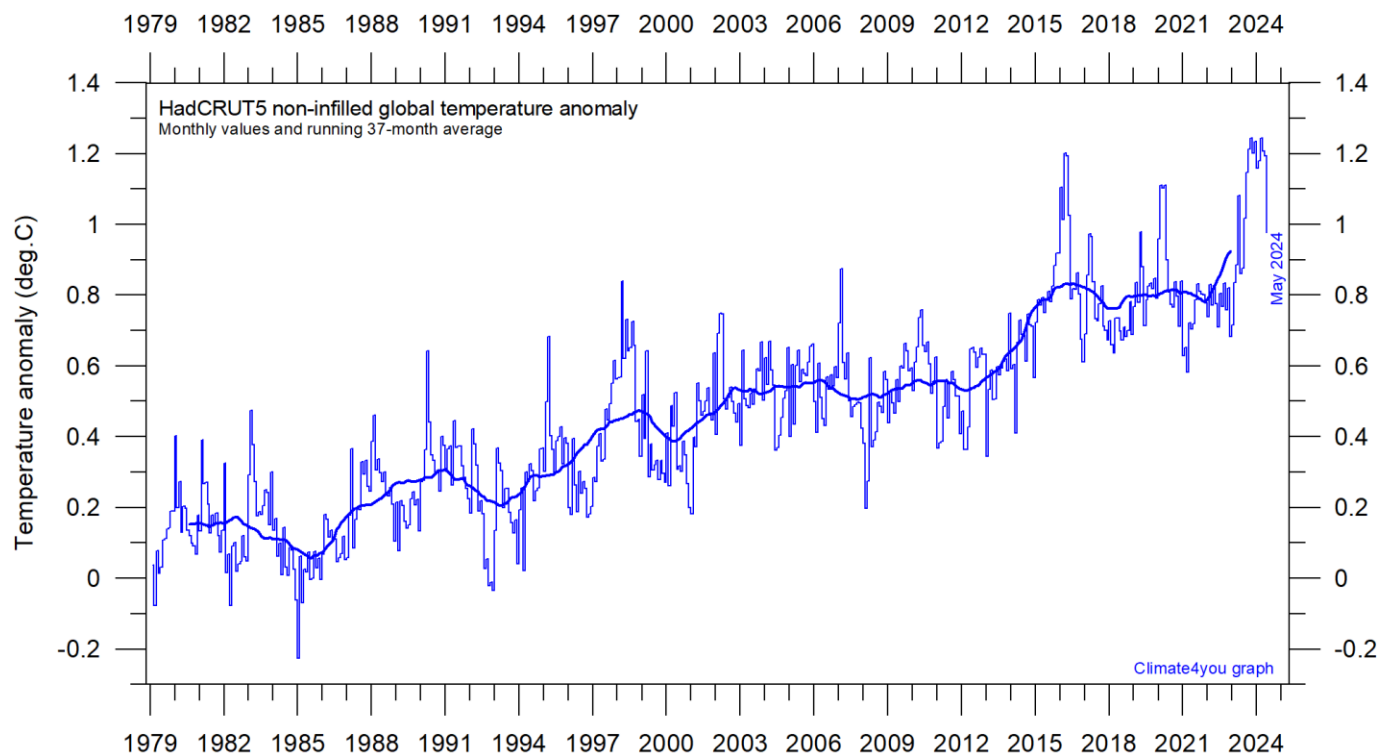
Global monthly average lower troposphere temperature (thin line) since 1979 according to [University of Alabama](#) at Huntsville, USA. The thick line is the simple running 37-month average. Reference period 1991-2020.



Global monthly average lower troposphere temperature (thin line) since 1979 according to according to [Remote Sensing Systems](#) (RSS), USA. The thick line is the simple running 37-month average.



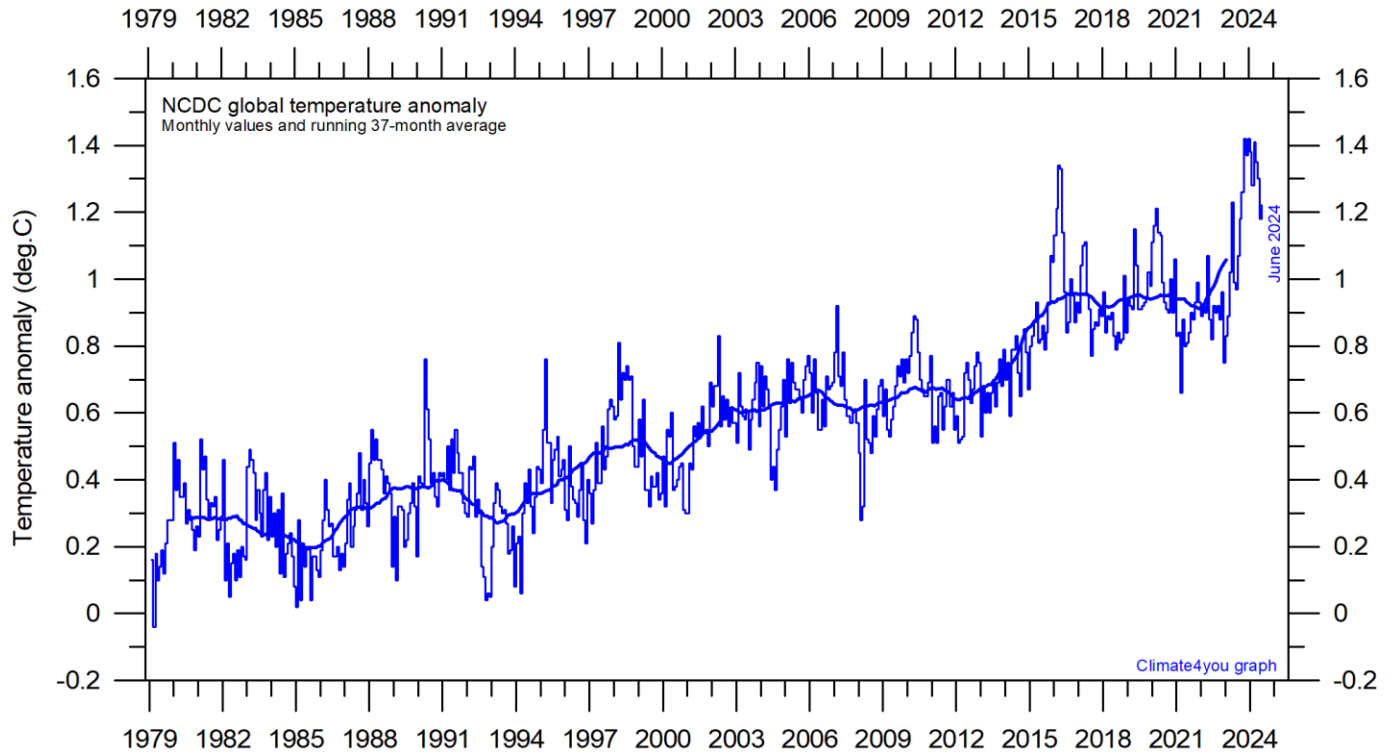
## Temperature quality class 2: HadCRUT global surface air temperature, updated to May 2024



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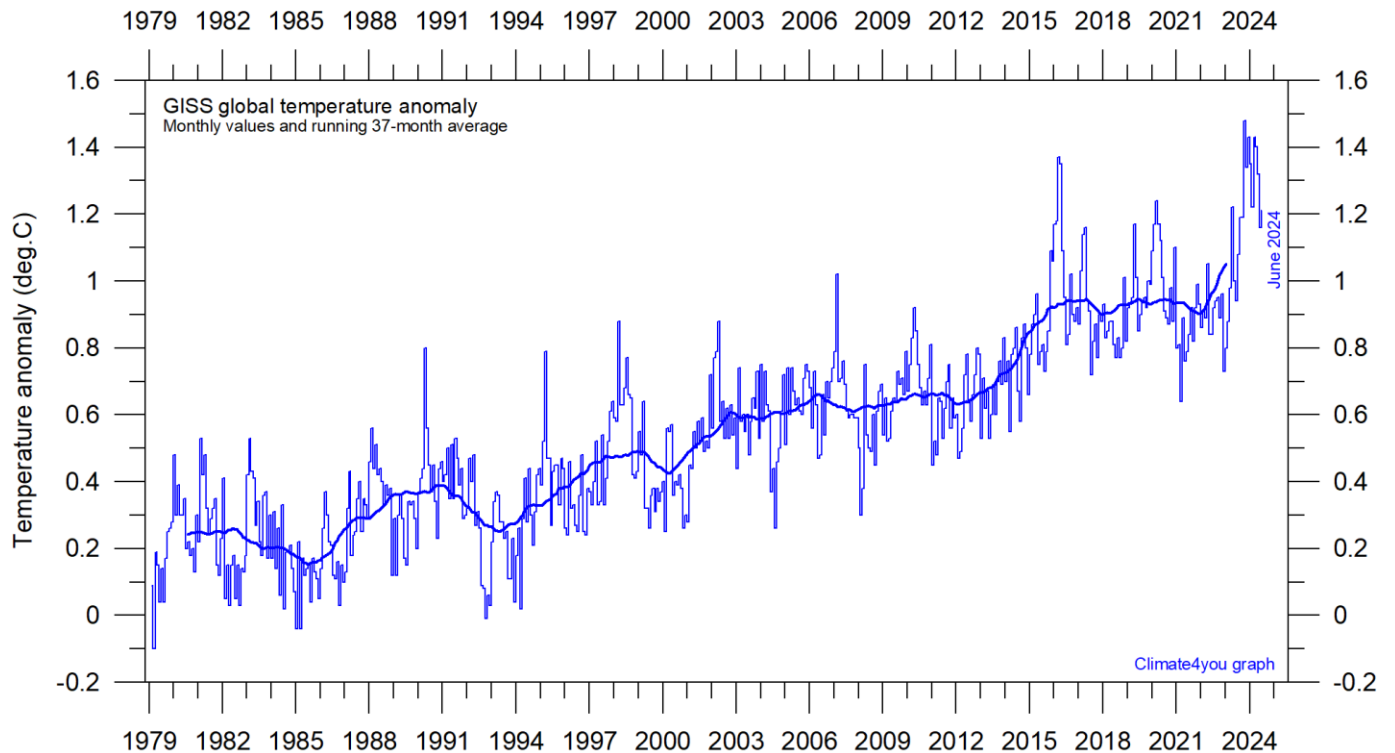
Global monthly average surface air temperature (thin line) since 1979 according to the Hadley Centre for Climate Prediction and Research and the University of East Anglia's [Climatic Research Unit \(CRU\)](#), UK. The thick line is the simple running 37-month average.

### Temperature quality class 3: GISS and NCDC global surface air temperature, updated to June 2024



Global monthly average surface air temperature since 1979 according to according to the [National Climatic Data Center](#) (NCDC), USA. The thick line is the simple running 37-month average.

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Global monthly average surface air temperature (thin line) since 1979 according to according to the [Goddard Institute for Space Studies](#) (GISS), at Columbia University, New York City, USA, using ERSST\_v4 ocean surface temperatures. The thick line is the simple running 37-month average.



#### A note on data record stability and -quality:

The temperature diagrams shown above all have 1979 as starting year. This roughly marks the beginning of the recent episode of global warming, after termination of the previous episode of global cooling from about 1940. In addition, the year 1979 also represents the starting date for the satellite-based global temperature estimates (UAH and RSS). For the three surface air temperature records (HadCRUT, NCDC and GISS), they begin much earlier (in 1850 and 1880, respectively), as can be inspected on [www.climate4you.com](http://www.climate4you.com).

For all three surface air temperature records, but especially NCDC and GISS, administrative changes to anomaly values are quite often introduced, even affecting observations many years back in time. Some changes from the recent past may be due to the delayed addition of new station data or change of station location, while others probably have their origin in changes of the technique implemented to calculate average values from the raw data. It is clearly impossible to evaluate the validity of such administrative changes for the outside user of these records; it is only possible to note that such changes quite often are introduced (see example diagram next page).

In addition, the three surface records represent a blend of sea surface data collected by moving ships or by other means, plus data from land stations of partly unknown quality and unknown degree of representativeness for their region. Many of the land stations also has been moved geographically during their period of operation, instrumentation have been changed, and they are influenced by changes in their near surroundings (vegetation, buildings, etc.). The surface network is inherently heterogeneous (dense over continents but sparse over oceans) and probably contaminated by urbanization surrounding many measurement sites.

The satellite temperature records also have their problems, but these are generally of a more technical nature and probably therefore better correctable. In

addition, the temperature sampling by satellites is more regular and complete on a global basis than that represented by the surface records. It is also important that the sensors on satellites measure temperature directly by microwave radiance (thereby unobstructed by clouds), while most modern surface temperature measurements are indirect, using electronic resistance.

Everybody interested in climate science should gratefully acknowledge the big efforts put into maintaining the different temperature databases referred to in the present newsletter. At the same time, however, it is also important to realise that all temperature records cannot be of equal scientific quality. The simple fact that they to some degree differ shows that they cannot all be correct.

On this background, and for practical reasons, Climate4you therefore operates with three quality classes (1-3) for global temperature records, with 1 representing the highest quality level:

Quality class 1: The satellite records (UAH and RSS).

Quality class 2: The HadCRUT surface record.

Quality class 3: The NCDC and GISS surface records.

The main reason for discriminating between the three surface records is the following:

While both NCDC and GISS often experience quite large administrative changes (see example on p.10), and therefore essentially must be considered as unstable records, the changes introduced to HadCRUT are fewer and smaller. For obvious reasons, as the past does not change, any record undergoing continuing changes cannot describe the past correctly all the time. Frequent and large corrections in a database unavoidably signal a fundamental uncertainty about what is likely to represent the correct values.

You can find more on the issue of lack of temporal stability on [www.climate4you.com](http://www.climate4you.com) (go to: *Global Temperature*, and then proceed to *Temporal Stability*).

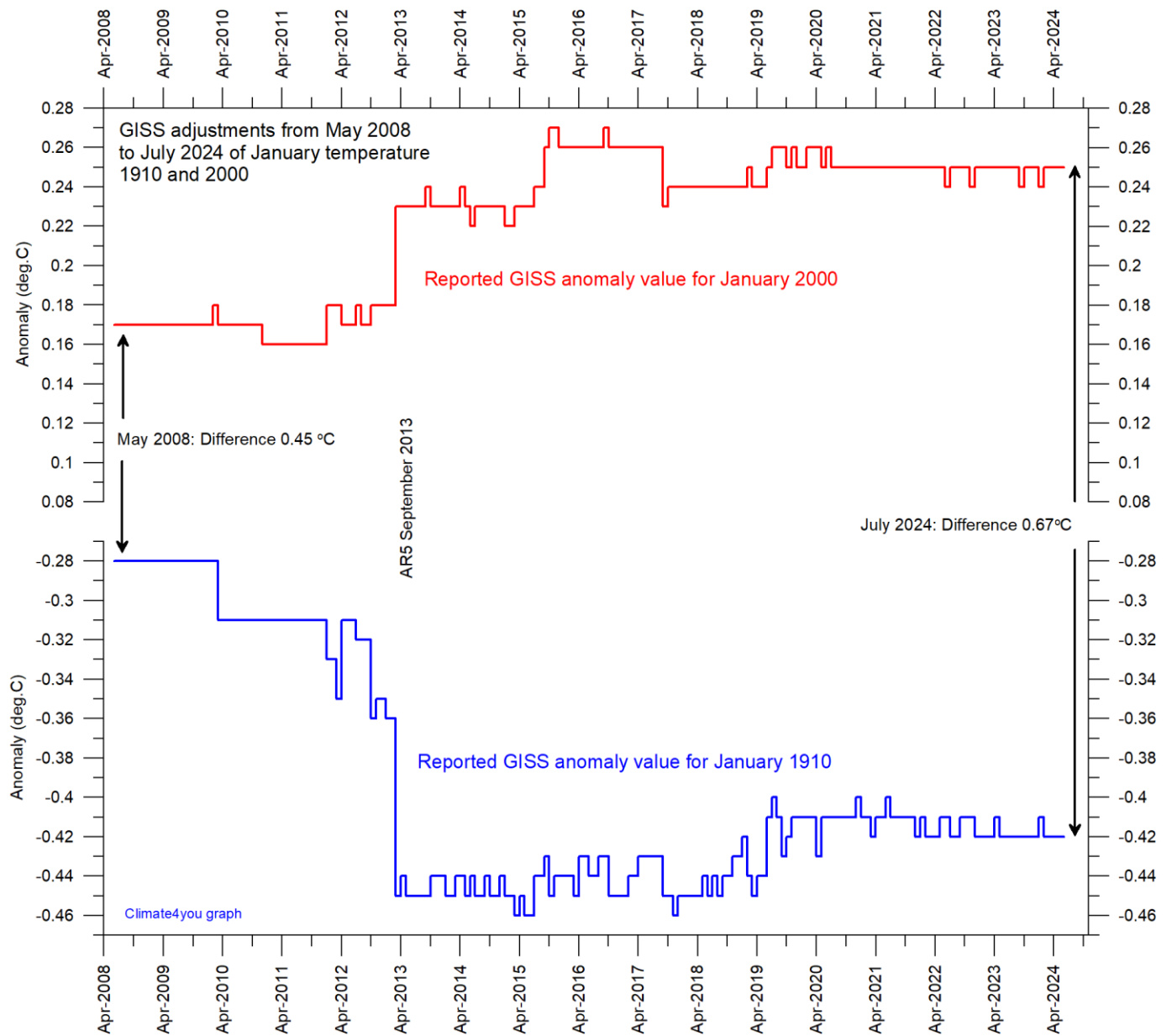


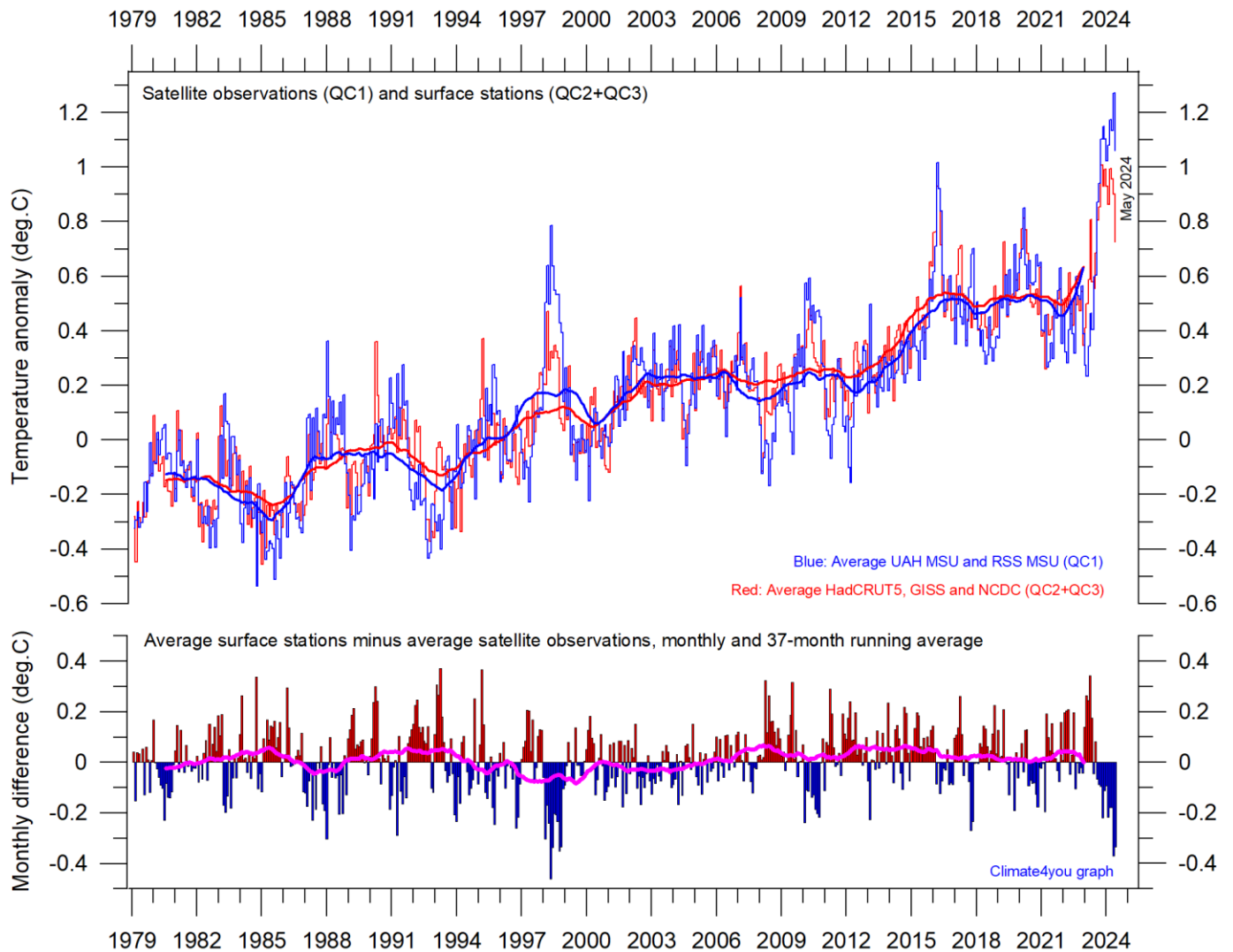
Diagram showing the monthly adjustments made since May 2008 by the [Goddard Institute for Space Studies](#) (GISS), USA, as recorded by published anomaly values for the two months January 1910 and January 2000. AR5 indicates timing of publication of IPCC report AR5 Climate Change 2013: The Physical Science Basis.

The administrative upsurge of the temperature increase from January 1915 to January 2000 has grown from 0.45 (reported May 2008) to 0.67°C (reported July 2024). This represents an about 49% administrative temperature increase over this period,

meaning that a significant (about half) part of the apparent global temperature increases from January 1910 to January 2000 (as reported by GISS) is caused by administrative changes of the original data since May 2008.



Comparing global surface air temperature and lower troposphere satellite temperatures;  
updated to May 2024



Plot showing the average of monthly global surface air temperature estimates (HadCRUT5, GISS and NCDC) and satellite-based temperature estimates (RSS MSU and UAH MSU). The thin lines indicate the monthly value, while the thick lines represent the simple running 37-month average, nearly corresponding to a running 3-yr average. The lower panel shows the monthly difference between average surface air temperature and satellite temperatures. As the base period differs for the different temperature estimates, they have all been normalised by comparing to the average value of 30 years from January 1979 to December 2008.

Global air temperature linear trends updated to May 2024

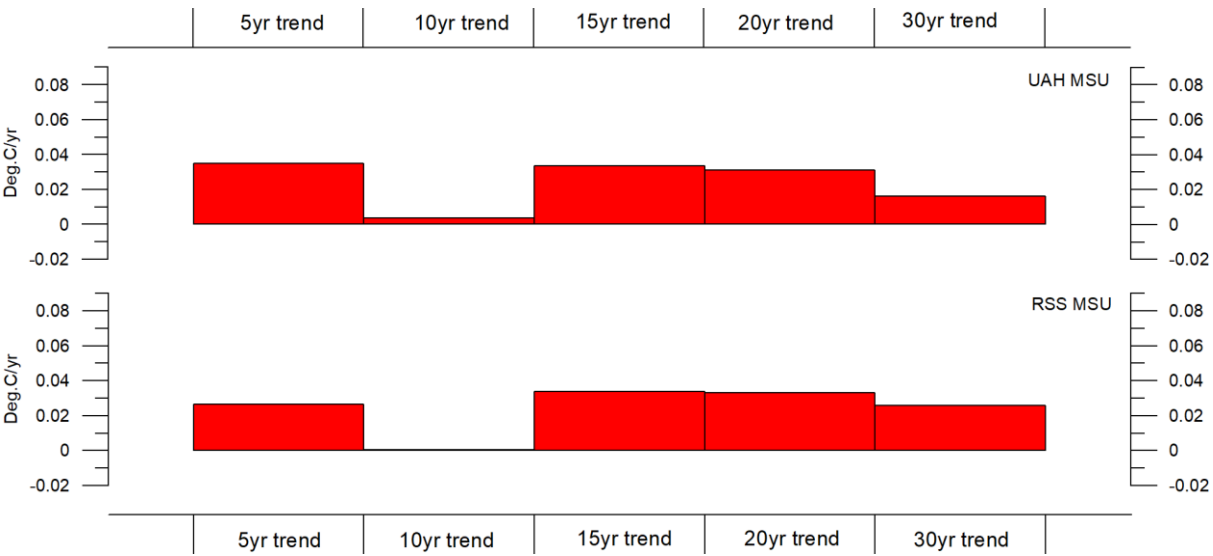


Diagram showing the latest 5, 10, 20 and 30-yr linear annual global temperature trend, calculated as the slope of the linear regression line through the data points, for two satellite-based temperature estimates (UAH MSU and RSS MSU).

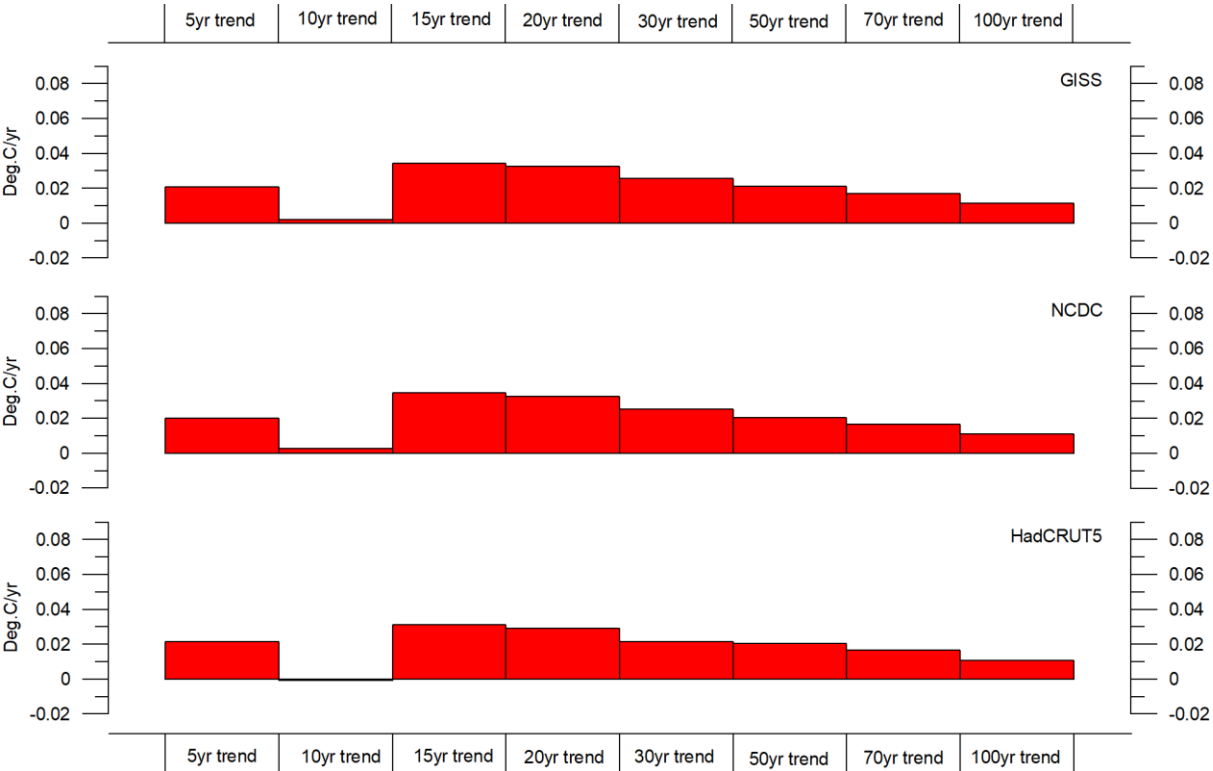
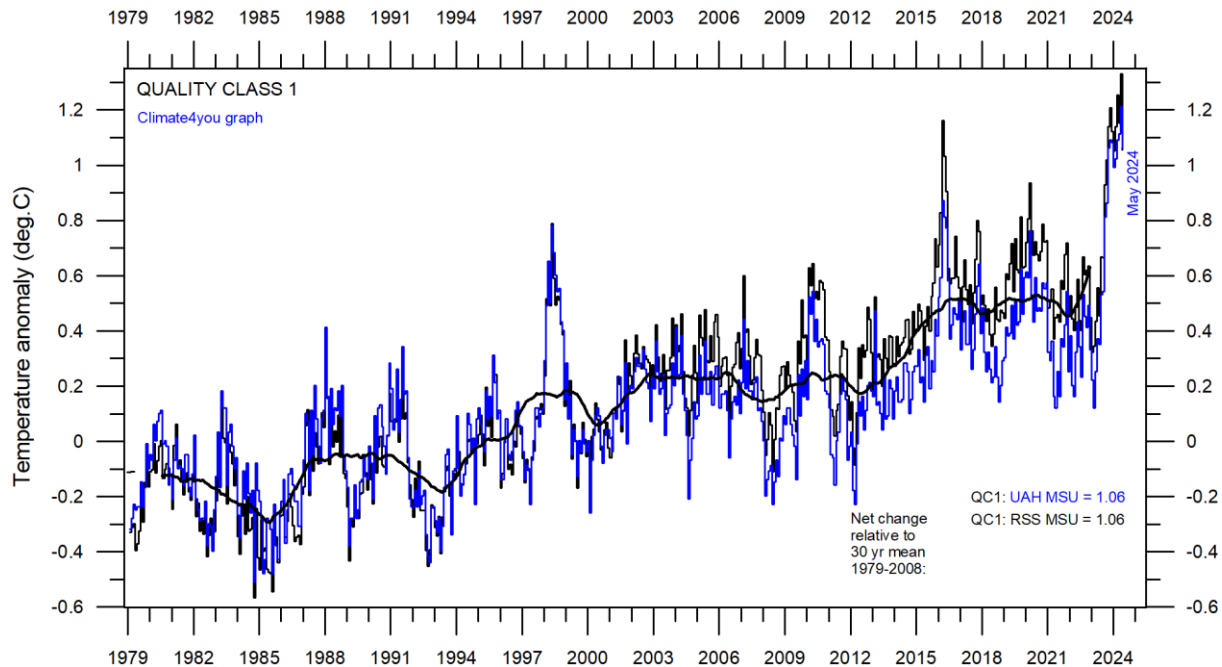


Diagram showing the latest 5, 10, 20, 30, 50, 70 and 100-year linear annual global temperature trend, calculated as the slope of the linear regression line through the data points, for three surface-based temperature estimates (GISS, NCDC and HadCRUT5).

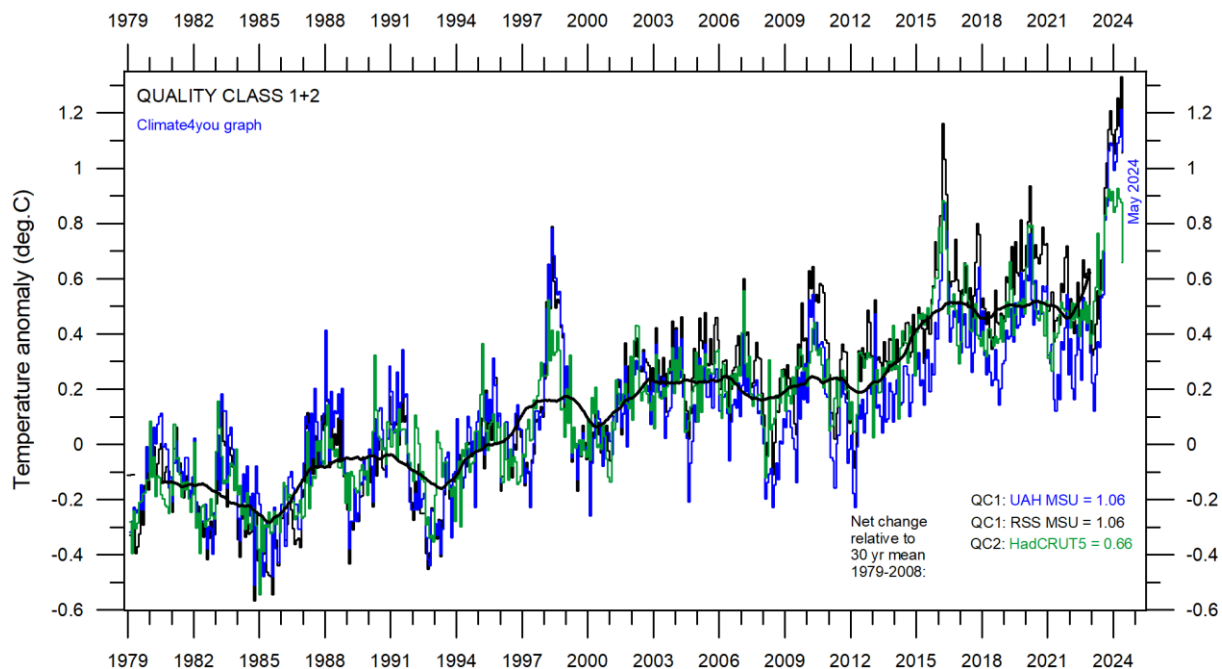


## All in one, Quality Class 1, 2 and 3; updated to May 2024

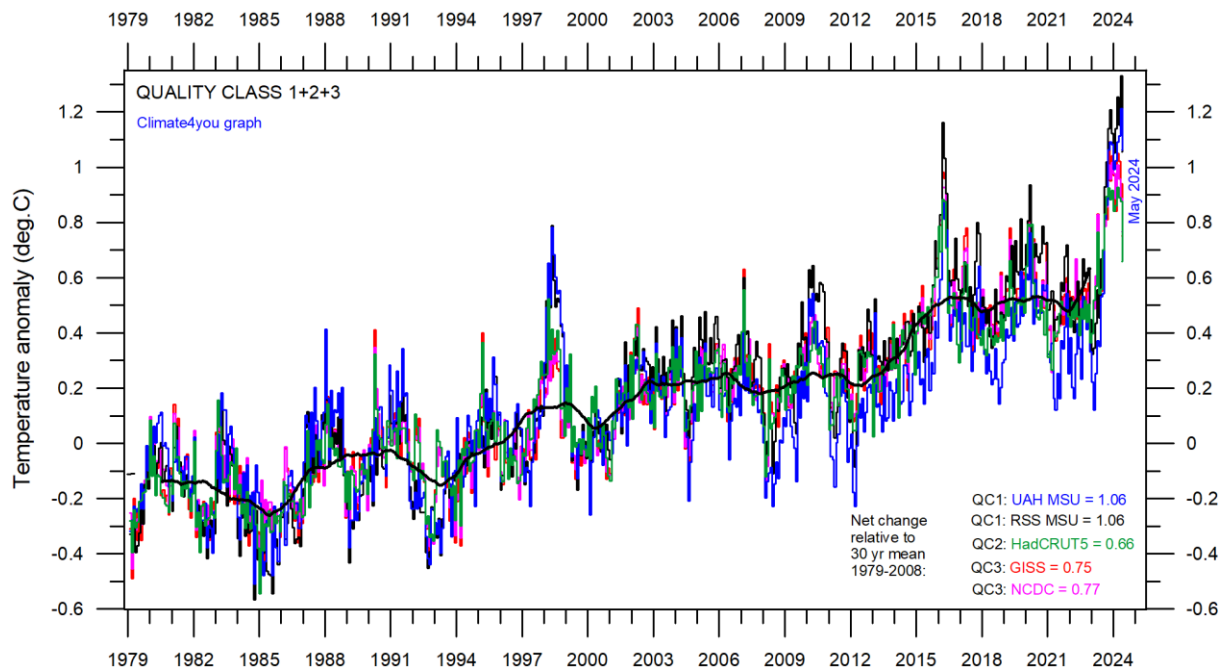


Superimposed plot of Quality Class 1 (UAH and RSS) global monthly temperature estimates. As the base period differs for the individual temperature estimates, they have all been normalised by comparing with the average value of the initial 120 months (30 years) from January 1979 to December 2008. The heavy black line represents the simple running 37 month (c. 3 year) mean of the average of both temperature records. The numbers shown in the lower right corner represent the temperature anomaly relative to the individual 1979-2008 averages.

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Superimposed plot of Quality Class 1 and 2 (UAH, RSS and HadCRUT) global monthly temperature estimates. As the base period differs for the individual temperature estimates, they have all been normalised by comparing with the average value of the initial 120 months (30 years) from January 1979 to December 2008. The heavy black line represents the simple running 37 month (c. 3 year) mean of the average of all three temperature records. The numbers shown in the lower right corner represent the temperature anomaly relative to the individual 1979-2008 averages.



*Superimposed plot of Quality Class 1, 2 and 3 global monthly temperature estimates (UAH, RSS, HadCRUT, GISS and NCDC). As the base period differs for the individual temperature estimates, they have all been normalised by comparing with the average value of the initial 120 months (30 years) from January 1979 to December 2008. The heavy black line represents the simple running 37 month (c. 3 year) mean of the average of all five temperature records. The numbers shown in the lower right corner represent the temperature anomaly relative to the individual 1979-2008 averages.*

14 Please see reflections on page 9 relating to the above three quality classes.

Satellite- and surface-based temperature estimates are derived from different types of measurements and comparing them directly as in the above diagrams therefore may be somewhat ambiguous.

However, as both types of estimates often are discussed together in various news media, the above composite diagrams may nevertheless be of some interest.

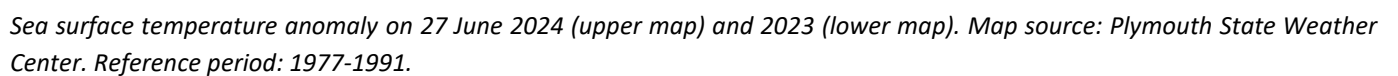
In fact, the different types of temperature estimates appear to agree as to the overall temperature variations on a 2-3-year scale, although on a shorter time scale there are often considerable differences between the individual records. However, since about 2003 the surface records used to be drifting towards higher temperatures than the combined satellite record, but this overall tendency was much removed by the major adjustment of the RSS satellite series in 2015 (see lower diagram on page 6).

The combined records (diagram above) suggest a modest global air temperature increase over the last 40 years, about 0.18°C per decade. It should be noted that the apparent temperature increases since about 2003 at least partly is the result of ongoing administrative adjustments (page 9-10). At the same time, none of the temperature records considered here indicates any overall temperature decrease during the last 20 years.

The present temperature development does not exclude the possibility that global temperatures may begin to increase significantly later. On the other hand, it also remains a possibility that Earth just now is passing an overall temperature peak, and that global temperatures may begin to decrease during the coming 5-10 years.

As always, time will show which of these possibilities is correct.

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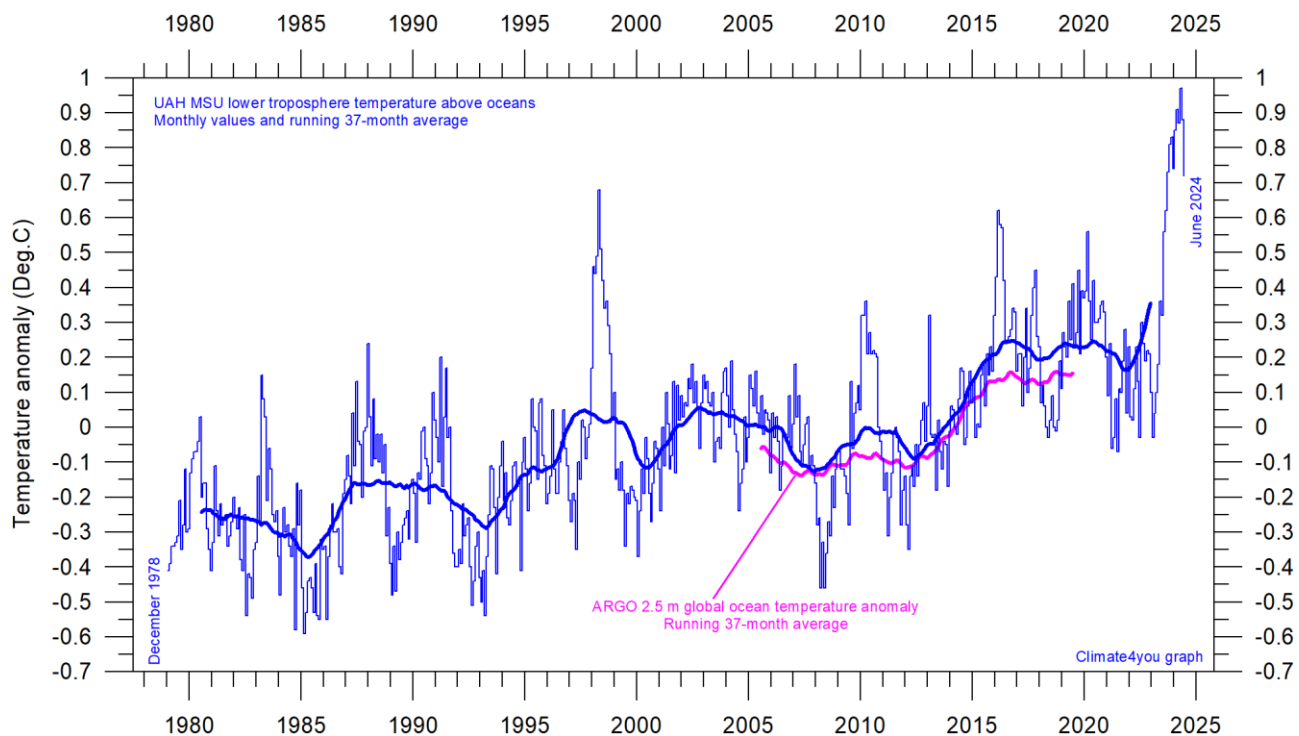


Because of the large surface areas near Equator, the temperature of the surface water in these regions is especially important for the global atmospheric temperature (p. 6-8). In fact, 50% of planet Earth's surface area is located within 30°N and 30°S.

A mixture of relatively warm and cold water presently dominates much of the global ocean surface, but with notable variations from month to month. All such ocean surface temperature changes will be influencing global air temperatures in the months to come. A cold La Niña episode (Pacific Ocean) has recently ended and was followed by a warm (now ending) El Niño episode (maps p.15 and diagram p.25).

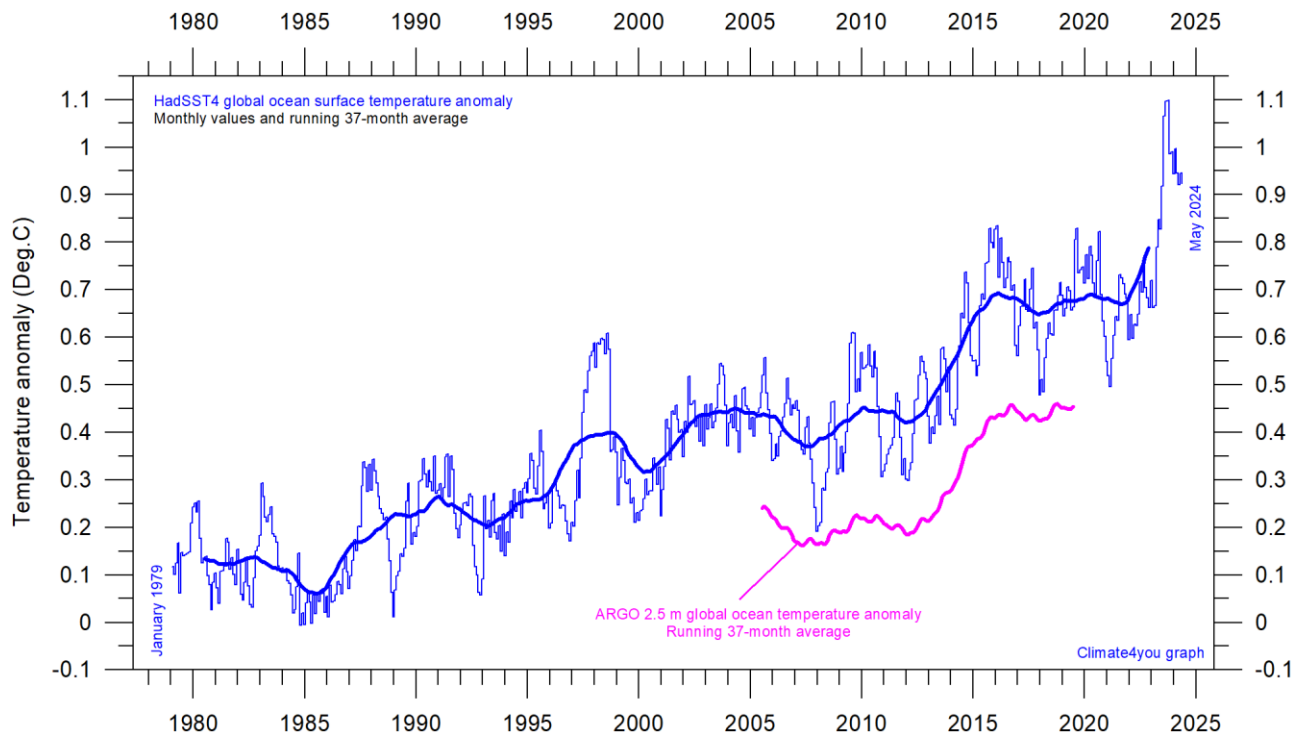
The significance of short-term cooling or warming reflected in air temperatures should never be overstated. Whenever Earth experiences cold La Niña or warm El Niño episodes major heat exchanges take place between the Pacific Ocean and the atmosphere above, sooner or later showing up in estimates of the global air temperature.

However, this does not necessarily reflect similar changes in the total heat content of the atmosphere-ocean system. In fact, global net changes can be small and such heat exchanges may mainly reflect redistribution of energy between ocean and atmosphere. What matters is the overall temperature development when seen over several years.



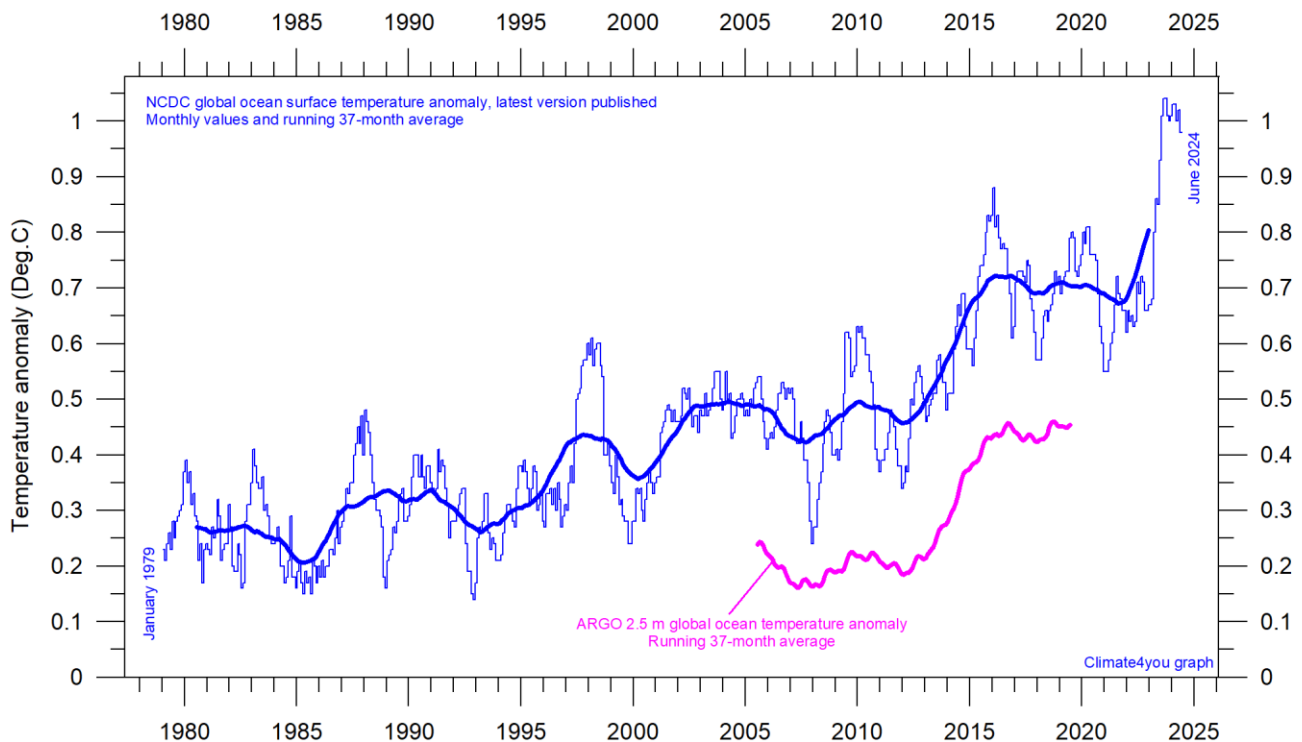
Global monthly average lower troposphere temperature over oceans (thin line) since 1979 according to [University of Alabama](#) at Huntsville, USA. The thick line is the simple running 37-month average. Insert: Argo global ocean temperature anomaly from floats, displaced vertically to make visual comparison easier. UAH reference period: 1991-2020.





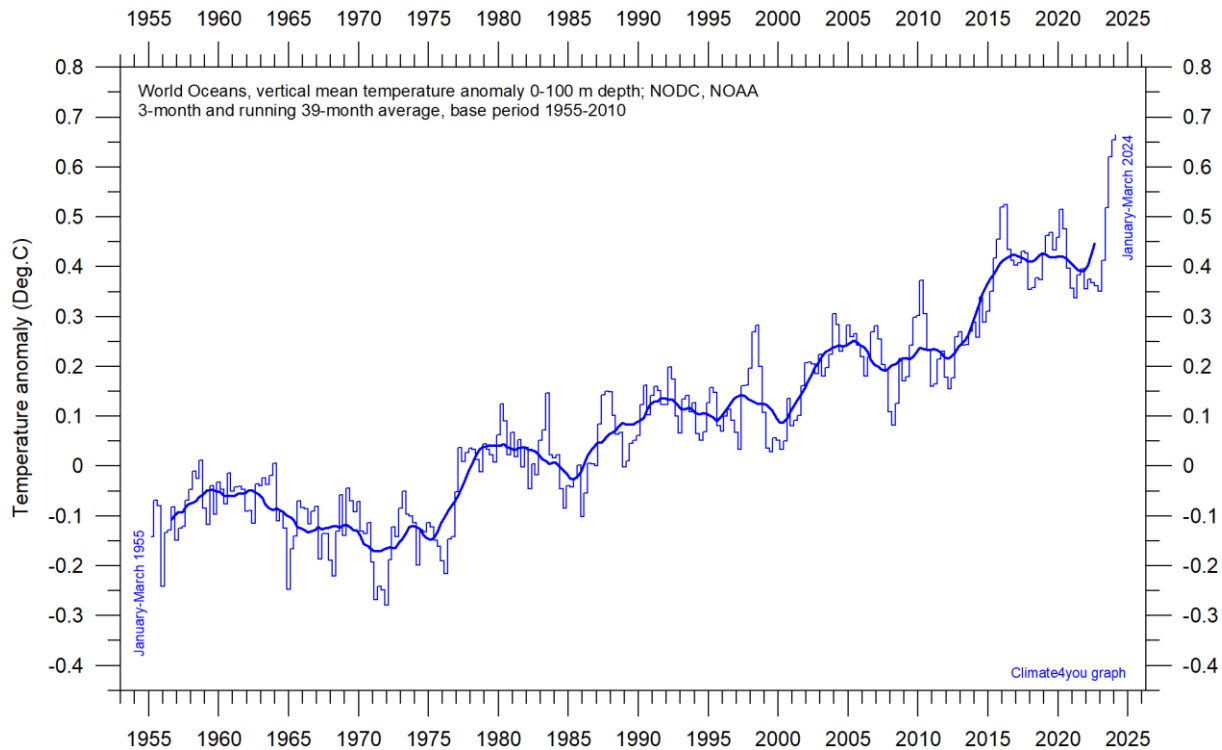
Global monthly average sea surface temperature since 1979 according to University of East Anglia's [Climatic Research Unit \(CRU\)](#), UK. Base period: 1961-1990. The thick line is the simple running 37-month average. Insert: Argo global ocean temperature anomaly from floats, displaced vertically to make visual comparison easier.

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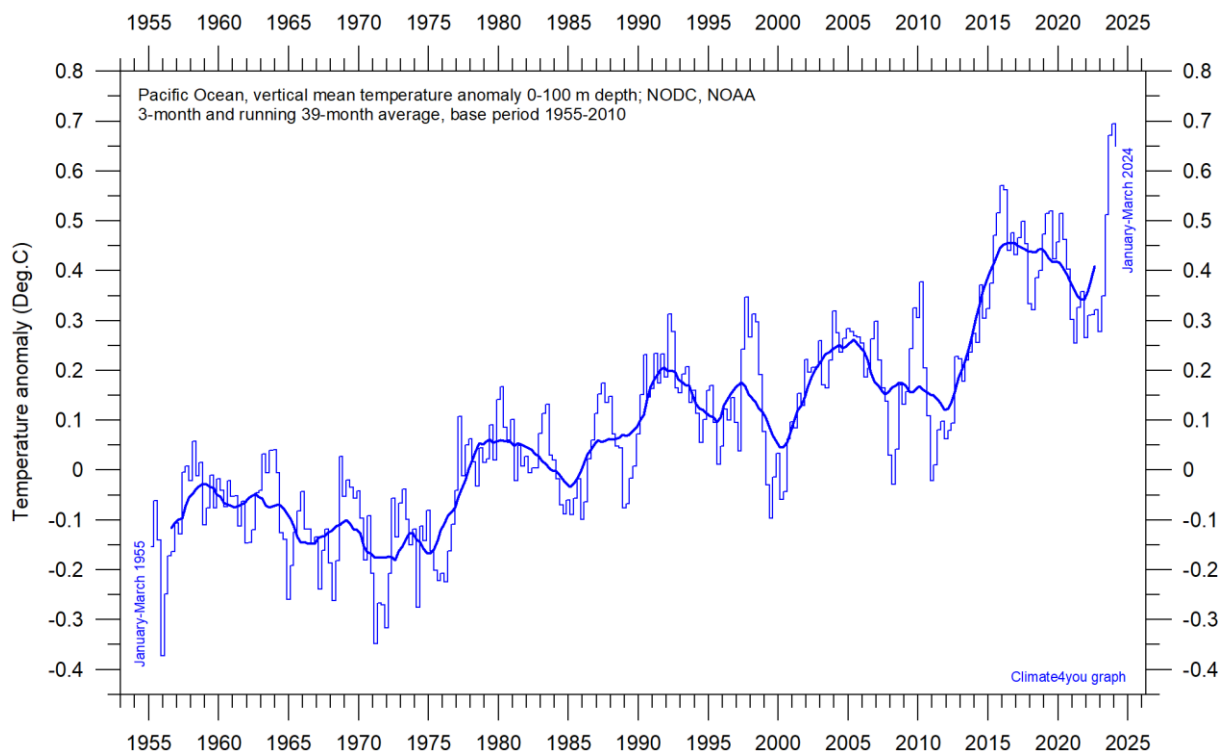
Global monthly average sea surface temperature since 1979 according to the [National Climatic Data Center \(NCDC\)](#), USA. Base period: 1901-2000. The thick line is the simple running 37-month average. Insert: Argo global ocean temperature anomaly from floats, displaced vertically to make visual comparison easier.

## Ocean temperature in uppermost 100 m, updated to March 2024

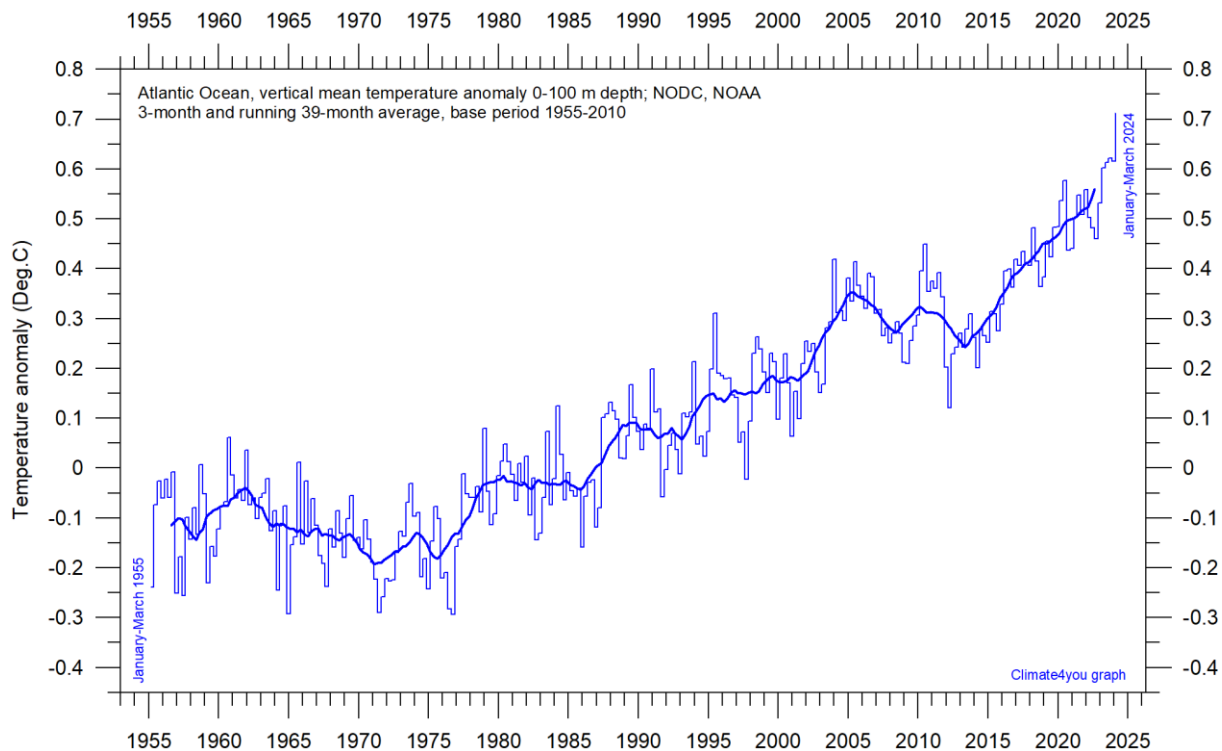


World Oceans vertical average temperature 0-100 m depth since 1955. The thin line indicates 3-month values, and the thick line represents the simple running 39-month (c. 3 year) average. Data source: [NOAA National Oceanographic Data Center](#) (NODC). Base period 1955-2010.

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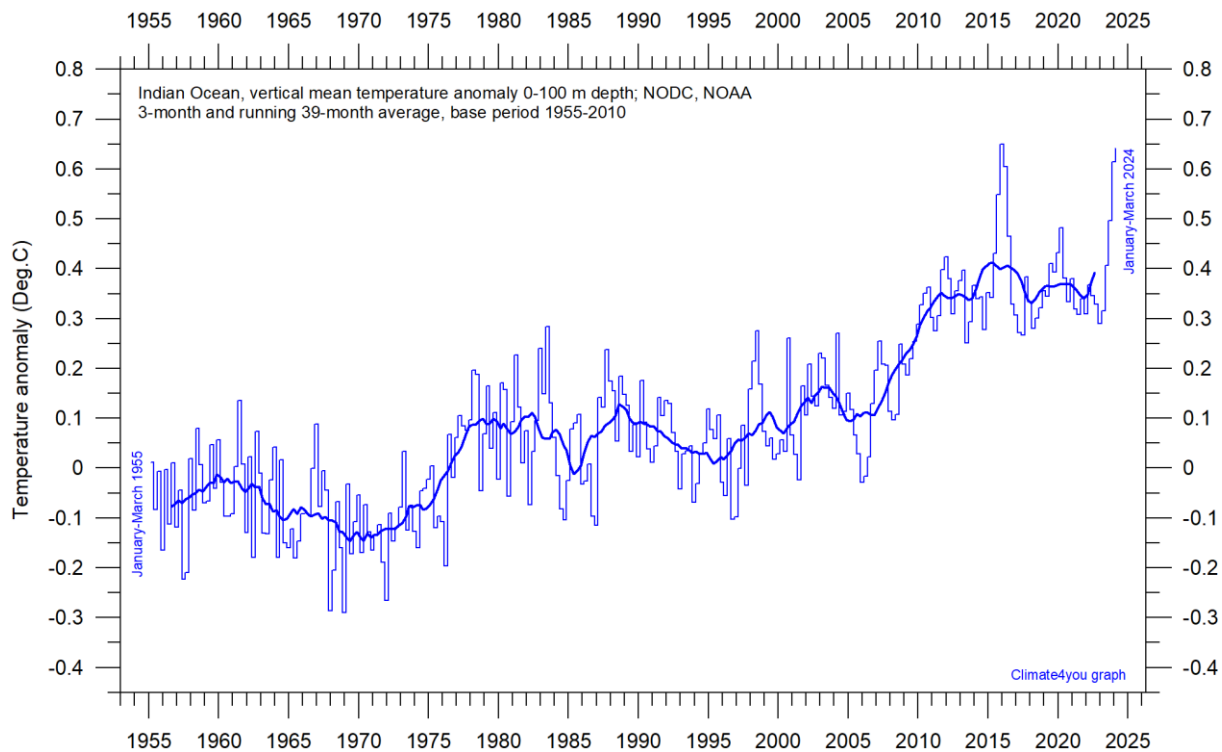


*Pacific Ocean vertical average temperature 0-100 m depth since 1955. The thin line indicates 3-month values, and the thick line represents the simple running 39-month (c. 3 year) average. Data source: [NOAA National Oceanographic Data Center](#) (NODC). Base period 1955-2010.*



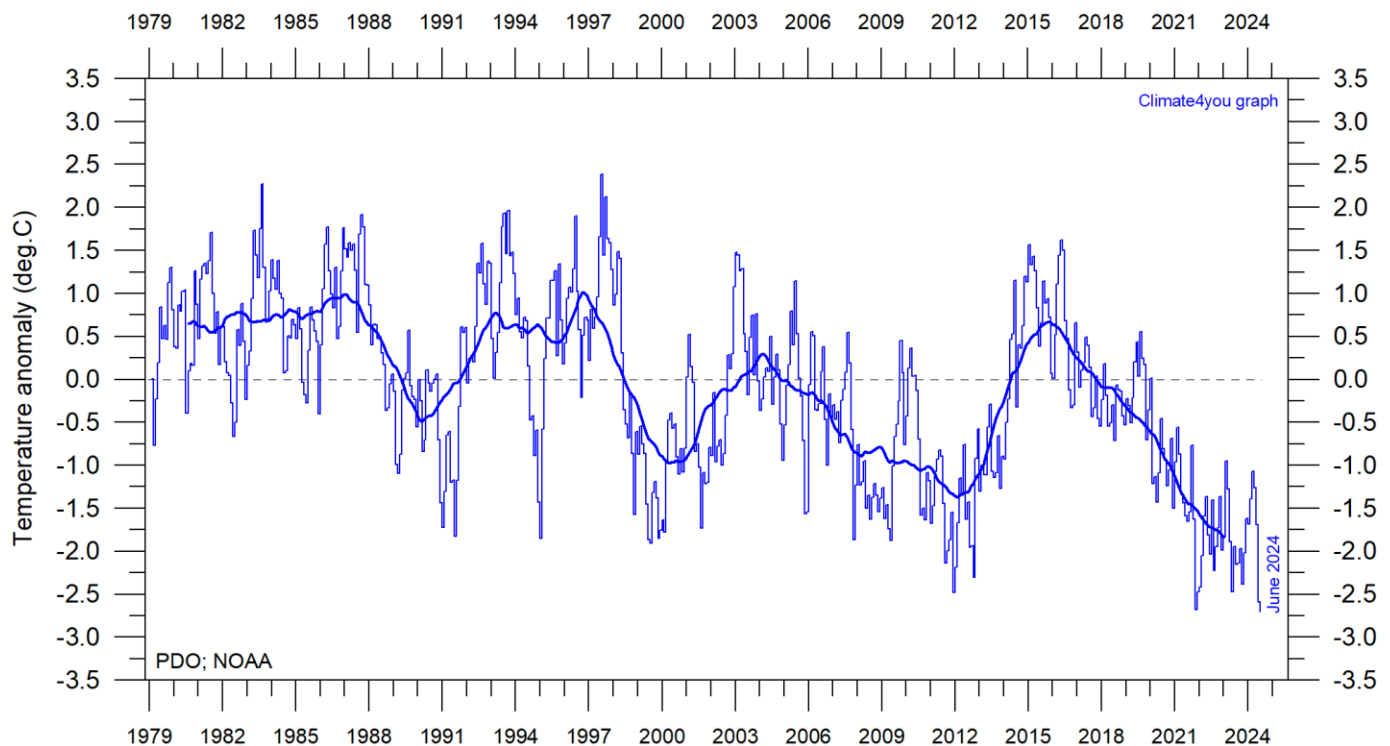
Atlantic Ocean vertical average temperature 0-100 m depth since 1955. The thin line indicates 3-month values, and the thick line represents the simple running 39-month (c. 3 year) average. Data source: [NOAA National Oceanographic Data Center](https://www.noaa.gov/data/ocean/summary/atlantic) (NODC). Base period 1955-2010.

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Indian Ocean vertical average temperature 0-100 m depth since 1955. The thin line indicates 3-month values, and the thick line represents the simple running 39-month (c. 3 year) average. Data source: [NOAA National Oceanographic Data Center](https://www.noaa.gov/data/ocean/summary/atlantic) (NODC). Base period 1955-2010.

## Pacific Decadal Oscillation (PDO), updated to June 2024



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Monthly values of the Pacific Decadal Oscillation (PDO) since January 1979. The PDO is a long-lived El Niño-like pattern of Pacific climate variability, and the data series goes back to January 1854. Base period: 1982-2002. The thin line indicates monthly PDO values, and the thick line is the simple running 37-month average. Data source: [NOAA Physical Science Laboratory](#) (version PDO ERSST V5 plotted above).

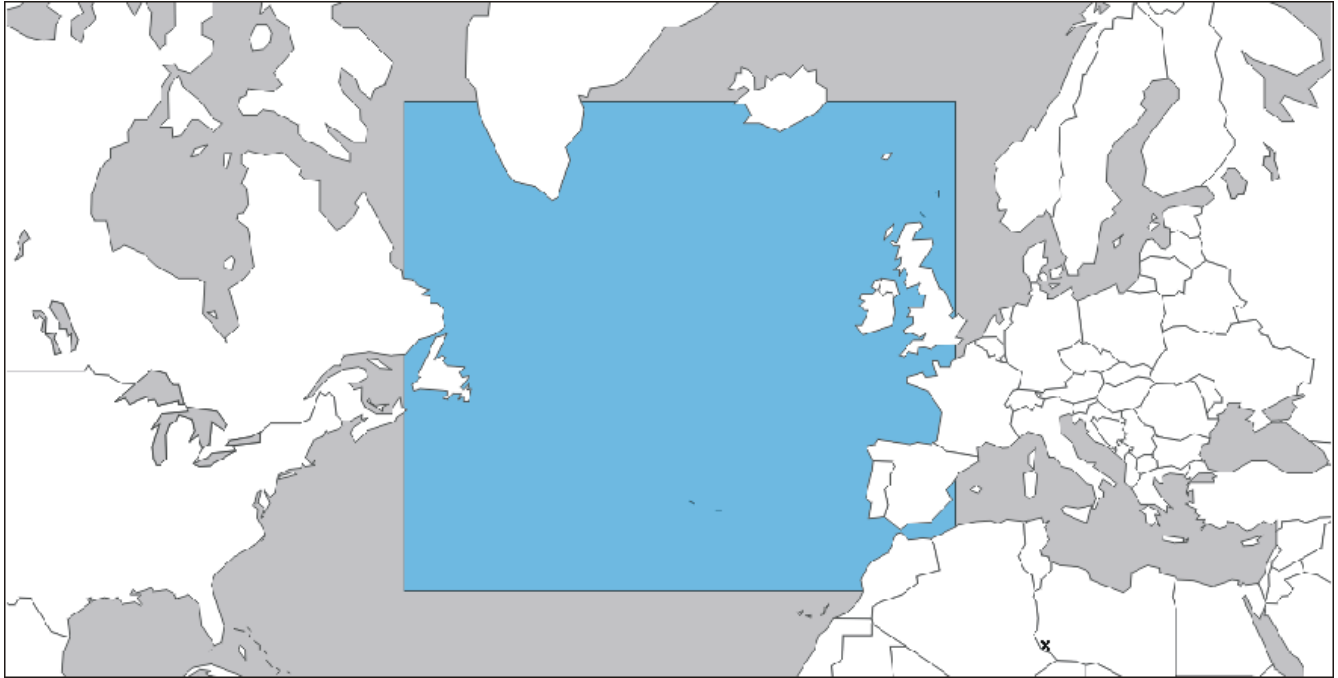
The PDO is a long-lived El Niño-like pattern of Pacific climate variability, with data extending back to January 1854. Causes for PDO are not currently known, but even in the absence of a theoretical understanding, PDO climate information improves season-to-season and year-to-year climate forecasts for North America because of its strong tendency for multi-season and multi-year persistence. The PDO also appears to be roughly in phase with global temperature changes. Thus, from a societal impact's perspective, recognition of PDO is important because it shows that "normal" climate conditions can vary over time periods comparable to the length of a human's lifetime.

The PDO illustrates how global temperatures are tied to sea surface temperatures in the Pacific Ocean, the largest ocean on Earth. When sea surface temperatures are relatively low (negative phase PDO), as it was from 1945 to 1977, global air temperature often decreases. When Pacific Ocean surface temperatures are high (positive phase PDO), as from 1977 to 1998, global surface air temperature often increases.

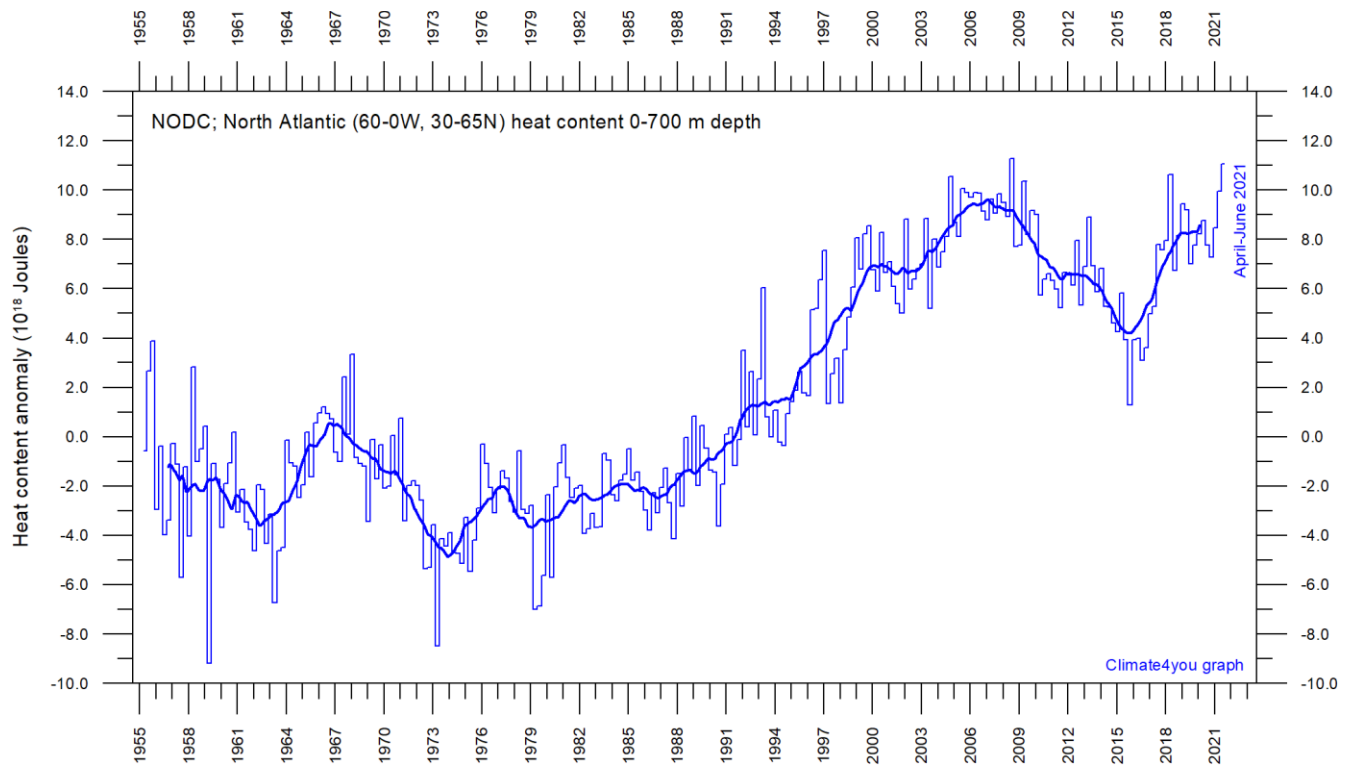
A Fourier frequency analysis (not shown here) shows the PDO record to be influenced by a significant 5.6-year cycle, and feasibly also by a longer 18.6-year long period, corresponding to the length of the lunar nodal tide.



## North Atlantic heat content uppermost 700 m, updated to June 2021

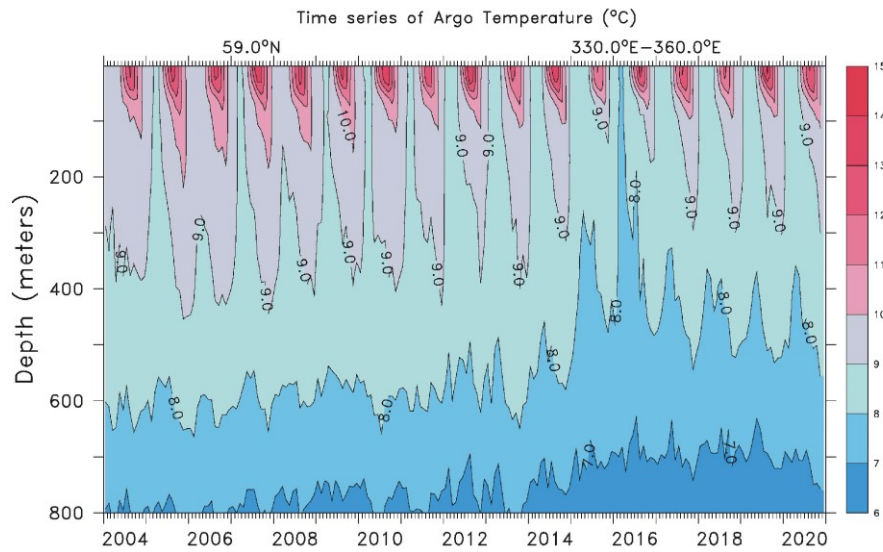


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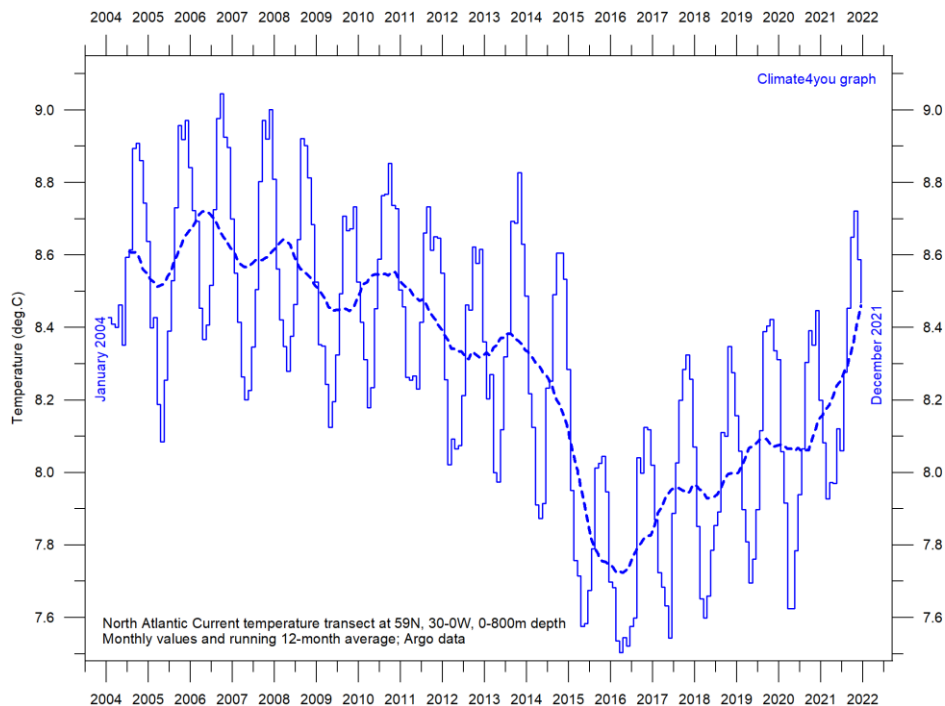
Global monthly heat content anomaly ( $10^{18}$  Joules) in the uppermost 700 m of the North Atlantic (60-0W, 30-65N; see map above) ocean since January 1955. The thin line indicates monthly values, and the thick line represents the simple running 37-month (c. 3 year) average. Data source: [National Oceanographic Data Center](#) (NODC).

## North Atlantic temperatures 0-800 m depth along 59°N, 30-0W, updated to December 2021



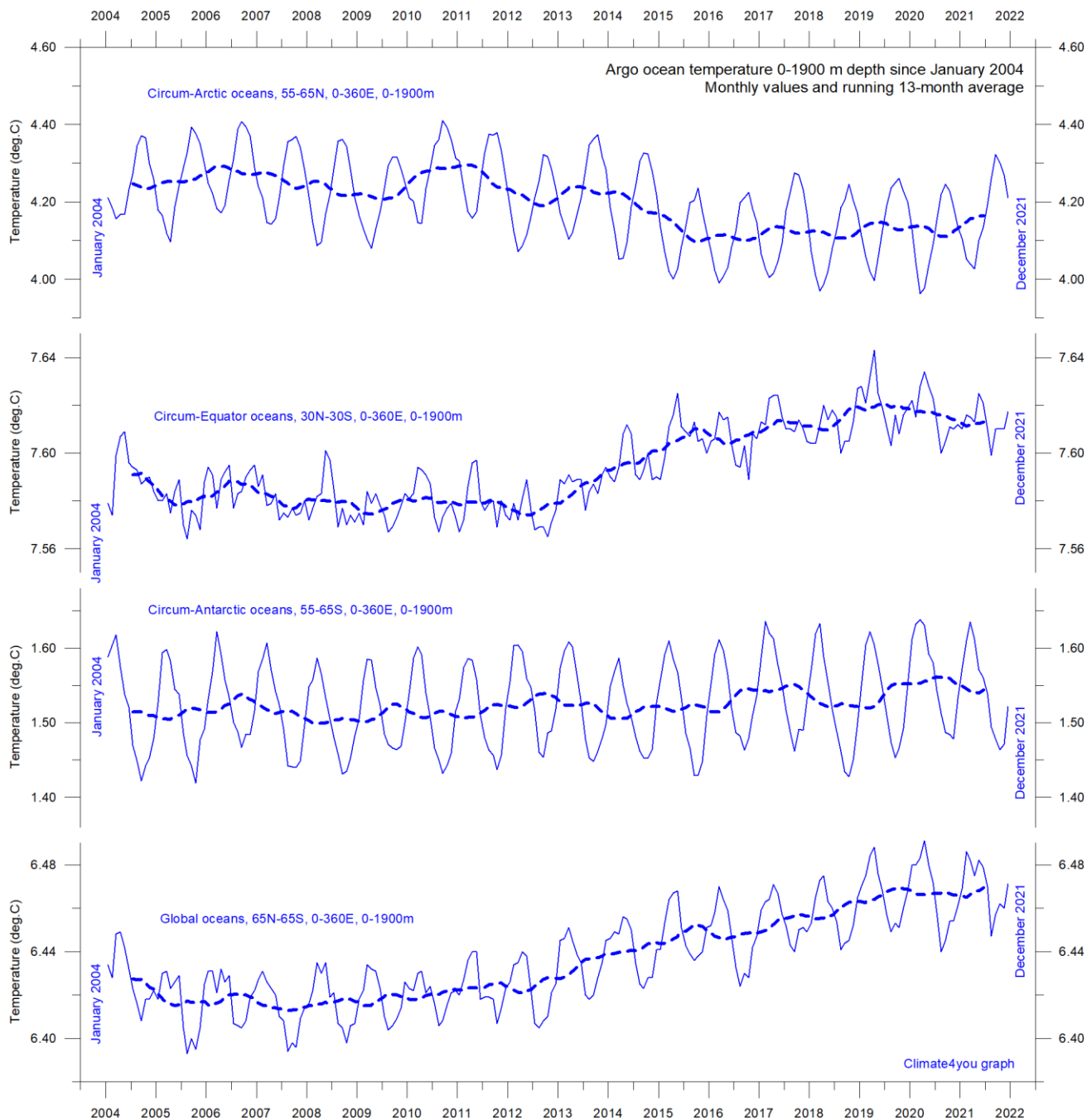
Time series depth-temperature diagram along 59 N across the North Atlantic Current from 30°W to 0°W, from surface to 800 m depth. Source: [Global Marine Argo Atlas](#). See also the diagram below.

22



Average temperature along 59 N, 30-0W, 0-800m depth, corresponding to the main part of the North Atlantic Current, using [Argo](#)-data. Source: [Global Marine Argo Atlas](#). Additional information can be found in: Roemmich, D. and J. Gilson, 2009. The 2004-2008 mean and annual cycle of temperature, salinity, and steric height in the global ocean from the Argo Program. [Progress in Oceanography](#), 82, 81-100.

## Global ocean temperature 0-1900 m depth summary, updated to December 2021

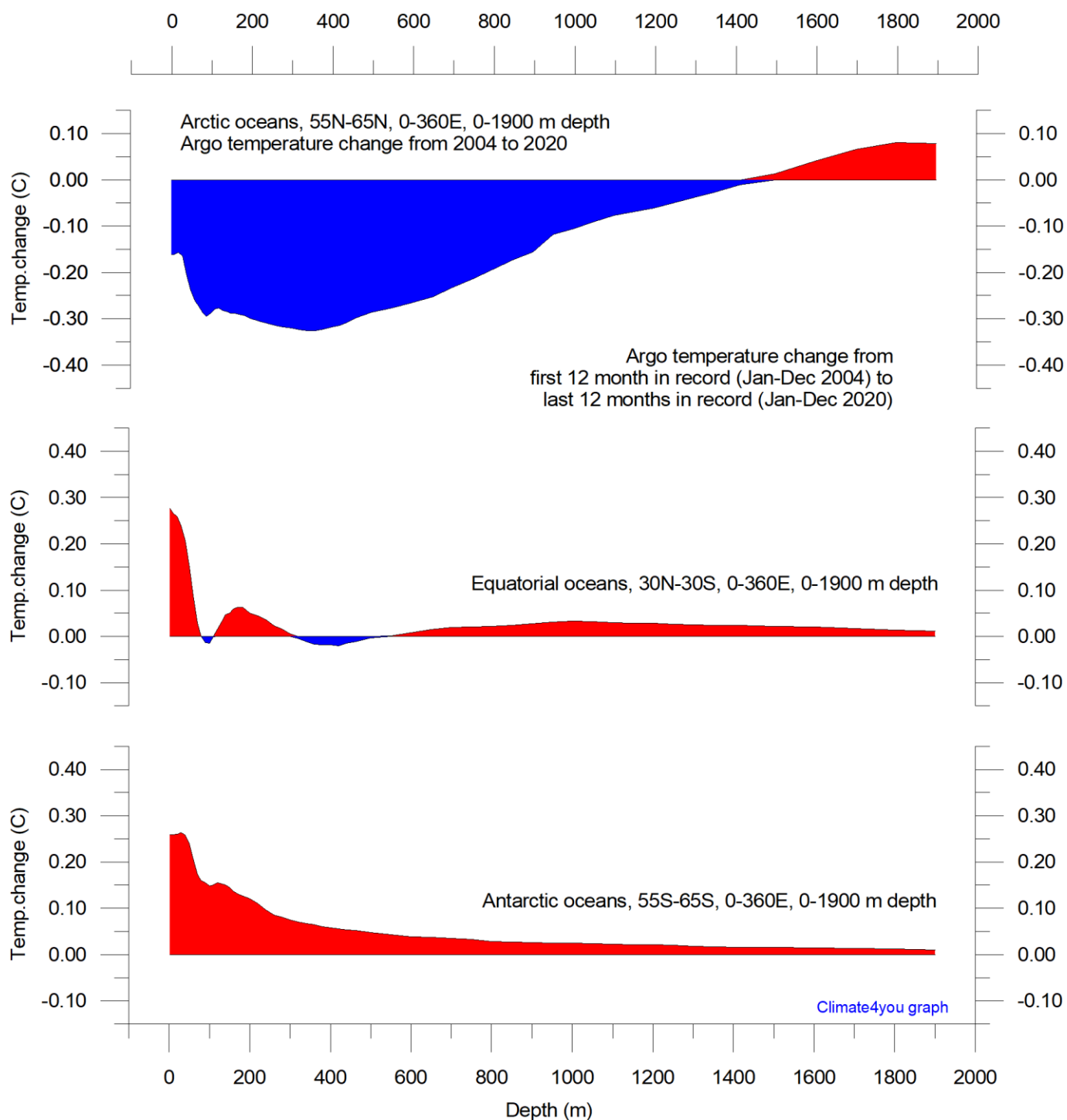


Summary of average temperature in uppermost 1900 m in different parts of the global oceans, using [Argo](#)-data. Source: [Global Marine Argo Atlas](#). Additional information can be found in: Roemmich, D. and J. Gilson, 2009. The 2004-2008 mean and annual cycle of temperature, salinity, and steric height in the global ocean from the Argo Program. [Progress in Oceanography](#), 82, 81-100.

The temperature of the global oceans down to 1900 m depth has been increasing since about 2011, but with a possible peak around 2020. The global increase since 2013 is mainly due to changes occurring near the Equator, between 30°N and 30°S. In contrast, for the circum-Arctic

oceans north of 55°N, depth-integrated ocean temperatures have been decreasing since 2011, but with a possible low around 2019. Near the Antarctic, south of 55°S, temperatures have essentially been stable. At most latitudes, a clear annual rhythm is evident.

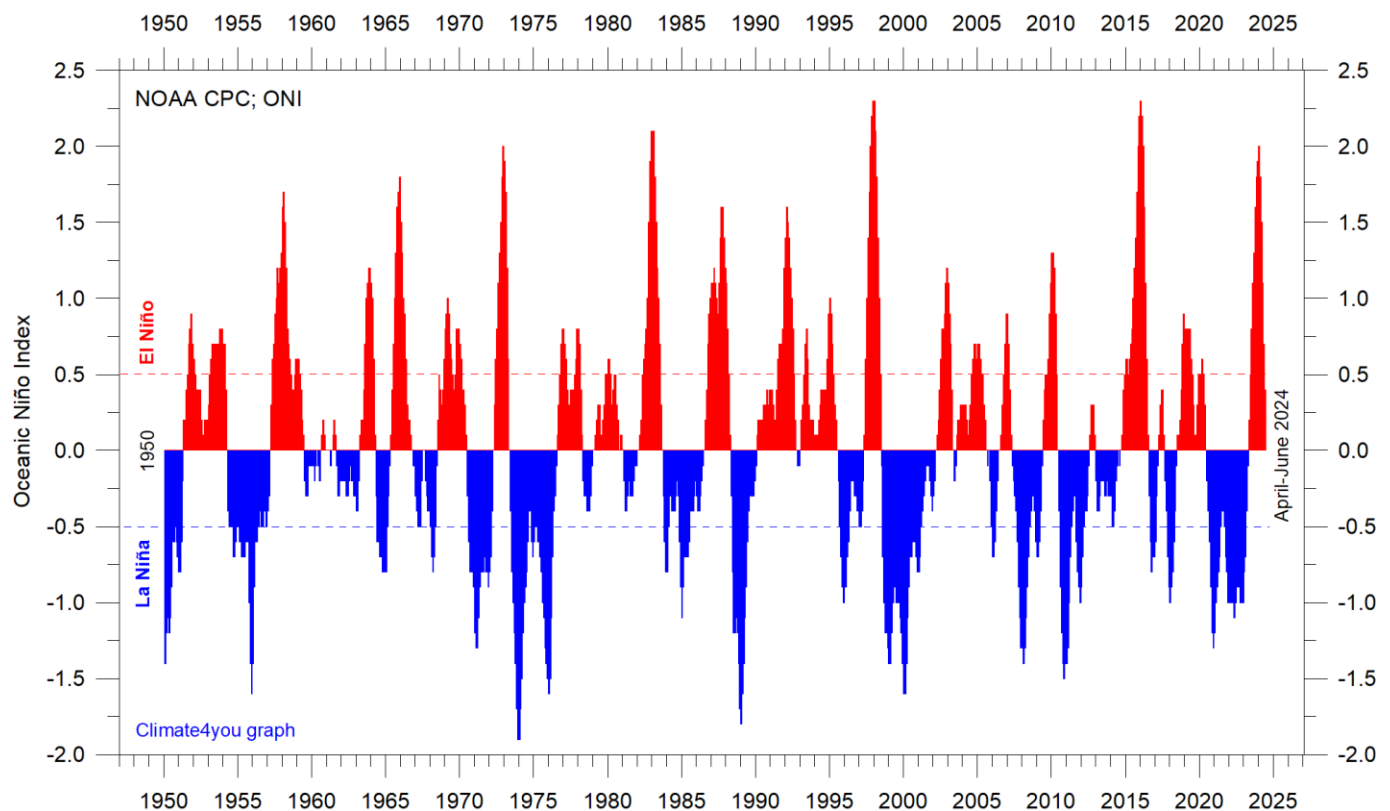
## Global ocean net temperature change since 2004 at different depths, updated to December 2020



Net temperature change since 2004 from surface to 1900 m depth in different parts of the global oceans, using [Argo](#)-data. Source: [Global Marine Argo Atlas](#). Additional information can be found in: Roemmich, D. and J. Gilson, 2009. The 2004-2008 mean and annual cycle of temperature, salinity, and steric height in the global ocean from the Argo Program. [Progress in Oceanography](#), 82, 81-100. Please note that due to the spherical form of Earth, northern and southern latitudes represent only small ocean volumes, compared to latitudes near the Equator.



## La Niña and El Niño episodes, Oceanic Niño Index (ONI), updated to June 2024



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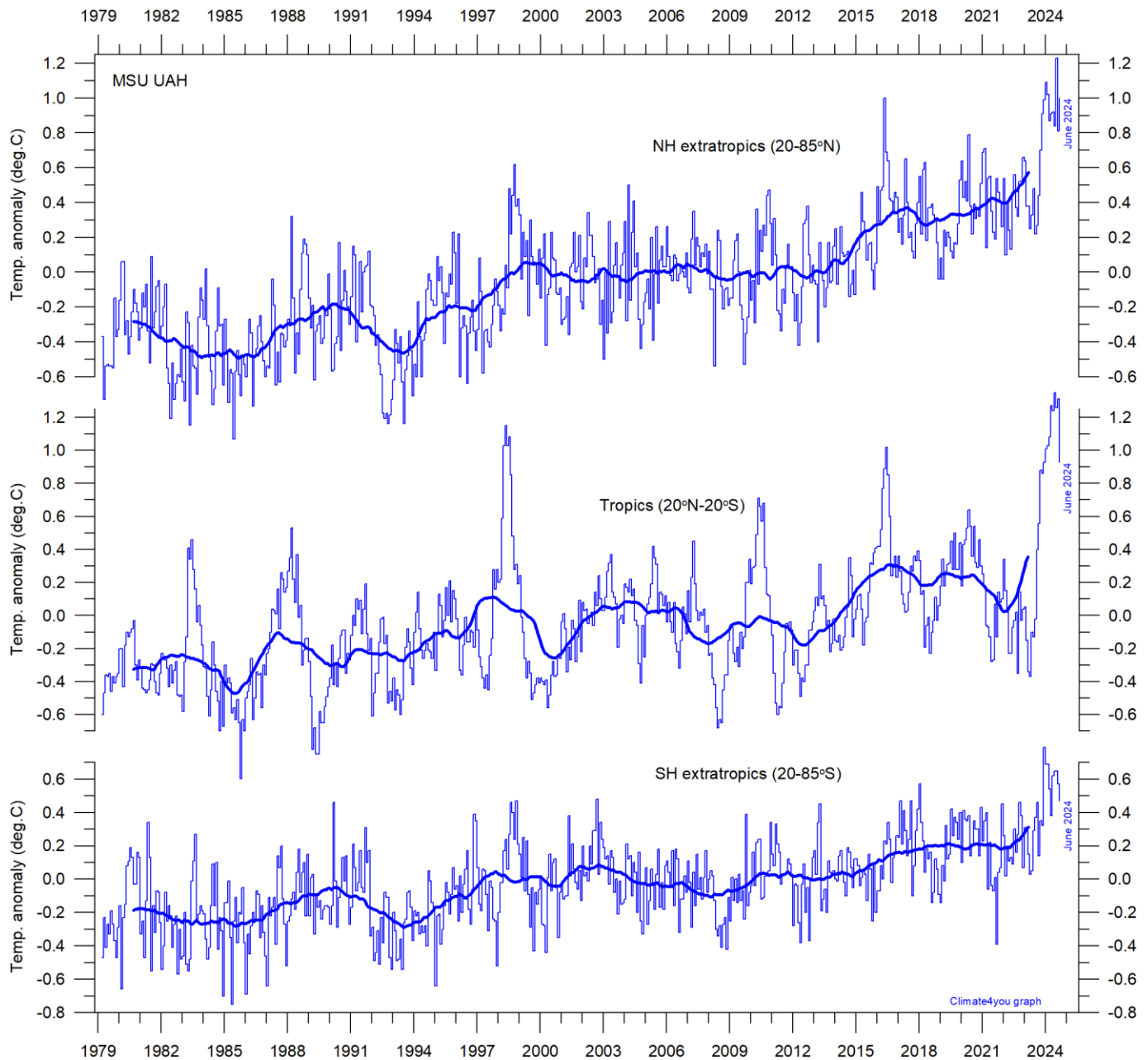
Warm ( $>+0.5^{\circ}\text{C}$ ) and cold ( $<-0.5^{\circ}\text{C}$ ) episodes for the [Oceanic Niño Index \(ONI\)](#), defined as 3 month running mean of ERSSTv4 SST anomalies in the Niño 3.4 region ( $5^{\circ}\text{N}$ - $5^{\circ}\text{S}$ ,  $120^{\circ}$ - $170^{\circ}\text{W}$ ). For historical purposes cold and warm episodes are defined when the threshold is met for a minimum of 5 consecutive over-lapping seasons. Anomalies are centred on 30-yr base periods updated every 5 years.

In the Pacific Ocean, trade winds usually blow west along the equator, pushing warm water from South America towards Asia. To replace that warm water, cold water rises from the depths near South America. During El Niño episodes, trade winds weaken, and warm water is spreading back east, toward South America. In contrast, during La Niña episodes, trade winds are stronger than usual, pushing more warm water than usual toward Asia, and upwelling of cold water near South America therefore increases.

The 2015-16 El Niño episode is among the strongest since the beginning of the record in 1950. Considering the entire record, however, recent variations between El Niño and La Niña episodes do not appear abnormal in any way.

A Fourier frequency analysis (not shown here) shows the ONI record to be influenced by a significant 3.6-year cycle, and feasibly also by a longer 5.6-year cycle.

## Zonal lower troposphere temperatures from satellites, updated to June 2024

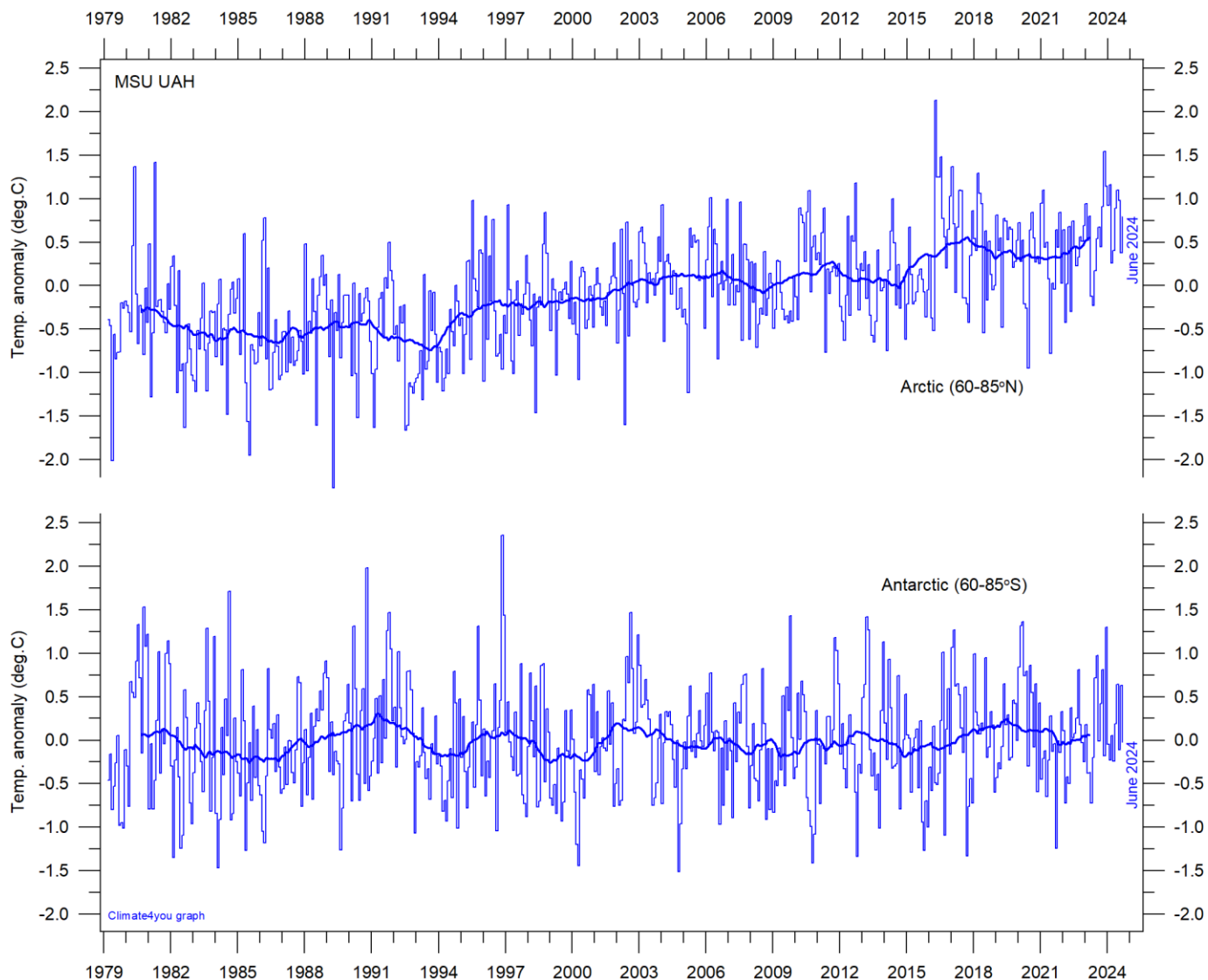


Global monthly average lower troposphere temperature since 1979 for the tropics and the northern and southern extratropics, according to University of Alabama at Huntsville, USA. Thin lines show the monthly temperature. Thick lines represent the simple running 37-month average, nearly corresponding to a running 3-year average. Reference period 1981-2010.

The overall warming since 1980 has dominantly been a northern hemisphere phenomenon, and mainly played out as a marked change between 1994 and 1999. However, this rather rapid temperature change is probably influenced by the Mt. Pinatubo eruption 1992-93 and the subsequent 1997 El Niño episode. The diagram also shows the

temperature effects of the strong Equatorial El Niño's in 1997 and 2015-16, as well as the moderate El Niño in 2019. Apparently, these effects were spreading to higher latitudes in both hemispheres with some delay. Recently, a new El Niño was playing out in the Pacific Ocean (p.25), as is clearly shown by tropics surface air temperatures.

## Arctic and Antarctic lower troposphere temperature, updated to June 2024



Global monthly average lower troposphere temperature since 1979 for the North Pole and South Pole regions, based on satellite observations ([University of Alabama](#) at Huntsville, USA). Thin lines show the monthly temperature. The thick line is the simple running 37-month average, nearly corresponding to a running 3-year average. Reference period 1991-2020.

In the Arctic region, warming mainly took place 1994-96, and less so subsequently. In 2016, however, temperatures peaked for several months, presumably because of oceanic heat given off to the atmosphere during the 2015-15 El Niño (see also diagram on page 25) and subsequently advected to higher latitudes.

This underscores how Arctic air temperatures may be affected not only by variations in local conditions but also by variations playing out in geographically remote regions.

A slight temperature decrease has characterised the Arctic since the marked 2016 El Niño peak. In contrast, the present (2023-24) El Niño episode is recorded by Arctic temperatures in a less pronounced way.

In the Antarctic region, temperatures have basically remained stable since the onset of the satellite record in 1979. In 2016-17 a small temperature peak visible in the monthly record may be interpreted as the subdued effect of the recent El Niño episode.

## Arctic and Antarctic surface air temperature, updated to December 2021

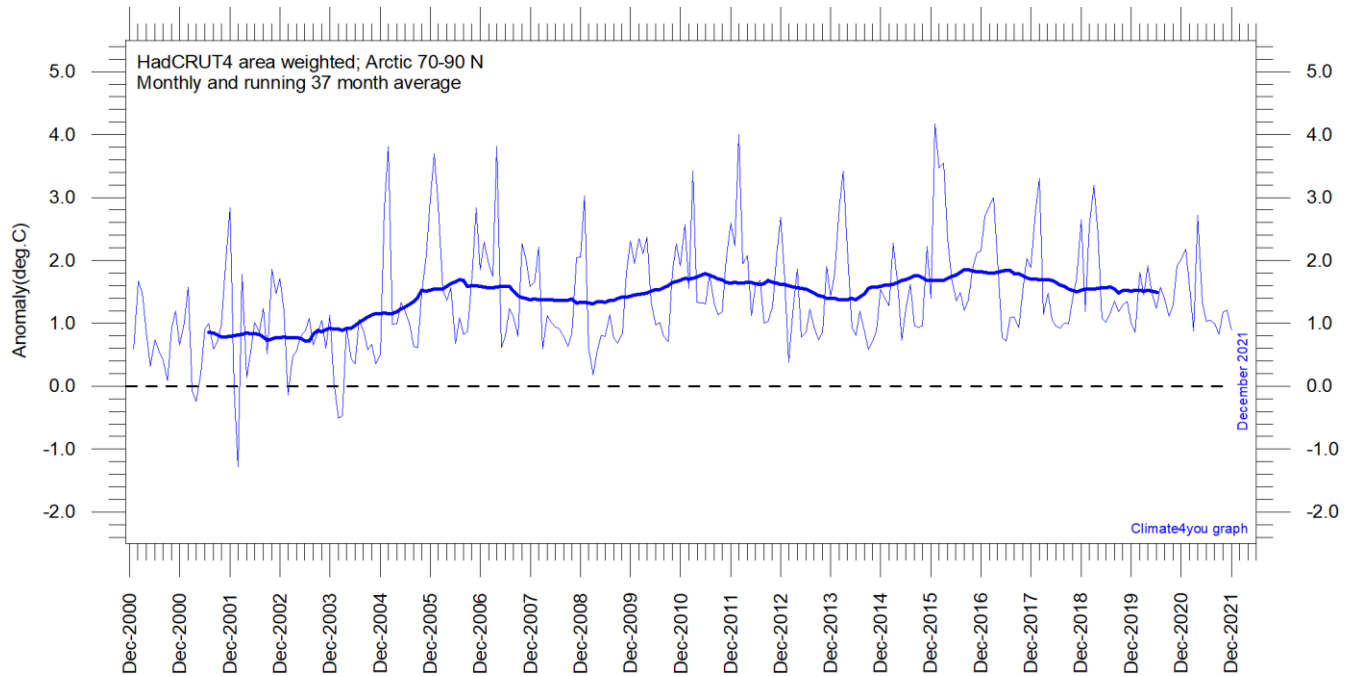


Diagram showing area weighted Arctic (70-90°N) monthly surface air temperature anomalies ([HadCRUT4](#)) since January 2000, in relation to the WMO [normal period](#) 1961-1990. The thin line shows the monthly temperature anomaly, while the thicker line shows the running 37-month (c. 3 year) average.

28

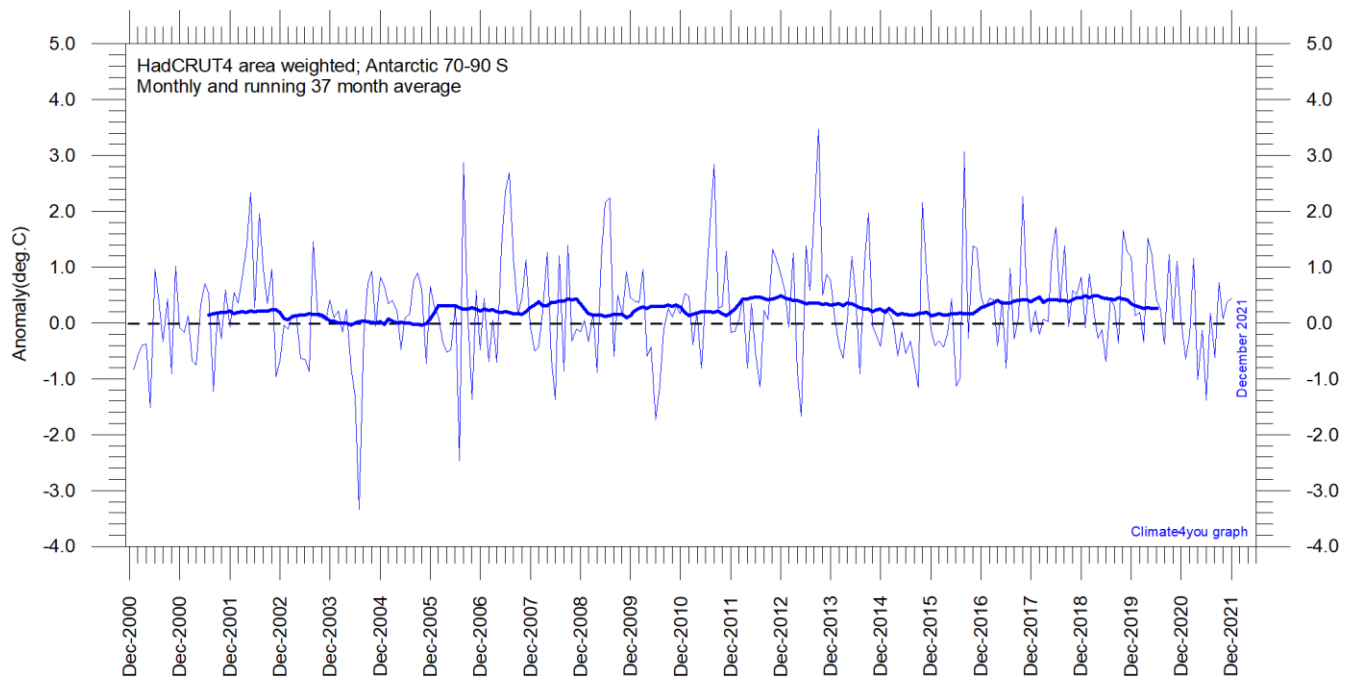


Diagram showing area weighted Antarctic (70-90°S) monthly surface air temperature anomalies ([HadCRUT4](#)) since January 2000, in relation to the WMO [normal period](#) 1961-1990. The thin line shows the monthly temperature anomaly, while the thicker line shows the running 37-month (c. 3 year) average.



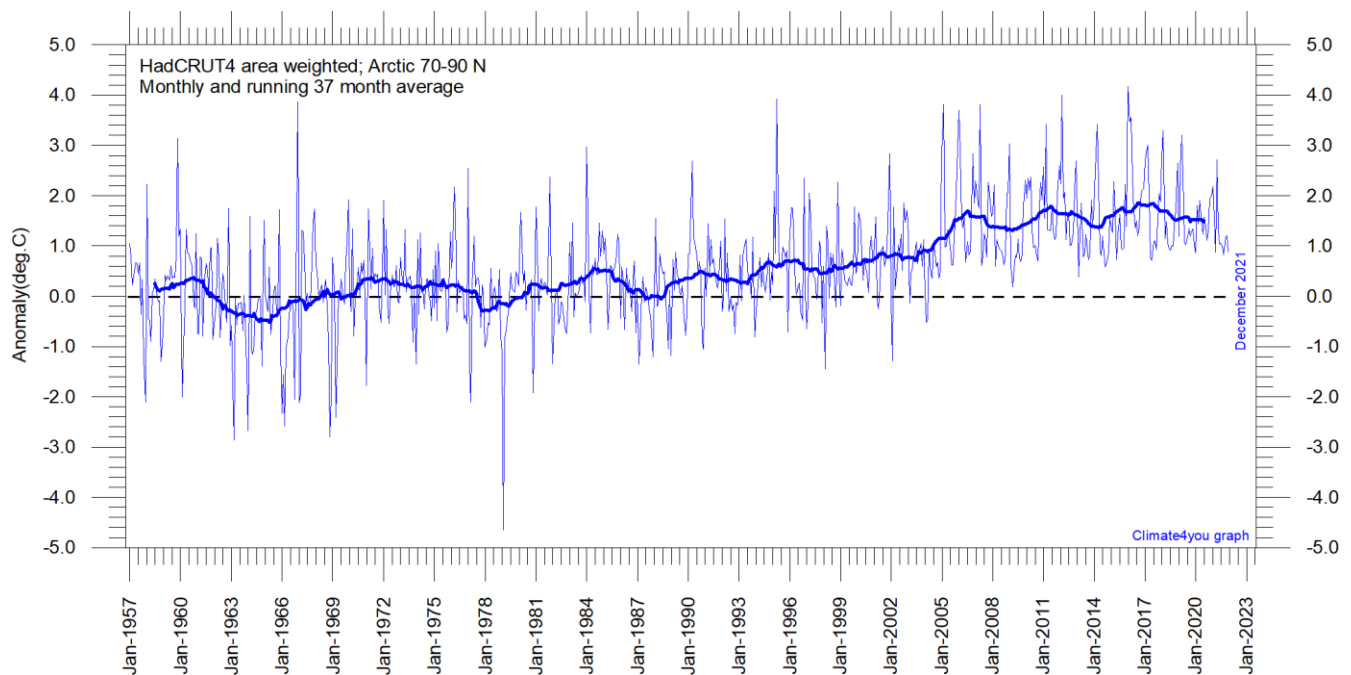


Diagram showing area weighted Arctic (70-90°N) monthly surface air temperature anomalies ([HadCRUT4](#)) since January 1957, in relation to the WMO [normal period](#) 1961-1990. The thin line shows the monthly temperature anomaly, while the thicker line shows the running 37-month (c. 3 year) average.

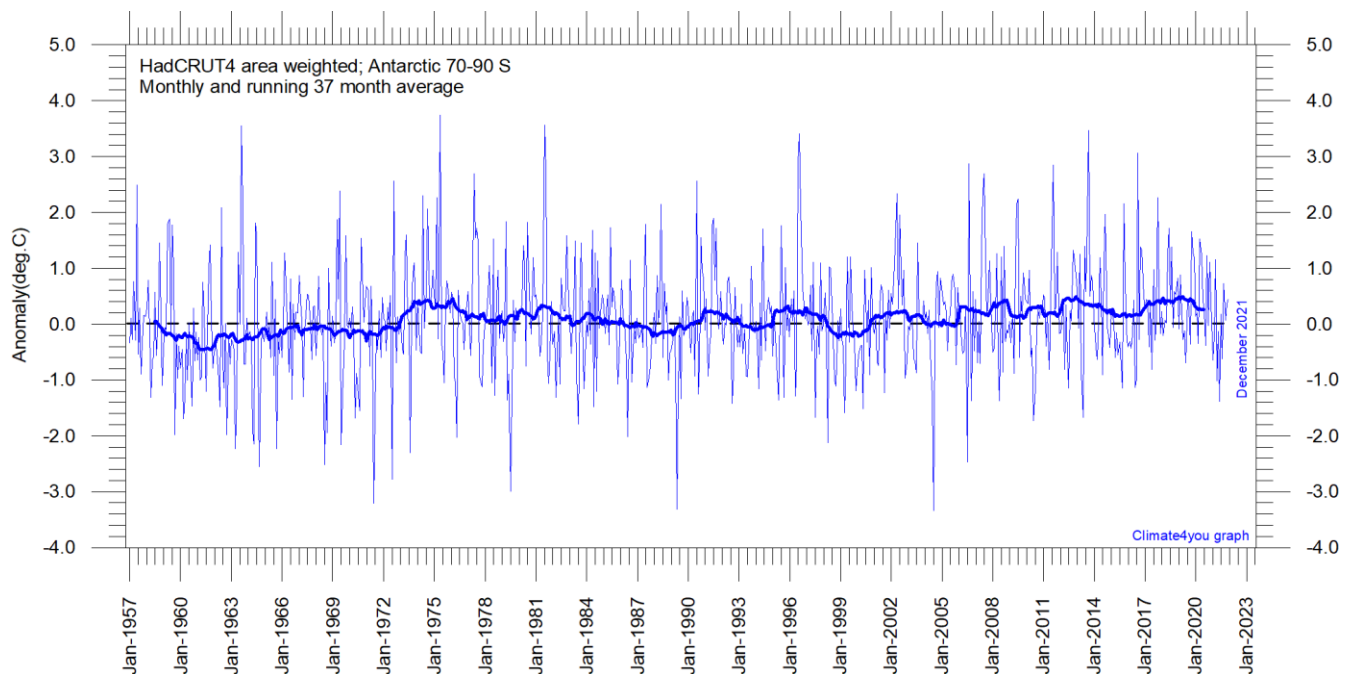


Diagram showing area weighted Antarctic (70-90°S) monthly surface air temperature anomalies ([HadCRUT4](#)) since January 1957, in relation to the WMO [normal period](#) 1961-1990. The thin line shows the monthly temperature anomaly, while the thicker line shows the running 37-month (c. 3 year) average.

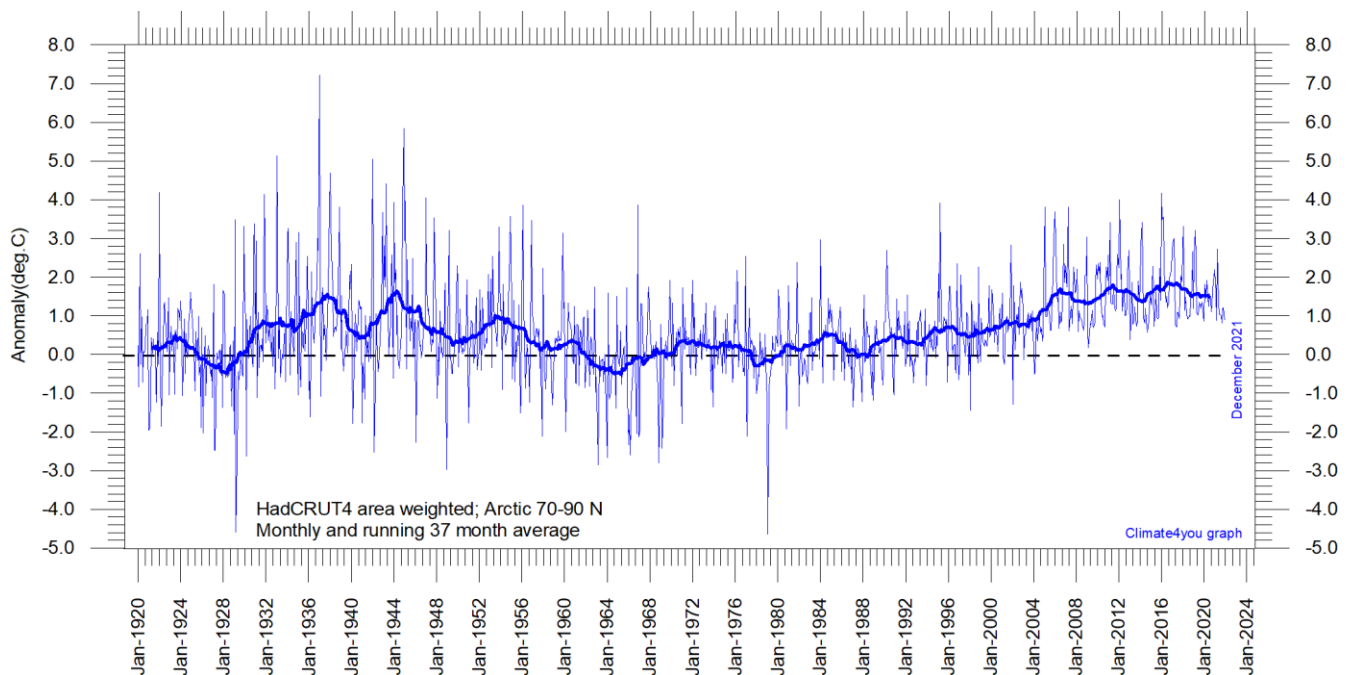


Diagram showing area-weighted Arctic (70-90°N) monthly surface air temperature anomalies ([HadCRUT4](#)) since January 1920, in relation to the WMO [normal period](#) 1961-1990. The thin line shows the monthly temperature anomaly, while the thicker line shows the running 37-month (c. 3 year) average.

Because of the relatively small number of Arctic stations before 1930, month-to-month variations in the early part of the Arctic temperature record 1920-2018 are higher than later (diagram above).

The period from about 1930 saw the establishment of many new Arctic meteorological stations, first in Russia and Siberia, and following the 2<sup>nd</sup> World War, also in North America, explaining the above difference.

The period since 2005 is warm, about as warm as the period 1930-1940.

As the HadCRUT4 data series has improved high latitude coverage data coverage (compared to the HadCRUT3 series), the individual 5°x5° grid cells have been weighted according to their surface area. This area correction is especially important for polar

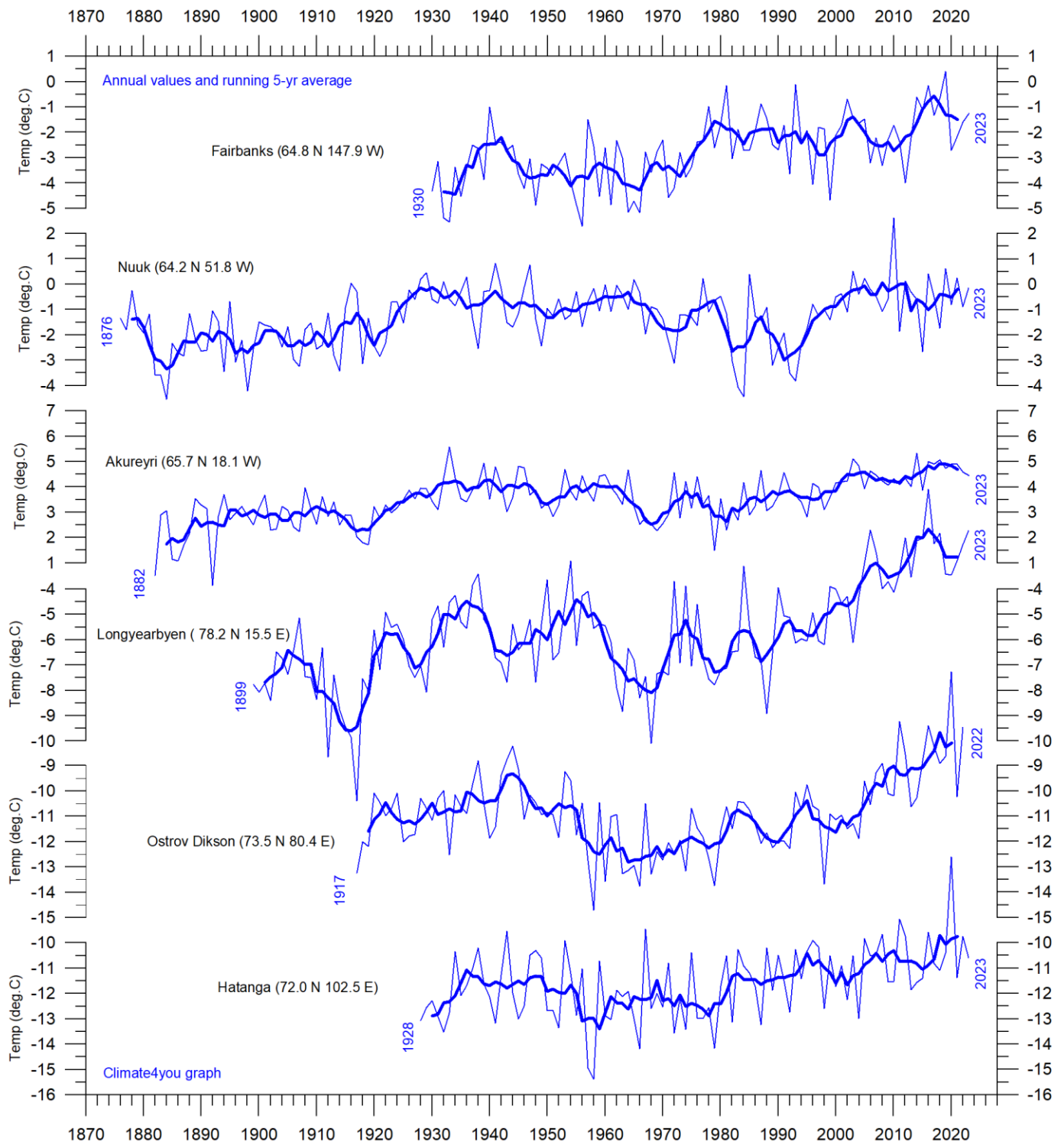
regions, where longitudes converge rapidly. This approach differs from the approach used by Gillett et al. 2008, which calculated a simple average, with no correction for the substantial latitudinal surface area effect in polar regions.

The area weighted Arctic HadCRUT4 surface air temperature anomalies (p.28-30) correspond rather well to the lower troposphere temperature anomalies recorded by satellites (p.27).

#### Literature:

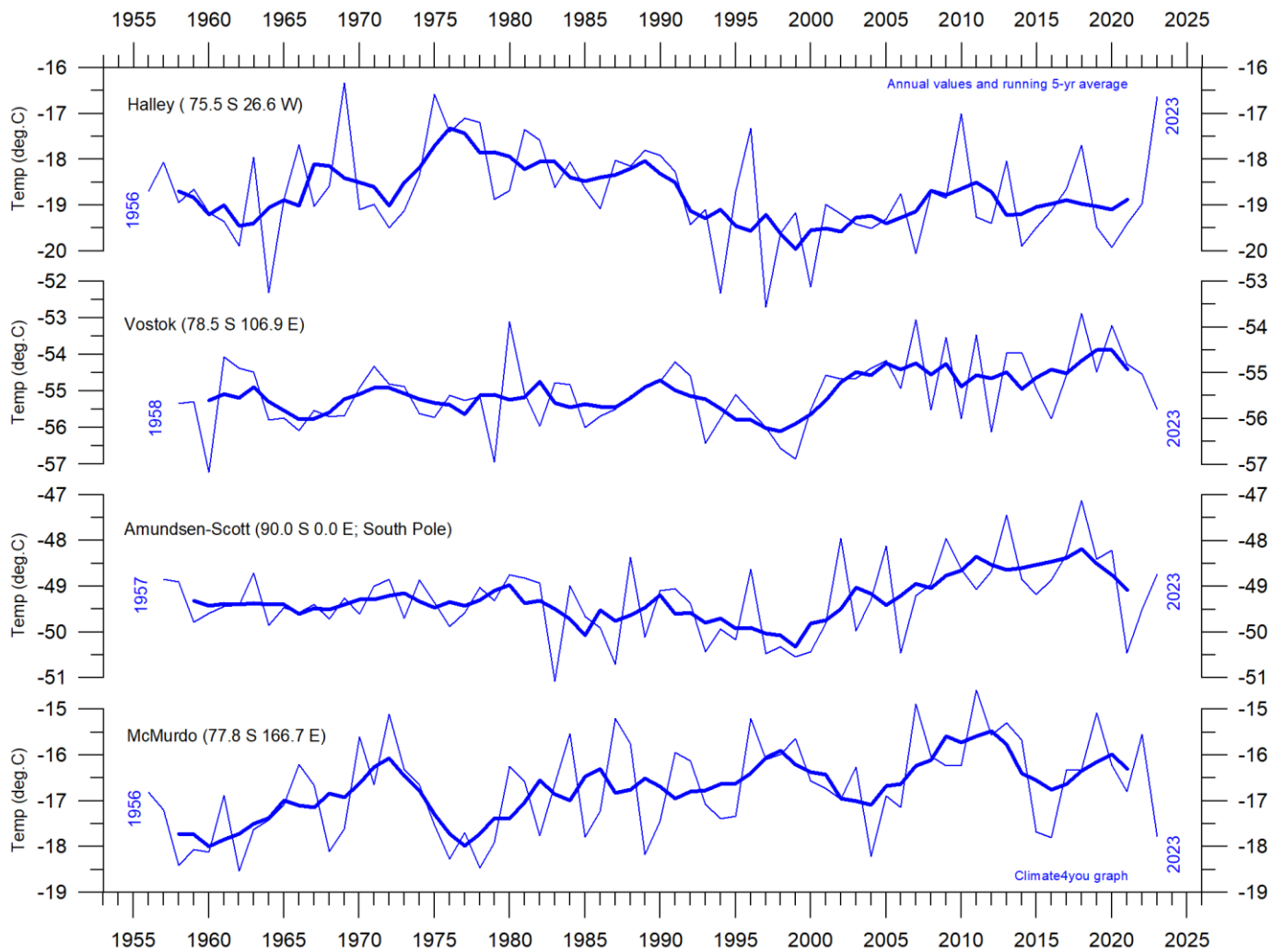
Gillett, N.P., Stone, D.A., Stott, P.A., Nozawa, T., Karpechko, A.Y.U., Hegerl, G.C., Wehner, M.F. and Jones, P.D. 2008. Attribution of polar warming to human influence. *Nature Geoscience* 1, 750-754.

## Long Arctic annual surface air temperature series, updated to year 2023



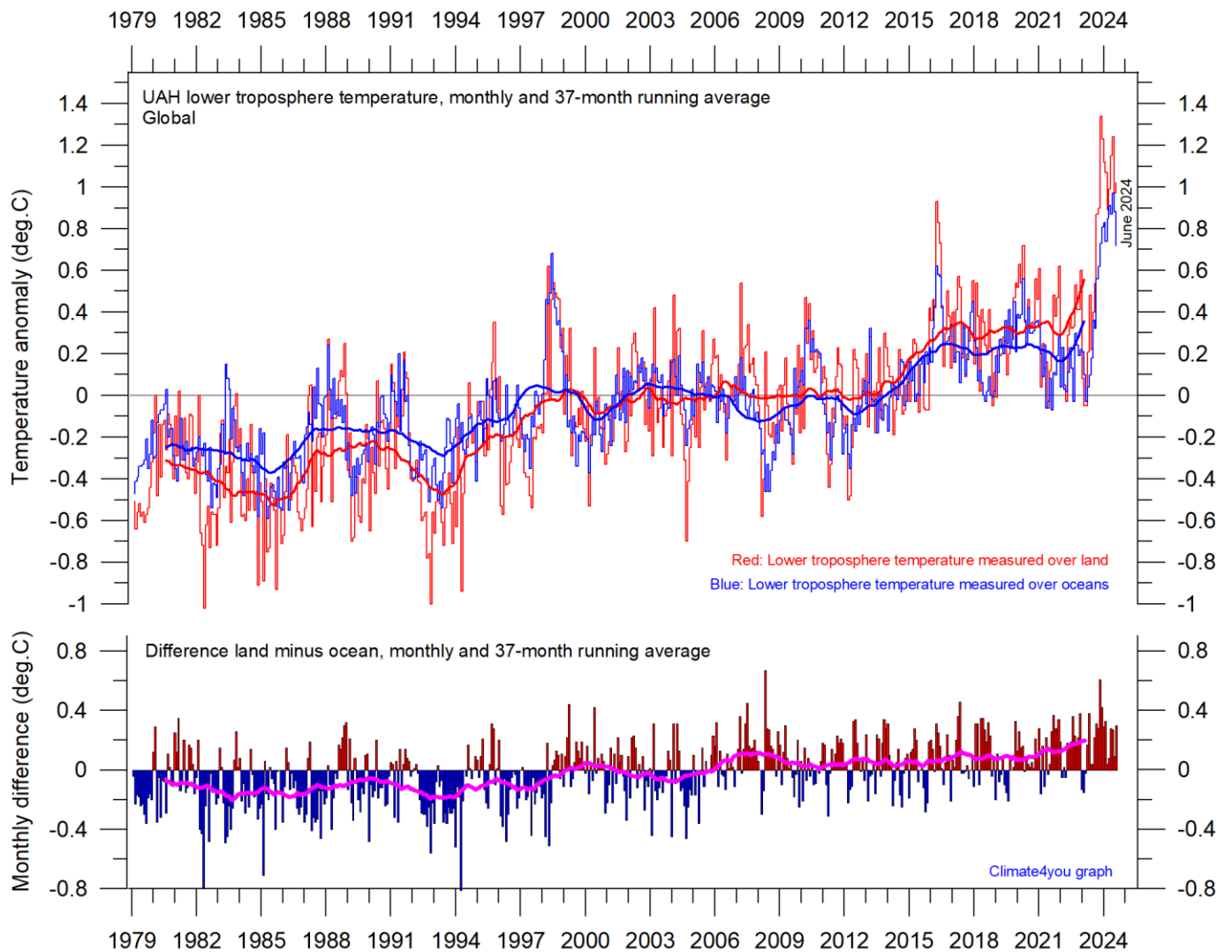
Arctic annual surface air temperature series, selected because of their length of observation time. The thin blue line represents the mean annual air temperature, and the thick blue line is the running 5-year average. Annual values were calculated from monthly average temperatures. More info on [Climate4you](https://climate4you.com).

## Long Antarctic annual surface air temperature series, updated to year 2023



Antarctic annual surface air temperature series, selected because of their length of observation time. The thin blue line represents the mean annual air temperature, and the thick blue line is the running 5-year average. Annual values were calculated from monthly average temperatures. More info on [Climate4you](https://climate4you.com).

## Temperature over land versus over oceans, updated to June 2024



Global monthly average lower troposphere temperature since 1979 measured over land and oceans, respectively, according to [University of Alabama](#) at Huntsville, USA. Thick lines are the simple running 37-month average, nearly corresponding to a running 3-year average. Reference period 1991-2020.

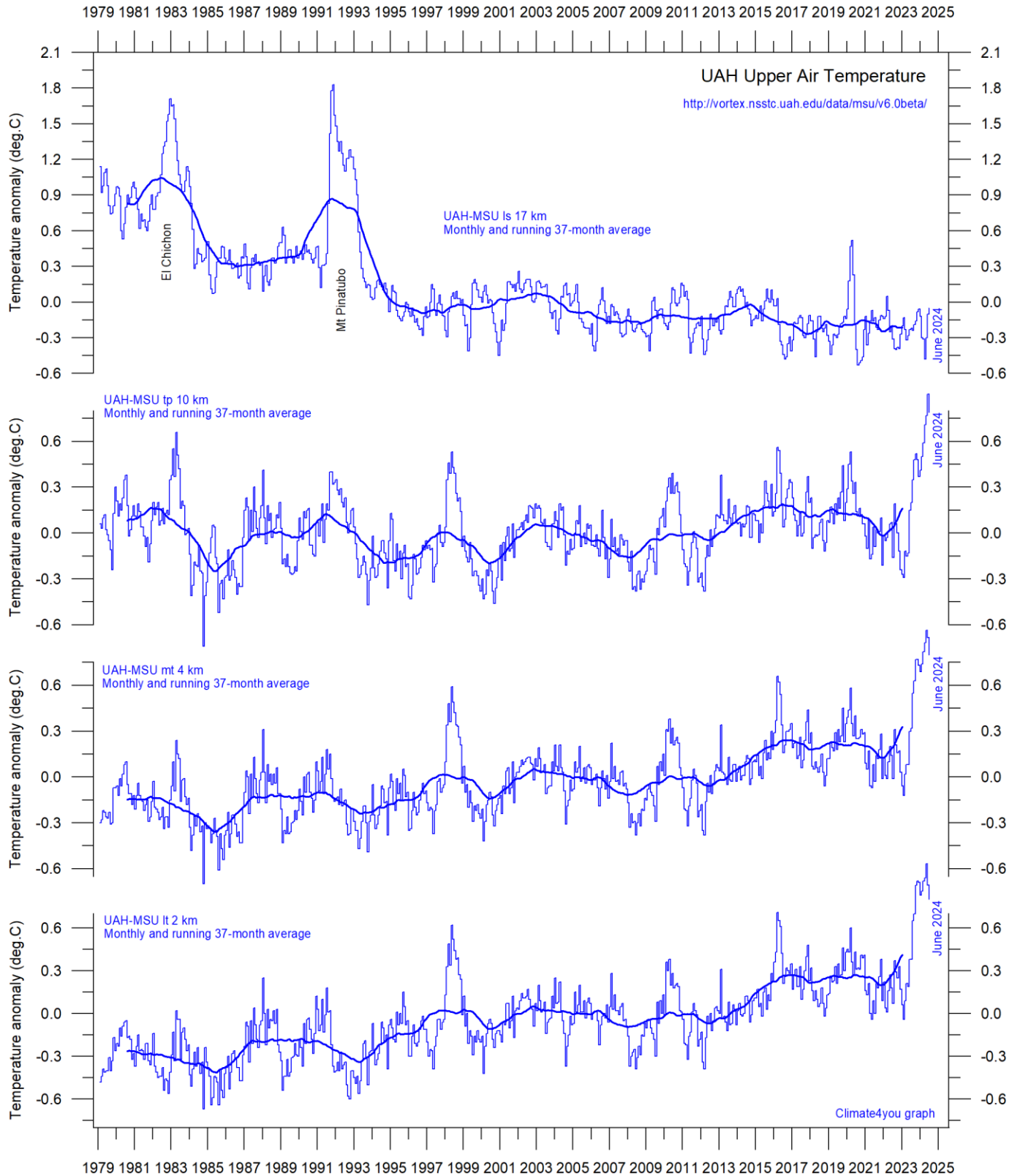
Since 1979, the lower troposphere over land has warmed much more than over oceans, suggesting that the overall warming is derived mainly from incoming solar radiation. In addition, there may be supplementary reasons for this divergence, such as,

e.g., variations in cloud cover and changes in land use. Compare also with cloud cover diagram on page 60.

The present (2023) El Niño episode is recorded more pronounced over land regions, compared to ocean regions.

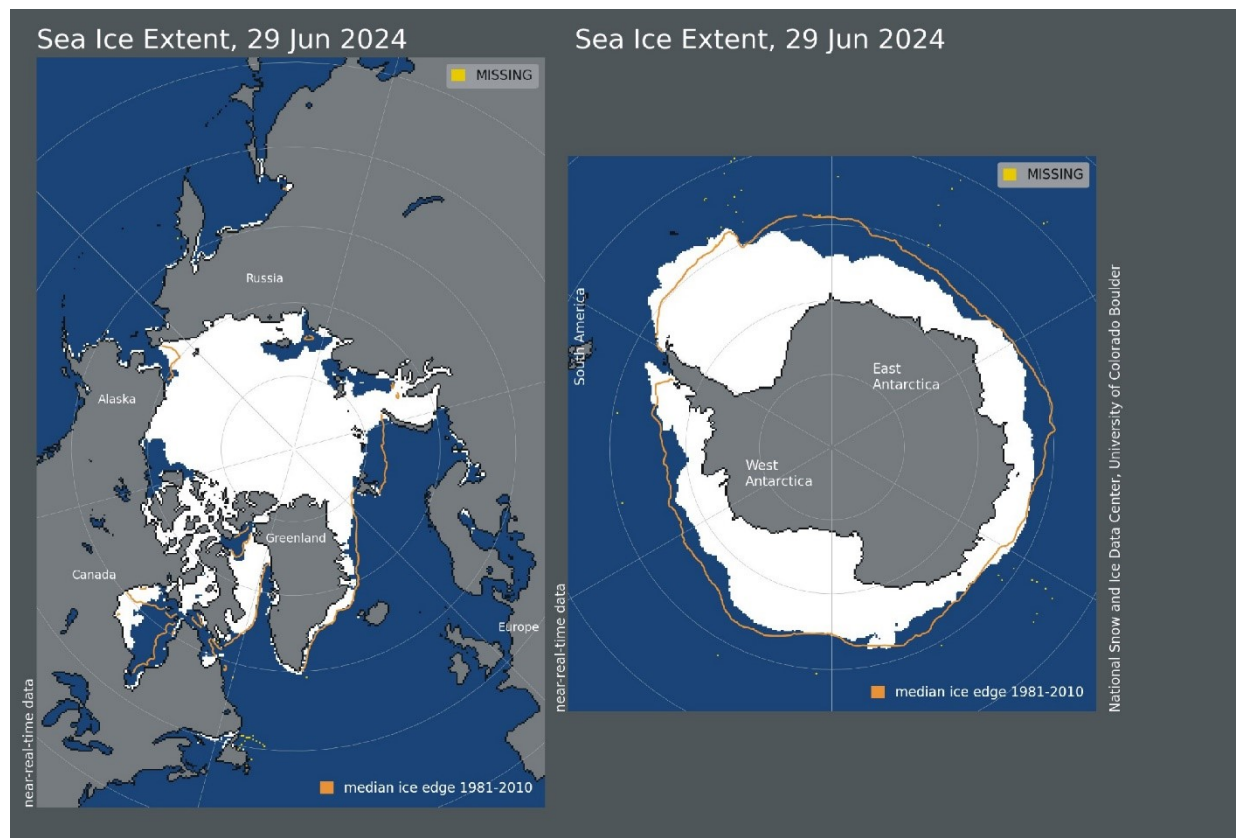


## Troposphere and stratosphere temperatures from satellites, updated to June 2024



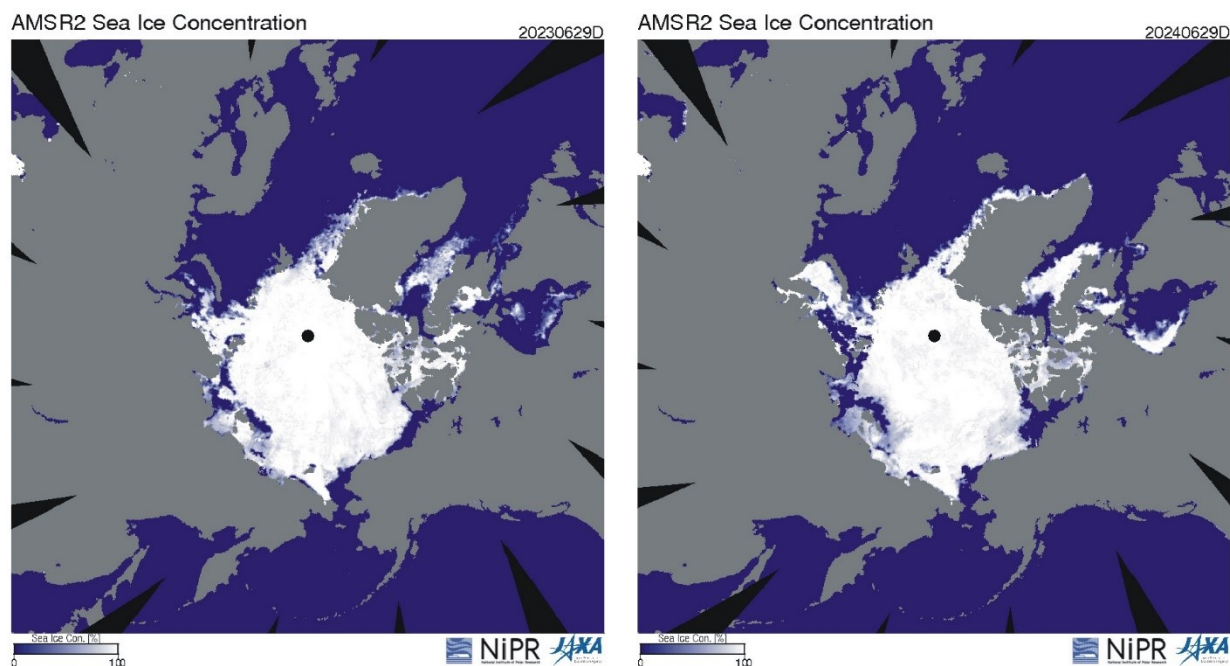
Global monthly average temperature in different according to University of Alabama at Huntsville, USA. The thin lines represent the monthly average, and the thick line the simple running 37-month average, nearly corresponding to a running 3-year average. Reference period 1991-2020.

## Arctic and Antarctic sea ice, updated to June 2024

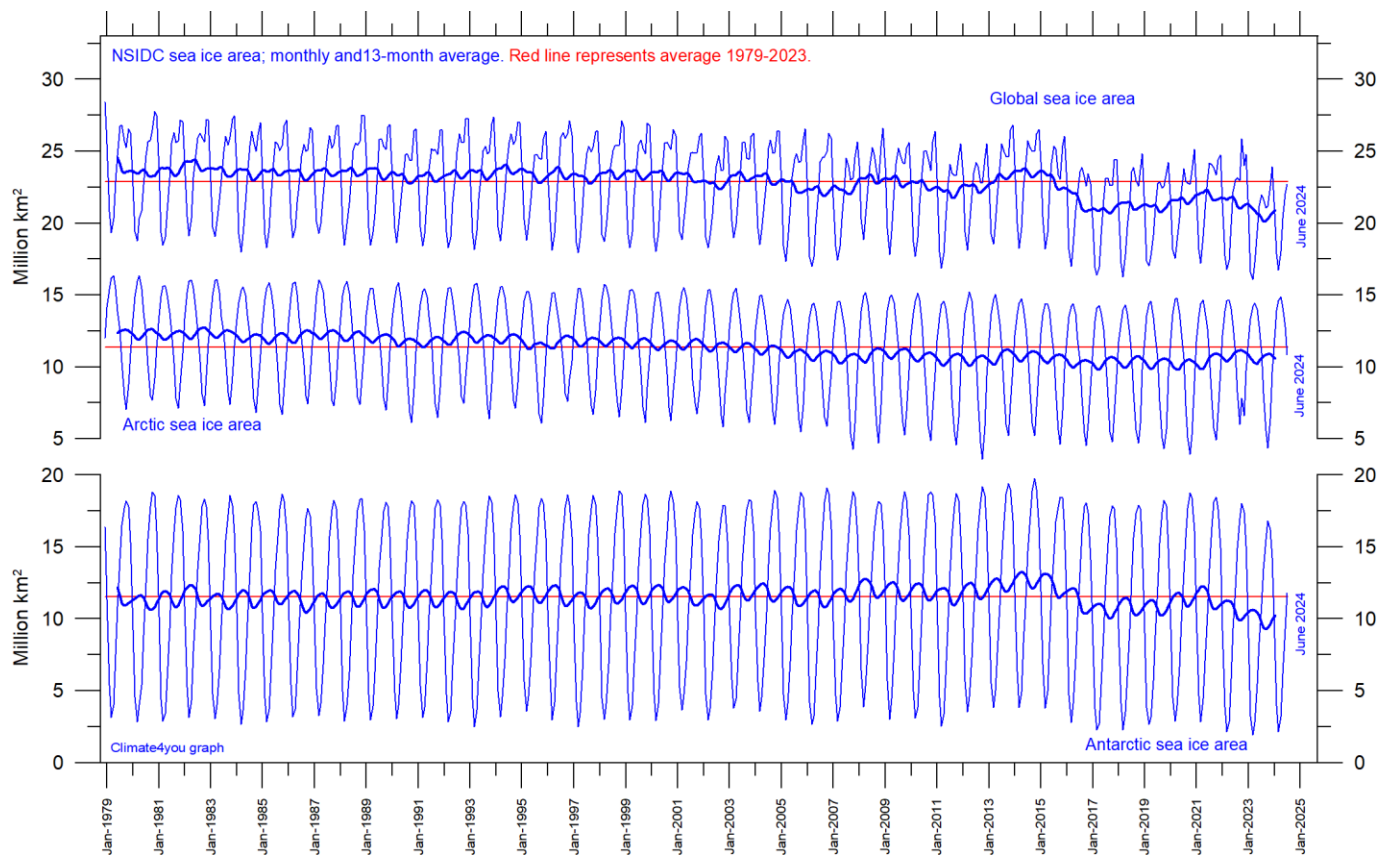


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Sea ice extent 29 June 2024. The median limit of sea ice (orange line) is defined as 15% sea ice cover, according to the average of satellite observations 1981-2010 (both years included). Sea ice may therefore well be encountered outside and open water areas inside the limit shown in the diagrams above. Map source: National Snow and Ice Data Center (NSIDC).



Diagrams showing Arctic sea ice extent and concentration 29 June 2023 (left) and 2024 (right), according to the Japan Aerospace Exploration Agency (JAXA).



Graphs showing monthly Antarctic, Arctic, and global sea ice extent since November 1978, according to the [National Snow and Ice data Center \(NSIDC\)](#).

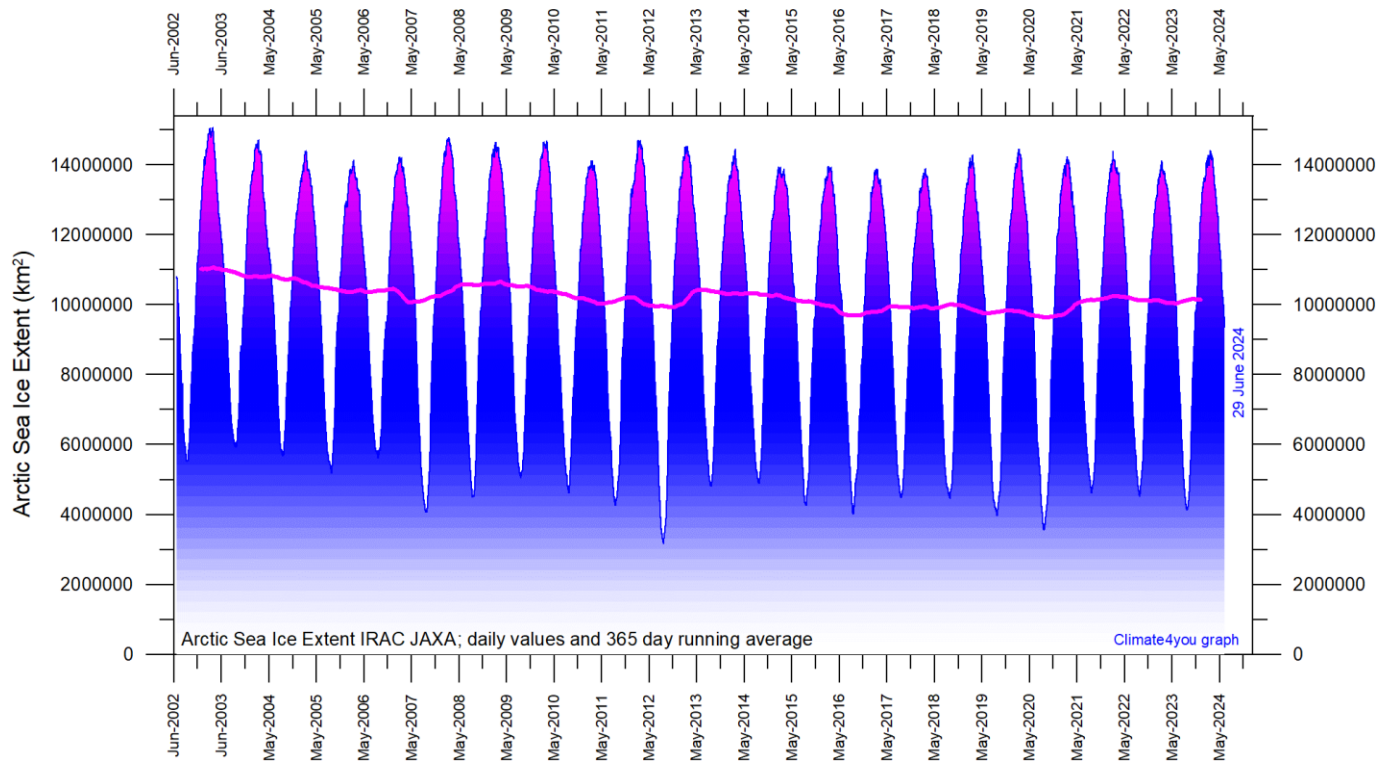
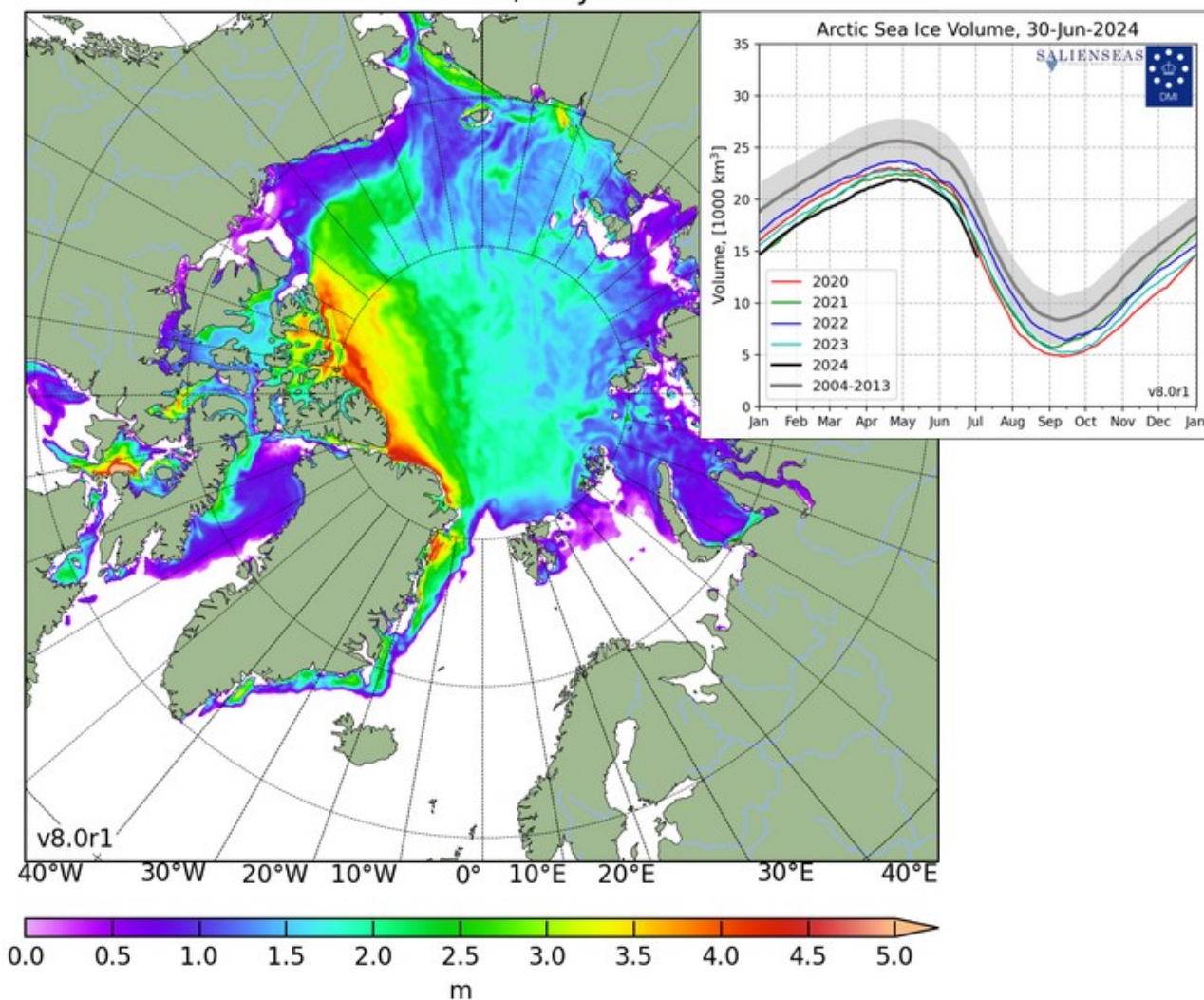


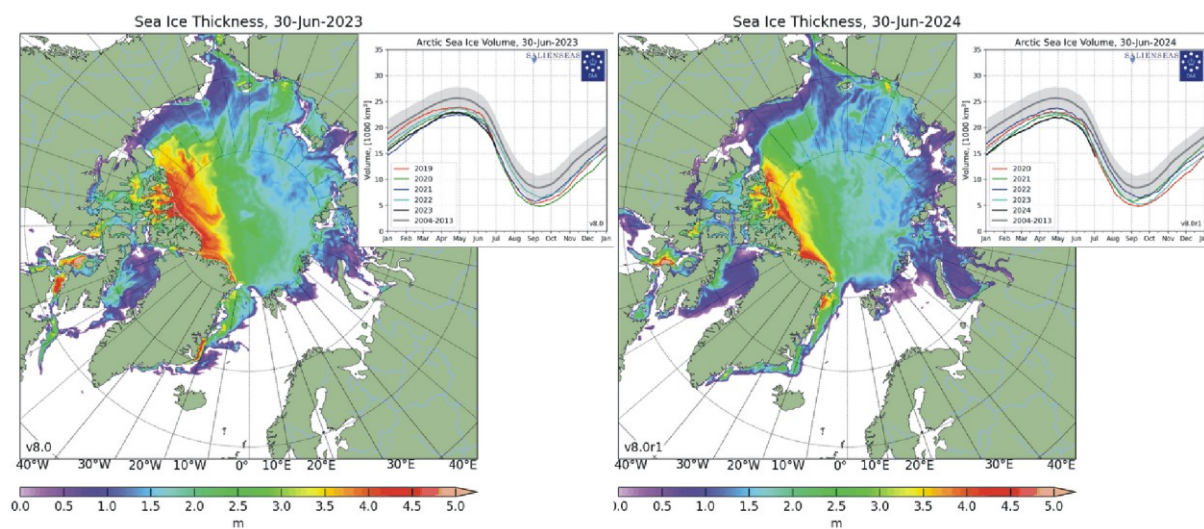
Diagram showing daily Arctic sea ice extent since June 2002, to 29 June 2024, data courtesy of [Japan Aerospace Exploration Agency \(JAXA\)](#).



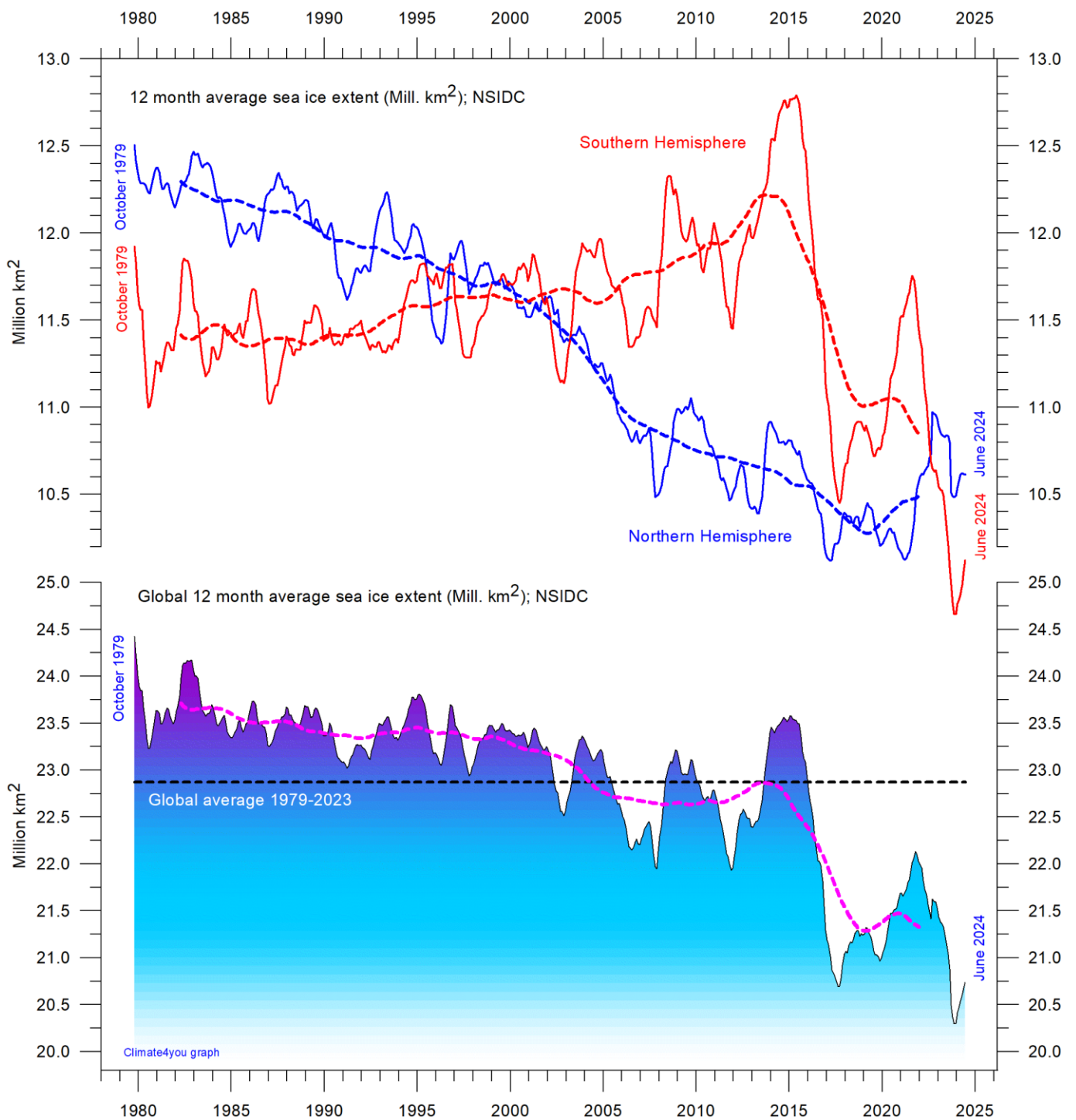
## Sea Ice Thickness, 30-Jun-2024



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Diagrams showing Arctic sea ice extent and thickness 30 June 2023 (left) and 2024 (right and above) and the seasonal cycles of the calculated total arctic sea ice volume, according to [The Danish Meteorological Institute \(DMI\)](http://polarportal.dk/en/sea-ice-and-icebergs/sea-ice-thickness-and-volume/). The mean sea ice volume and standard deviation for the period 2004-2013 are shown by grey shading. Please note that DMI on 7 December 2021 changed their sea ice calculation model. DMI's description of the model version change can be read here: <http://polarportal.dk/en/sea-ice-and-icebergs/sea-ice-thickness-and-volume/>



12 month running average sea ice extension, global and in both hemispheres since 1979, the satellite-era. The October 1979 value represents the monthly 12-month average of November 1978 - October 1979, the November 1979 value represents the average of December 1978 - November 1979, etc. The stippled lines represent a 61-month (ca. 5 years) average. Data source: National Snow and Ice Data Center (NSIDC).



## Sea level in general

Global (or eustatic) sea-level change is measured relative to an idealised reference level, the geoid, which is a mathematical model of planet Earth's surface (Carter et al. 2014). Global sea-level is a function of the volume of the ocean basins and the volume of water they contain. Changes in global sea-level are caused by – but not limited to – four main mechanisms:

1. Changes in local and regional air pressure and wind, and tidal changes introduced by the Moon.
2. Changes in ocean basin volume by tectonic (geological) forces.
3. Changes in ocean water density caused by variations in currents, water temperature and salinity.
4. Changes in the volume of water caused by changes in the mass balance of terrestrial glaciers.

In addition to these there are other mechanisms influencing sea-level, such as storage of ground water, storage in lakes and rivers, evaporation, etc.

Mechanism 1 is controlling sea-level at many sites on a time scale from months to several years. As an example, many coastal stations show a pronounced annual variation reflecting seasonal changes in air pressures and wind speed. Longer-term climatic changes playing out over decades or centuries will also affect measurements of sea-level changes. Hansen et al. (2011, 2015) provide excellent analyses of sea-level changes caused by recurrent changes of the orbit of the Moon and other phenomena.

Mechanism 2 – with the important exception of earthquakes and tsunamis - typically operates over long (geological) time scales and is not significant on human time scales. It may relate to variations in the seafloor spreading rate, causing volume changes in mid-ocean mountain ridges, and to the slowly changing configuration of land and oceans. Another effect may be the slow rise of basins due to isostatic offloading by deglaciation after an ice age. The floor of the Baltic Sea and the Hudson Bay are

presently rising, causing a slow net transfer of water from these basins into the adjoining oceans. Slow changes of excessively big glaciers (ice sheets) and movements in the mantle will affect the gravity field and thereby the vertical position of the ocean surface. Any increase of the total water mass as well as sediment deposition into oceans increase the load on their bottom, generating sinking by viscoelastic flow in the mantle below. The mantle flow is directed towards the surrounding land areas, which will rise, thereby partly compensating for the initial sea level increase induced by the increased water mass in the ocean.

Mechanism 3 (temperature-driven expansion) only affects the uppermost part of the oceans on human time scales. Usually, temperature-driven changes in density are more important than salinity-driven changes. Seawater is characterised by a relatively small coefficient of expansion, but the effect should however not be overlooked, especially when interpreting satellite altimetry data. Temperature-driven expansion of a column of seawater will not affect the total mass of water within the column considered and will therefore not affect the potential at the top of the water column. Temperature-driven ocean water expansion will therefore not in itself lead to any lateral displacement of water, but only locally lift the ocean surface. Near the coast, where people are living, the depth of water approaches zero, so no measurable temperature-driven expansion will take place here (Mörner 2015). Mechanism 3 is for that reason not important for coastal regions.

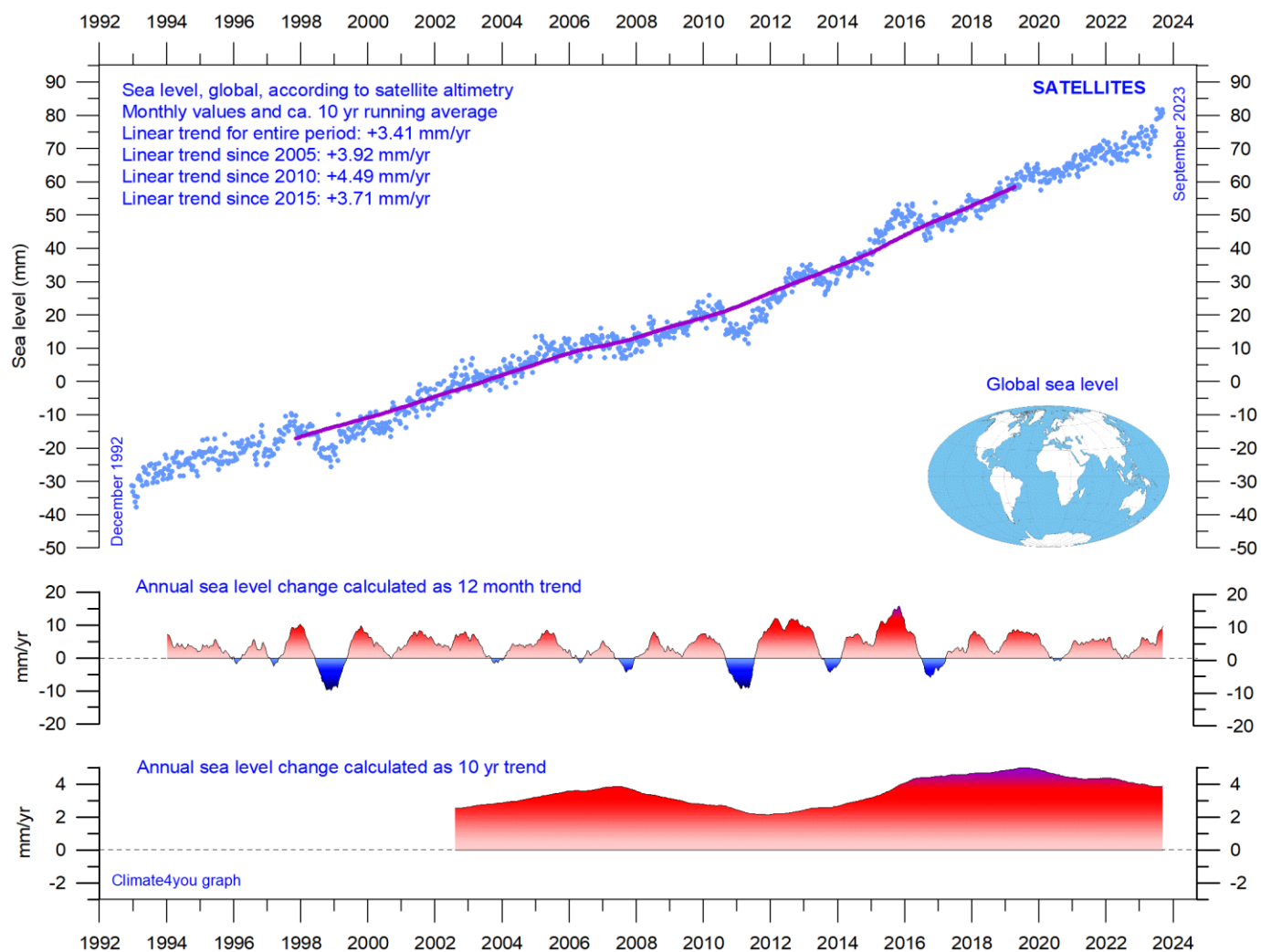
Mechanism 4 (changes in glacier mass balance) is an important driver for global sea-level changes along coasts, for human time scales. Volume changes of floating glaciers – ice shelves – has no influence on the global sea-level, just like volume changes of floating sea ice has no influence. Only the mass-balance of grounded or land-based glaciers is important for the global sea-level along coasts.

Summing up: Presumably, mechanism 1 and 4 are the most important for understanding sea-level changes along coasts.

### References:

- Carter R.M., de Lange W., Hansen, J.M., Humlum O., Idso C., Kear, D., Legates, D., Mörner, N.A., Ollier C., Singer F. & Soon W. 2014. Commentary and Analysis on the Whitehead& Associates 2014 NSW Sea-Level Report. Policy Brief, NIPCC, 24. September 2014, 44 pp. <http://climatechangereconsidered.org/wp-content/uploads/2014/09/NIPCC-Report-on-NSW-Coastal-SL-9z-corrected.pdf>
- Hansen, J.-M., Aagaard, T. and Binderup, M. 2011. Absolute sea levels and isostatic changes of the eastern North Sea to central Baltic region during the last 900 years. *Boreas*, 10.1111/j.1502-3885.2011.00229.x. ISSN 0300-9483.
- Hansen, J.-M., Aagaard, T. and Huijpers, A. 2015. Sea-Level Forcing by Synchronization of 56- and 74-Year Oscillations with the Moon's Nodal Tide on the Northwest European Shelf (Eastern North Sea to Central Baltic Sea). *Journ. Coastal Research*, 16 pp.
- Mörner, Nils-Axel 2015. Sea Level Changes as recorded in nature itself. *Journal of Engineering Research and Applications*, Vol.5, 1, 124-129.

## Global sea level from satellite altimetry, updated to September 2023



Global sea level since December 1992 according to the Colorado Center for Astrodynamics Research at University of Colorado at Boulder. The blue dots are the individual observations, and the purple line represents the running 121-month (ca. 10 year) average. The two lower panels show the annual sea level change, calculated for 1 and 10-year time windows, respectively. These values are plotted at the end of the interval considered. Compare with tide-gauge diagram on page 41.

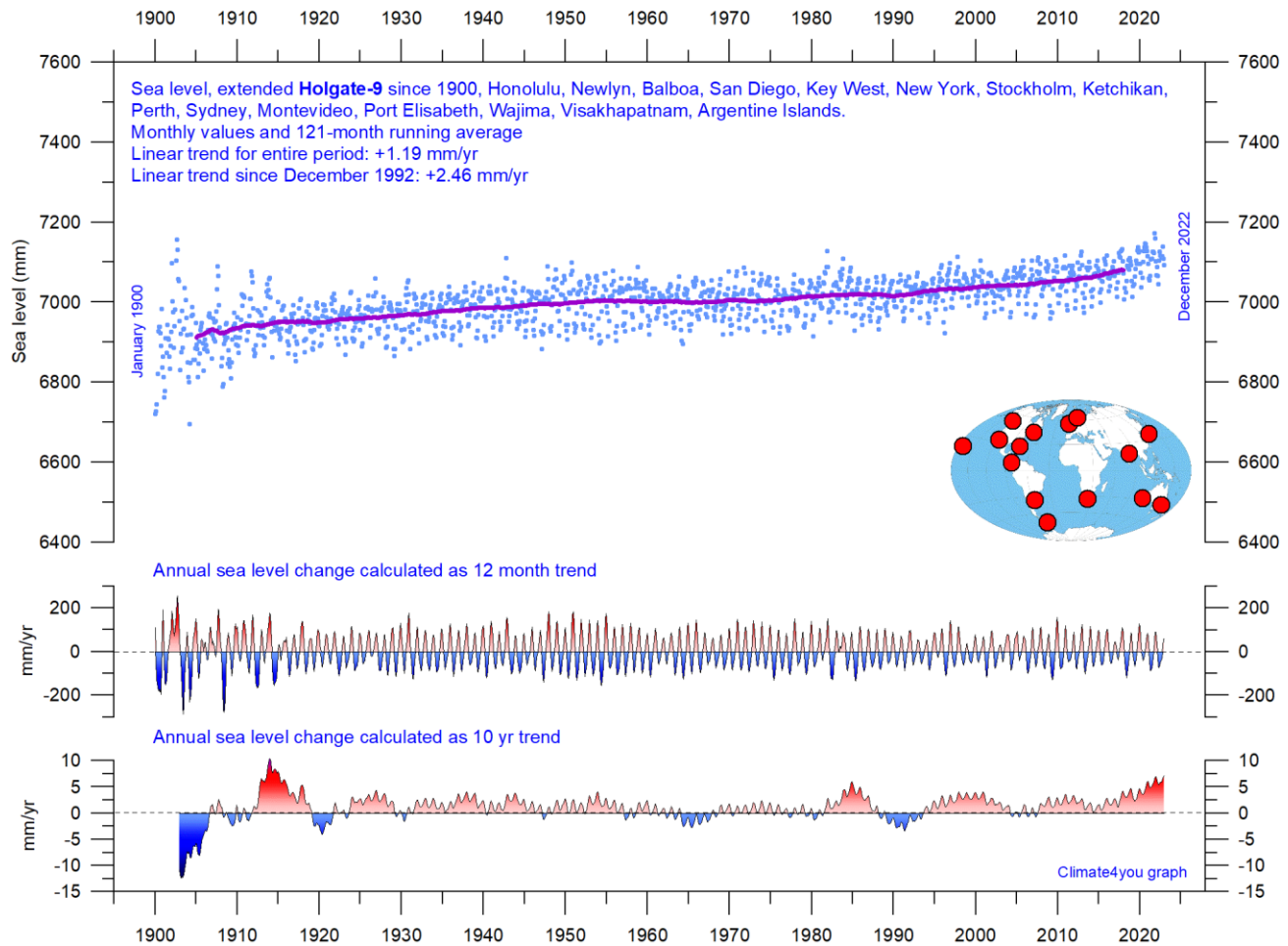
Ground truth is a term used in various fields to refer to information provided by direct observation as opposed to information provided by inference, such as, e.g., by satellite observations.

In remote sensing using satellite observations, ground truth data refers to information collected on location. Ground truth allows the satellite data to be related to real features observed on the planet surface. The collection of ground truth data enables calibration of remote-sensing data, and

aids in the interpretation and analysis of what is being sensed or recorded by satellites. Ground truth sites allow the remote sensor operator to correct and improve the interpretation of satellite data.

For satellite observations on sea level ground true data are provided by the classical tide gauges (example diagram on next page), that directly measures the local sea level many places distributed along the coastlines on the surface of the planet.

## Global sea level from tide-gauges, extended Holgate-9, updated to December 2022



Extended Holgate-9 monthly tide-gauge data from PSMSL Data Explorer. Holgate (2007) suggested 9 stations to capture the global variability found in a larger number of stations over the last half century studied previously. However, some of the stations suggested by Holgate has not reported values for several years, leading to the southern hemisphere now being seriously underrepresented in his original data set. Therefore, in the above diagram several other long tide-gauge series have been included, to provide a more balanced representation of both hemispheres (15 stations in total). The blue dots are the individual average monthly observations, and the purple line represents the running 121-month (ca. 10 year) average. The two lower panels show the average annual sea level change, calculated for moving 1 and 10-year windows, respectively. These values are plotted at the end of the time window considered, month by month.

Data from tide-gauges all over the world suggest an average global sea-level rise of 1-2 mm/year, while the modern satellite-derived record (since 1992, page 40) suggest a rise of about 3.4 mm/year, or more. The difference between the two data sets is remarkable. It is however known that satellite observations are facing

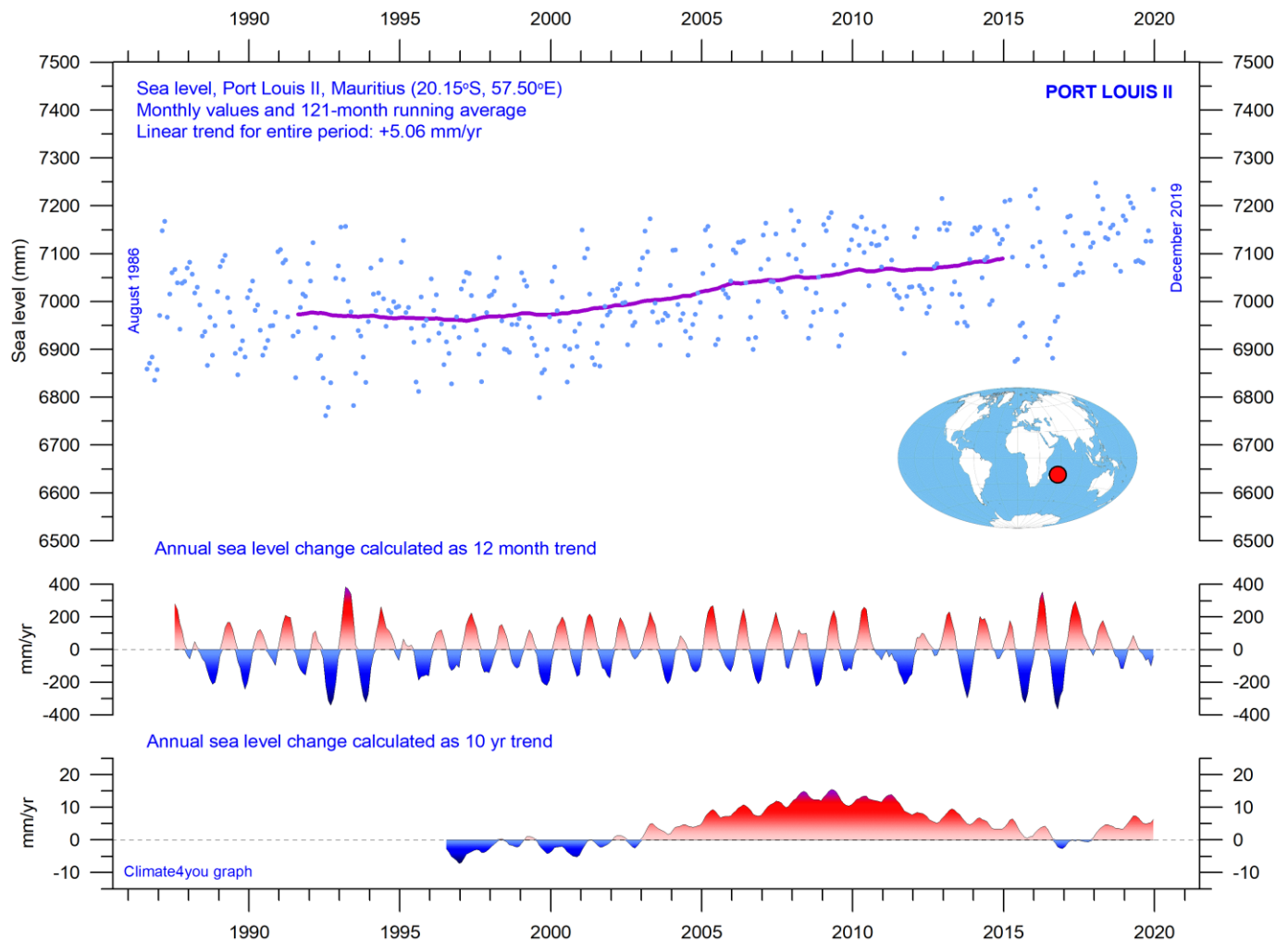
### References:

Holgate, S.J. 2007. On the decadal rates of sea level change during the twentieth century. *Geophys. Res. Letters*, 34, L01602, doi:10.1029/2006GL028492

Vignudelli et al. 2019. Satellite Altimetry Measurements of Sea Level in the Coastal Zone. *Surveys in Geophysics*, Vol. 40, p. 1319–1349. <https://link.springer.com/article/10.1007/s10712-019-09569-1>

several complications in areas near the coast. Vignudelli et al. (2019) provide an updated overview of the current limitations of classical satellite altimetry in coastal regions. Since 2015 a sea level increase rate may be suggested by the above composite record.

## This month's selected sea level station (tide-gauge): Port Louis, Republic of Mauritius, Southern Indian Ocean



Port Louis monthly tide gauge data from [PSMSL Data Explorer](#). The blue dots are the individual monthly observations, and the purple line represents the running 121-month (ca. 10 yr) average. The two lower panels show the annual sea level change, calculated for 1 and 10 yr time windows, respectively. These values are plotted at the end of the interval considered.

Port Louis is the capital of Mauritius (Republic of Mauritius). Mauritius is an island nation in the Indian Ocean, about 950 km east of Madagascar. Along with the other Mascarene Islands, Mauritius is known for its many species endemic to the island. The island was the only known home of the flightless dodo bird – famous from ‘Alice's Adventures in Wonderland’ – which was made extinct by human activities relatively shortly after the island's settlement in the late 16th

century. If the observed relative sea level rise since 1986 at Port Louis continues, relative sea level will have increased about 40 cm by year 2100.

The Indian Ocean is the third-largest of the world's oceanic divisions, covering 70,560,000 km<sup>2</sup> or almost 20% of the water on Earth's surface. In contrast to the Atlantic and Pacific, the Indian Ocean is enclosed by major landmasses and an archipelago

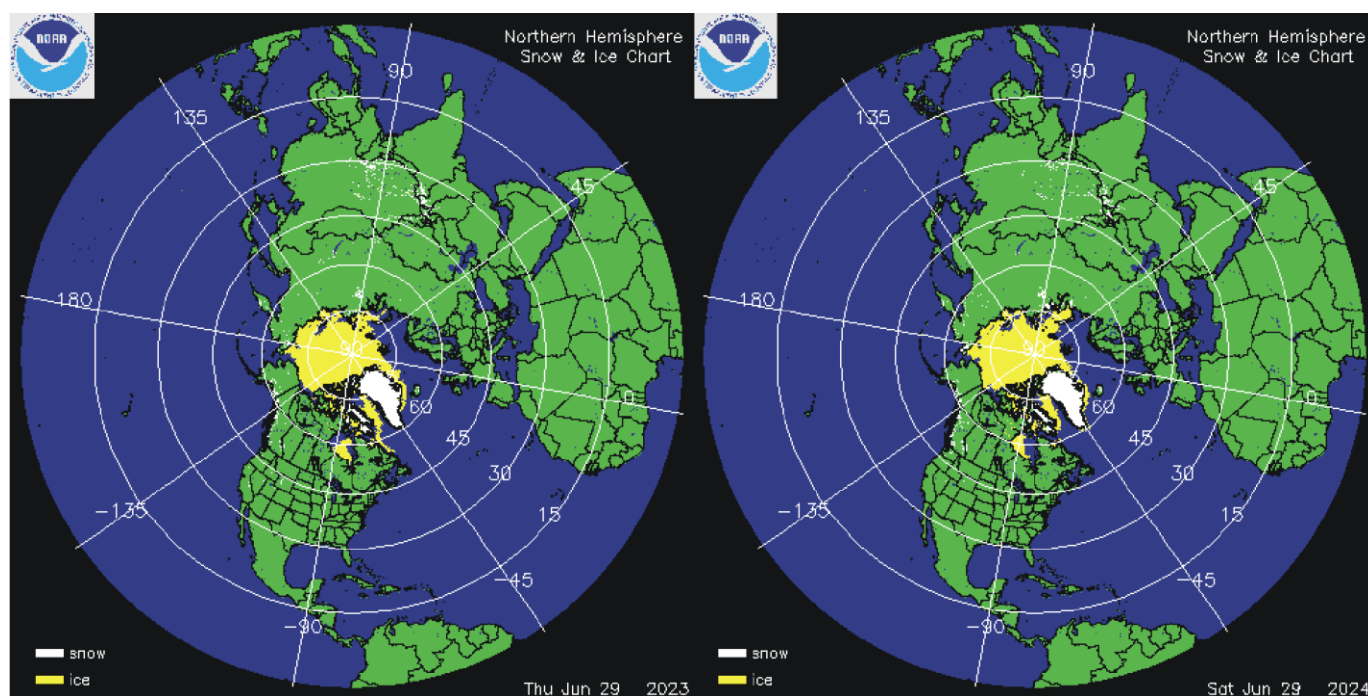
on three sides and does not stretch from pole to pole. In fact, it can be likened to an embayed ocean, and several other features make the Indian Ocean unique. It constitutes the core of the large-scale Tropical Warm Pool which, when interacting with the atmosphere, affects the climate both regionally and globally. Asia blocks heat export in the ocean towards north, and the Indian Ocean is the warmest ocean in the world.

The Indian Ocean contains several islands, some of which is known from the ongoing sea-level change debate, mainly because of a claimed rapid relative sea level rise. Many of these islands are volcanic in origin, and due to their high bedrock density, they will

inevitably sink slowly because of crustal deformation. Several of these volcanic islands were eroded down to the former 120-130 m long-lasting lower sea level during the Quaternary glaciations. The position and outline of several of these eroded and drowned volcanoes are today indicated at the ocean surface by fringing coral reefs, where colonies of reef building corals have been able to accommodate the about 120 m sea level rise since the maximum of the last glacial period, keeping pace with rising sea level by vertical growth and accretion. In the Indian Ocean, coral reefs are widespread north of 30°S.

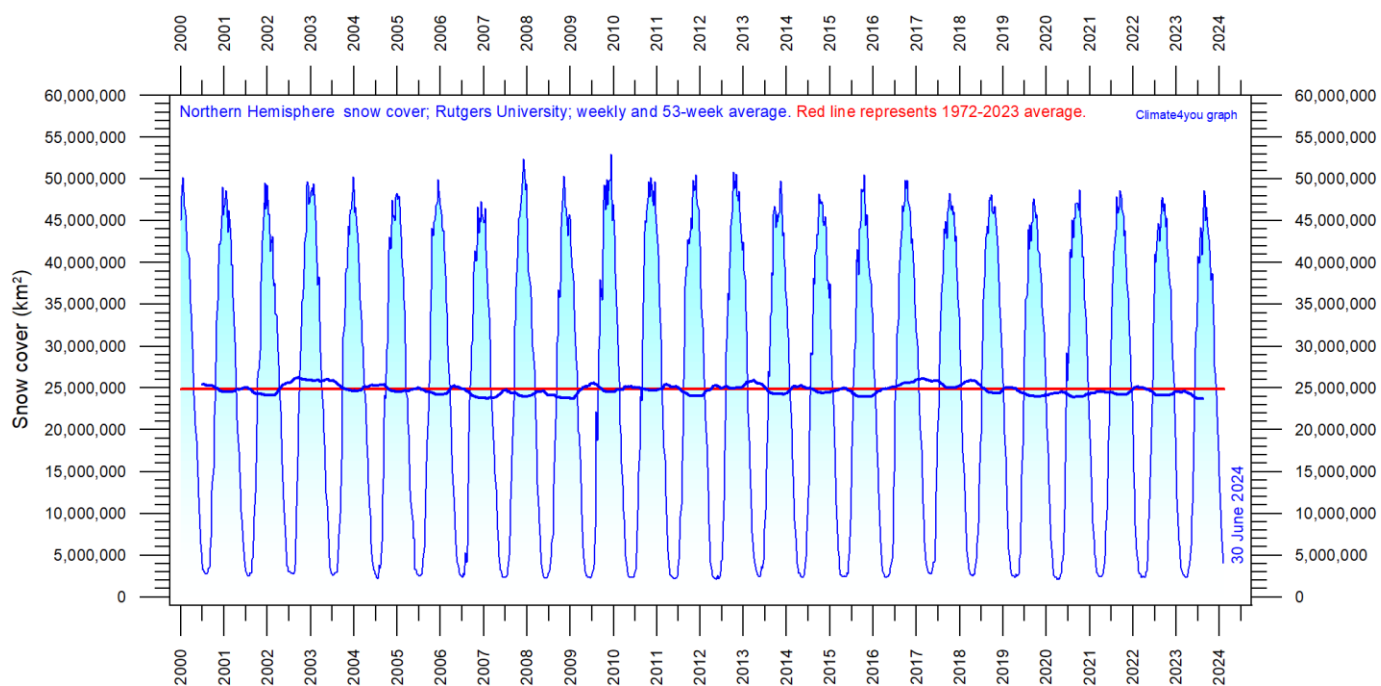


## Northern Hemisphere weekly and seasonal snow cover, updated to June 2024

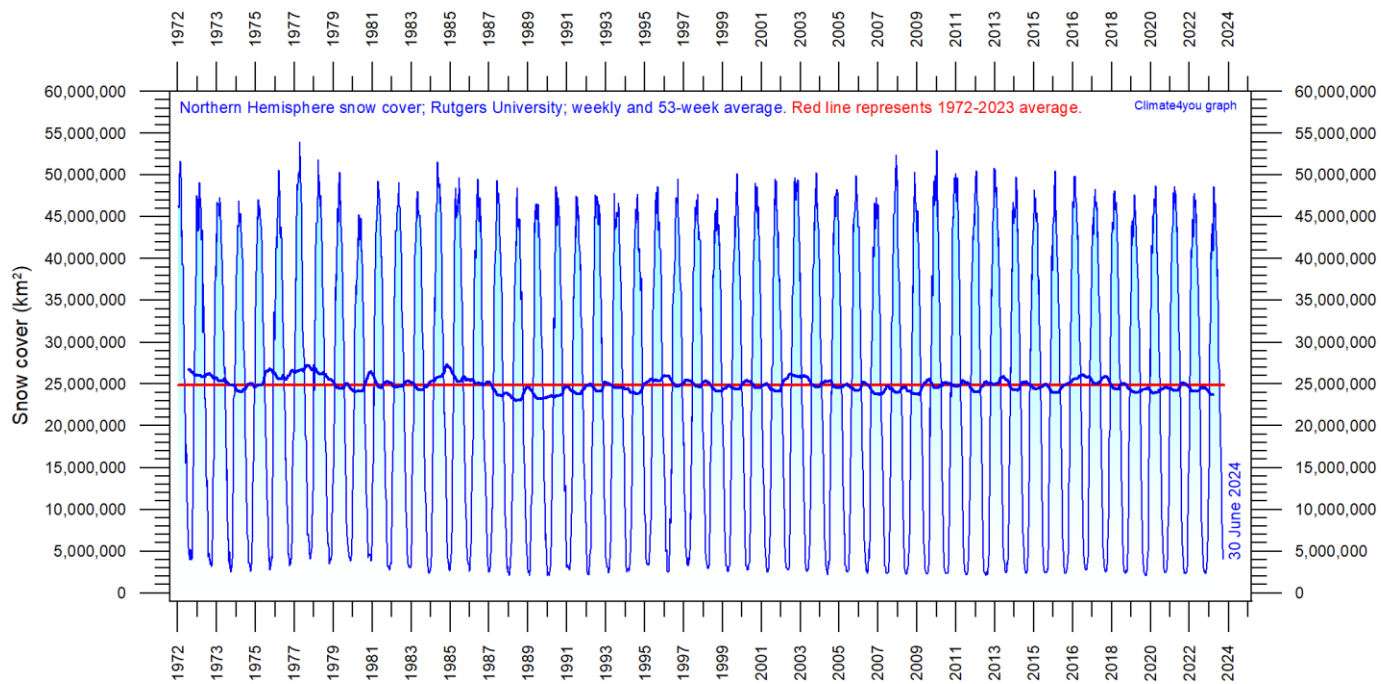


Northern hemisphere snow cover (white) and sea ice (yellow) 29 June 2023 (left) and 2024 (right). Map source: [National Ice Center \(NIC\)](#).

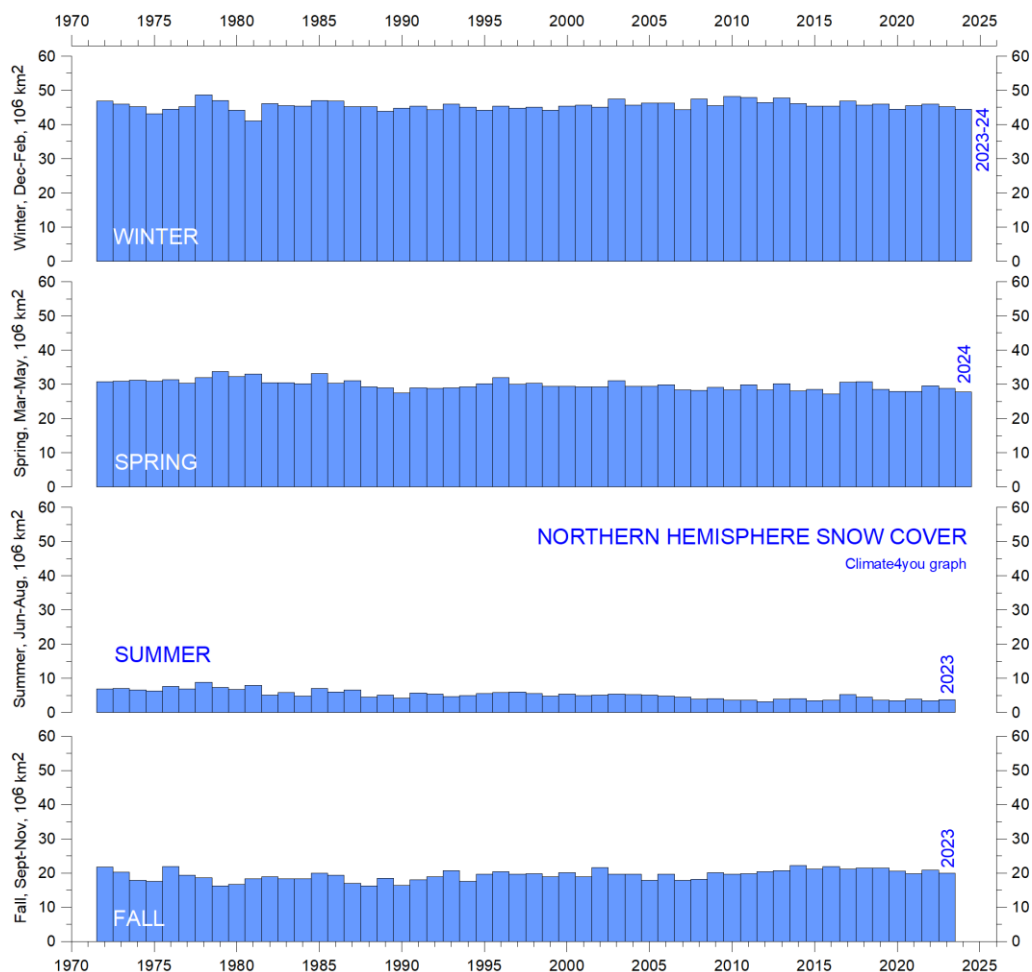
44



Northern hemisphere weekly snow cover since January 2000 according to Rutgers University Global Snow Laboratory. The thin blue line is the weekly data, and the thick blue line is the running 53-week average (approximately 1 year). The horizontal red line is the 1972-2023 average.

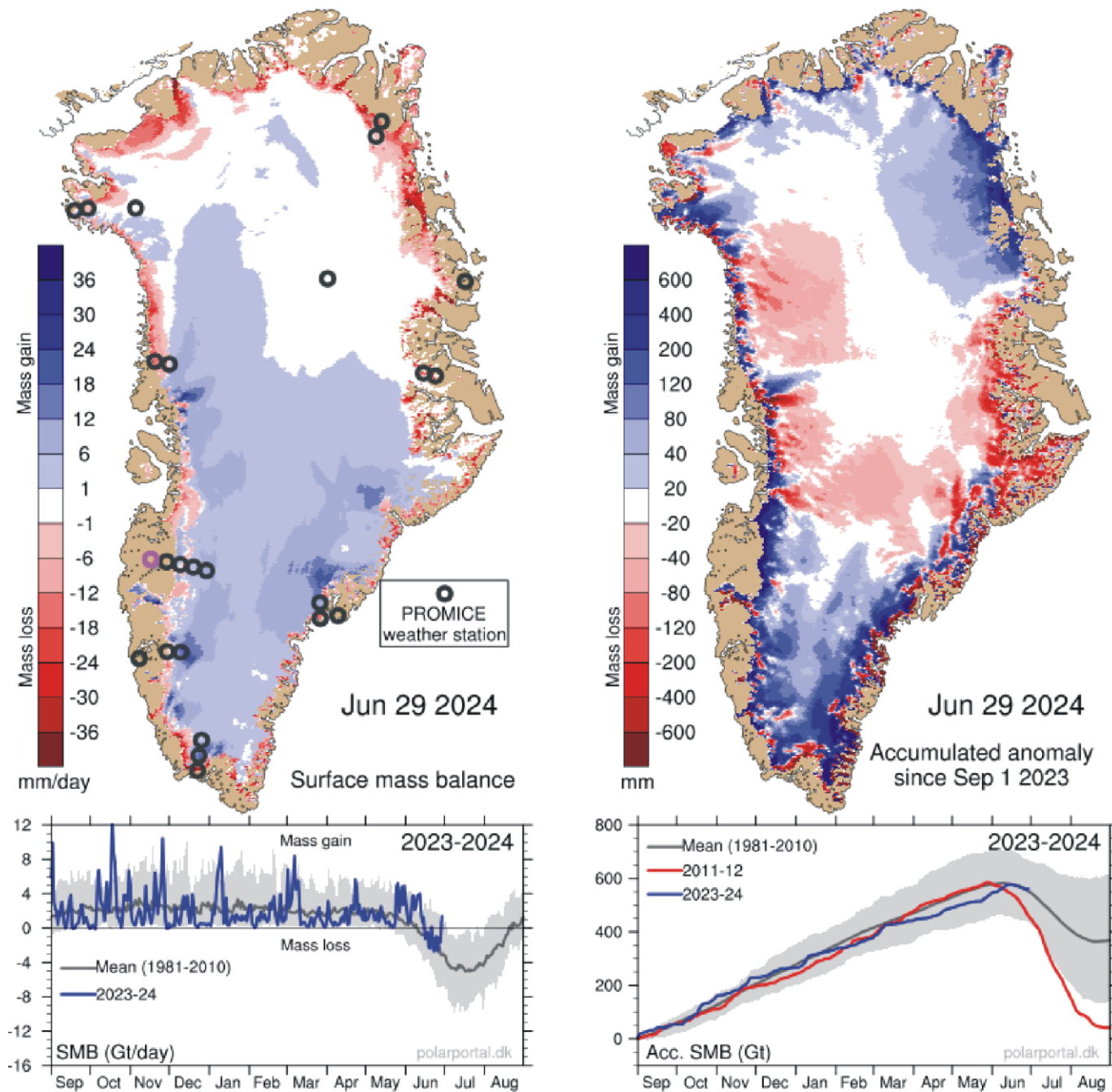


Northern hemisphere weekly snow cover since January 1972 according to Rutgers University Global Snow Laboratory. The thin blue line is the weekly data, and the thick blue line is the running 53-week average (approximately 1 year). The horizontal red line is the 1972-2023 average.



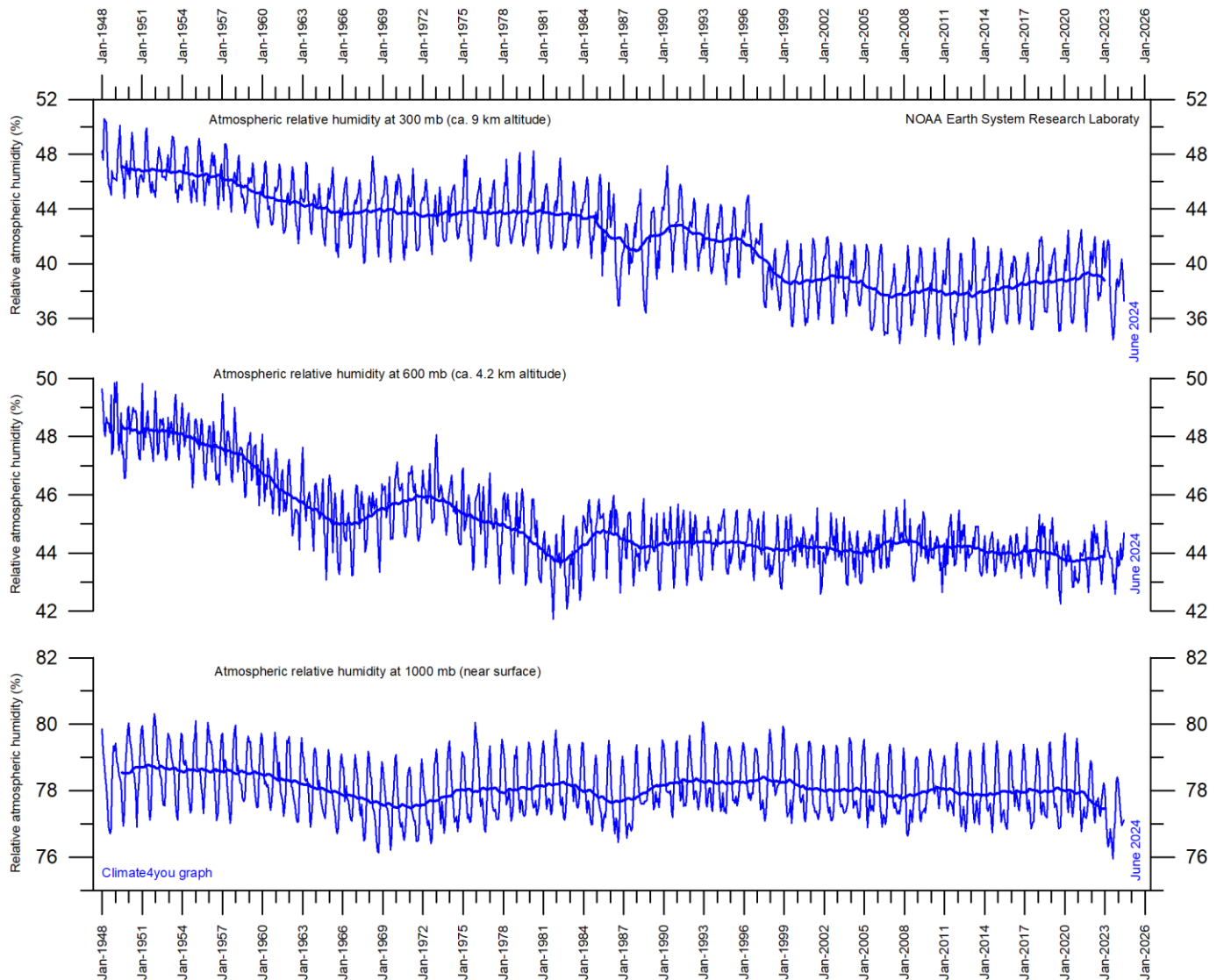
Northern hemisphere seasonal snow cover since January 1972 according to Rutgers University Global Snow Laboratory.

## Greenland Ice Sheet net surface mass balance, updated to June 2024

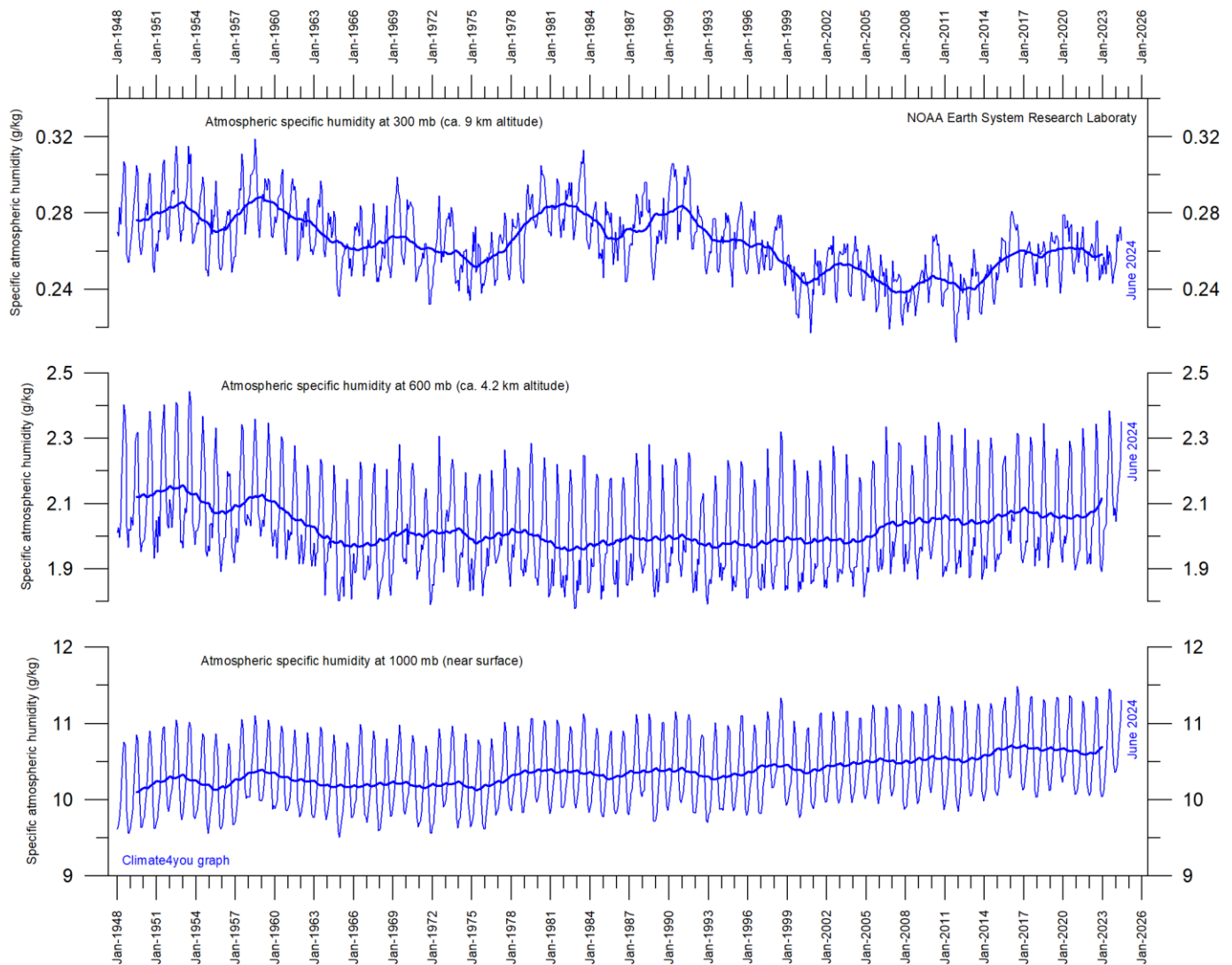


Left: Surface mass balance 29 June 2024. Right: Net surface mass balance anomaly since September 1, 2023. Courtesy of Danish Meteorological Institute (DMI).

## Atmospheric relative and specific humidity, updated to June 2024



[Relative atmospheric humidity](#) (g/kg) at three different altitudes in the lower part of the atmosphere ([the Troposphere](#)) since January 1948 ([Kalnay et al. 1996](#)). The thin blue lines show monthly values, while the thick blue lines show the running 37-month average (about 3 years). Data source: [Earth System Research Laboratory \(NOAA\)](#).



Specific atmospheric humidity (g/kg) at three different altitudes in the lower part of the atmosphere (the Troposphere) since January 1948 (Kalnay et al. 1996). The thin blue lines show monthly values, while the thick blue lines show the running 37-month average (about 3 years). Data source: Earth System Research Laboratory (NOAA).

Water vapor is the most important greenhouse gas in the Troposphere. The highest concentration is found within a latitudinal range from 50°N to 60°S. The two polar regions of the Troposphere are comparatively dry.

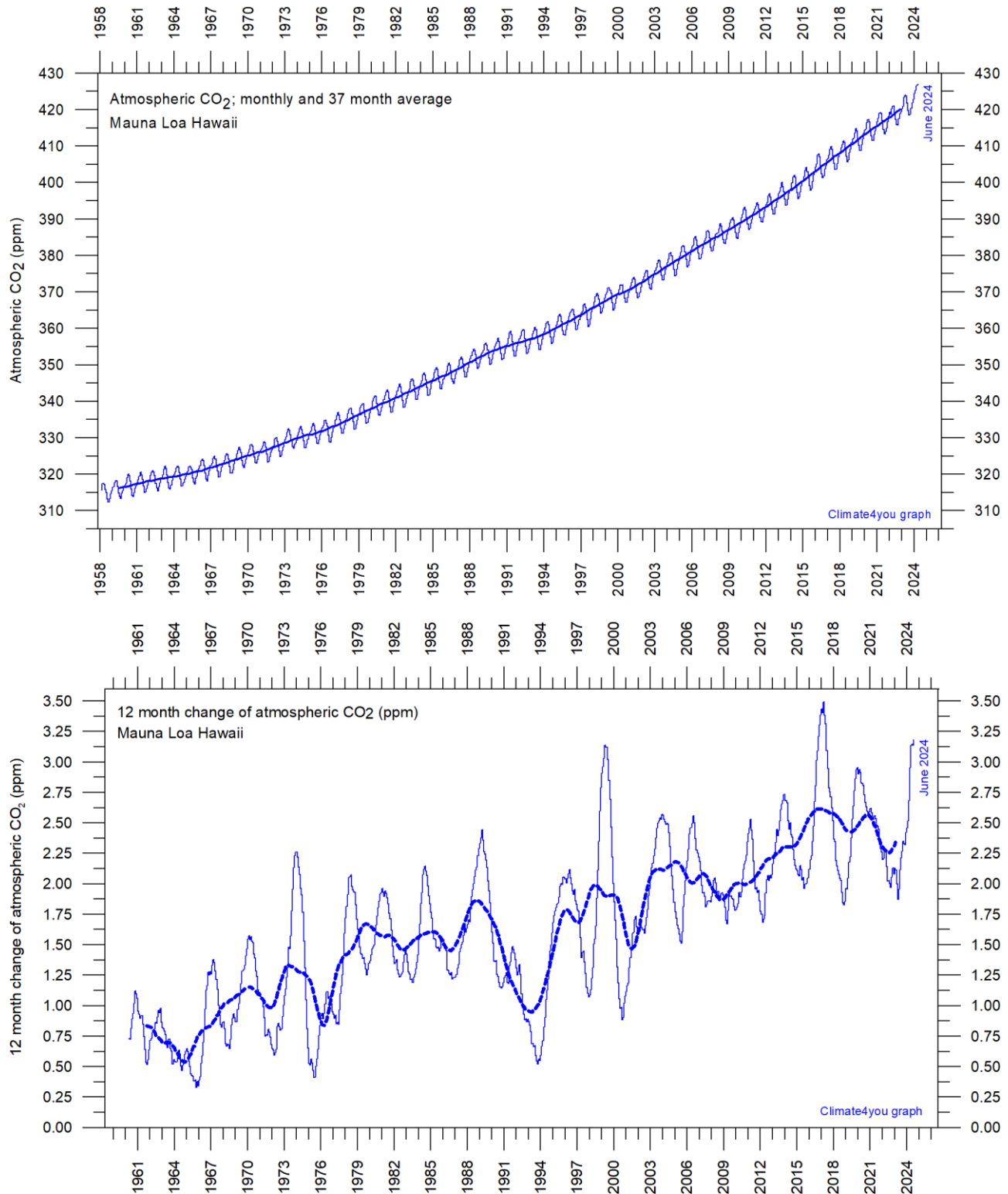
The diagram above shows the specific atmospheric humidity to be stable or slightly increasing up to about 4-5 km altitude. At higher levels in the Troposphere (about 9 km), the specific humidity has been decreasing for the duration of the record (since 1948), but with shorter variations superimposed on the falling trend.

A Fourier frequency analysis (not shown here) suggests these changes are influenced, not only by the significant annual variation, but feasibly also by a longer variation of about 35-years' duration.

The persistent decrease in specific humidity at about 9 km altitude is particularly noteworthy, as this altitude roughly corresponds to the level where the theoretical temperature effect of increased atmospheric CO<sub>2</sub> is expected initially to play out.

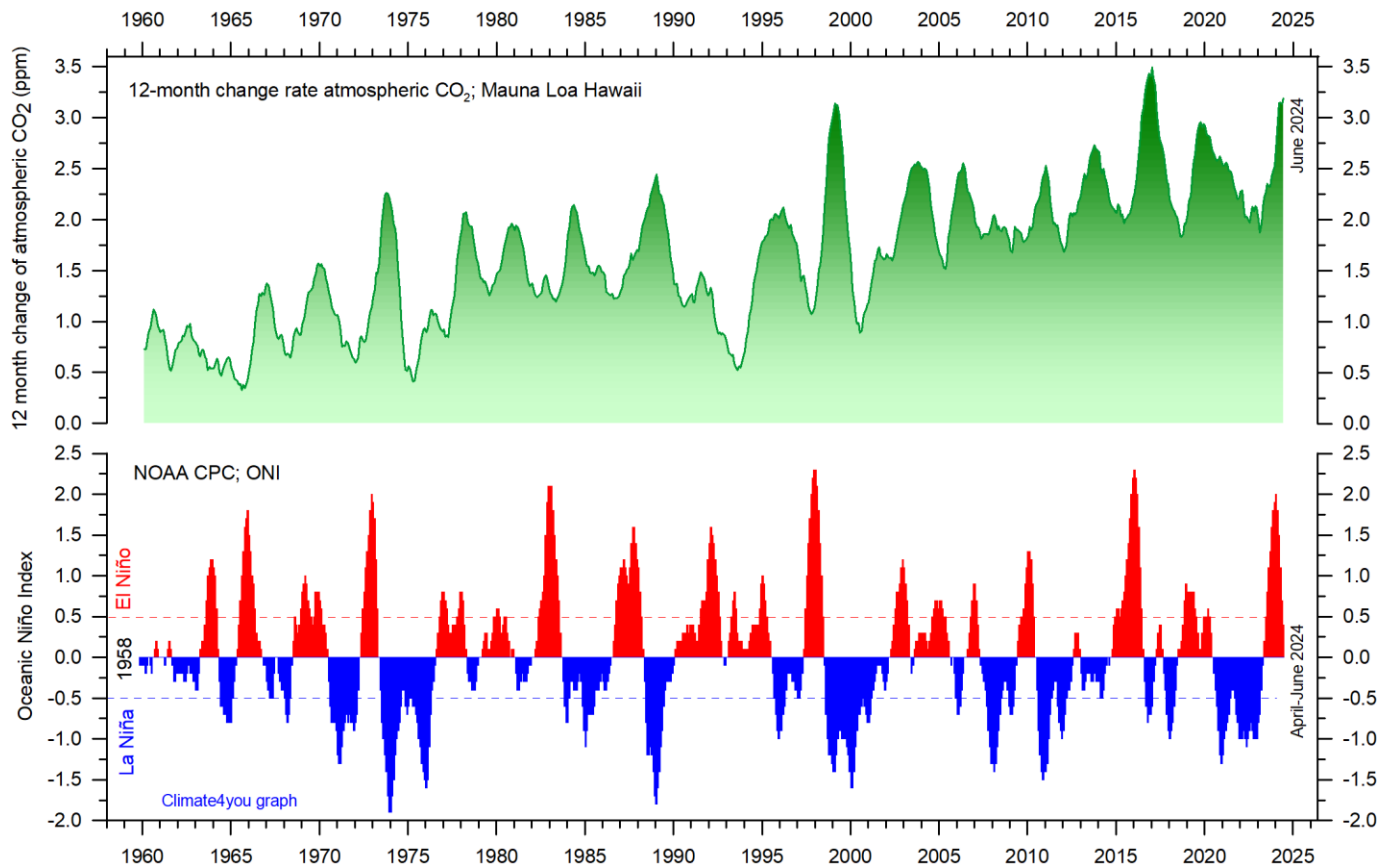


## Atmospheric CO<sub>2</sub>, updated to June 2024



Monthly amount of atmospheric CO<sub>2</sub> (upper diagram) and annual growth rate (lower diagram); average last 12 months minus average preceding 12 months, thin line) of atmospheric CO<sub>2</sub> since 1959, according to data provided by the [Mauna Loa Observatory](#), Hawaii, USA. The thick, stippled line is the simple running 37-observation average, nearly corresponding to a running 3-year average. A Fourier frequency analysis (not shown here) shows the 12-month change of Tropospheric CO<sub>2</sub> to be influenced especially by periodic variations of 2.5- and 3.8-years' duration.

## The relation between annual change of atmospheric CO<sub>2</sub> and La Niña and El Niño episodes, updated to June 2024



Visual association between annual growth rate of atmospheric CO<sub>2</sub> (upper panel) and Oceanic Niño Index (lower panel). See also diagrams on page 47 and 25, respectively.

Changes in the global atmospheric CO<sub>2</sub> is seen to vary roughly in concert with changes in the Oceanic Niño Index. The typical sequence of events is that changes in the global atmospheric CO<sub>2</sub> to a certain degree follows changes in the Oceanic Niño Index, but clearly not in all details. Many processes, natural as well as anthropogenic, controls the amount of atmospheric CO<sub>2</sub>, but oceanographic processes are clearly particularly important (see also diagram on next page).

### Atmospheric CO<sub>2</sub> and the recent coronavirus pandemic

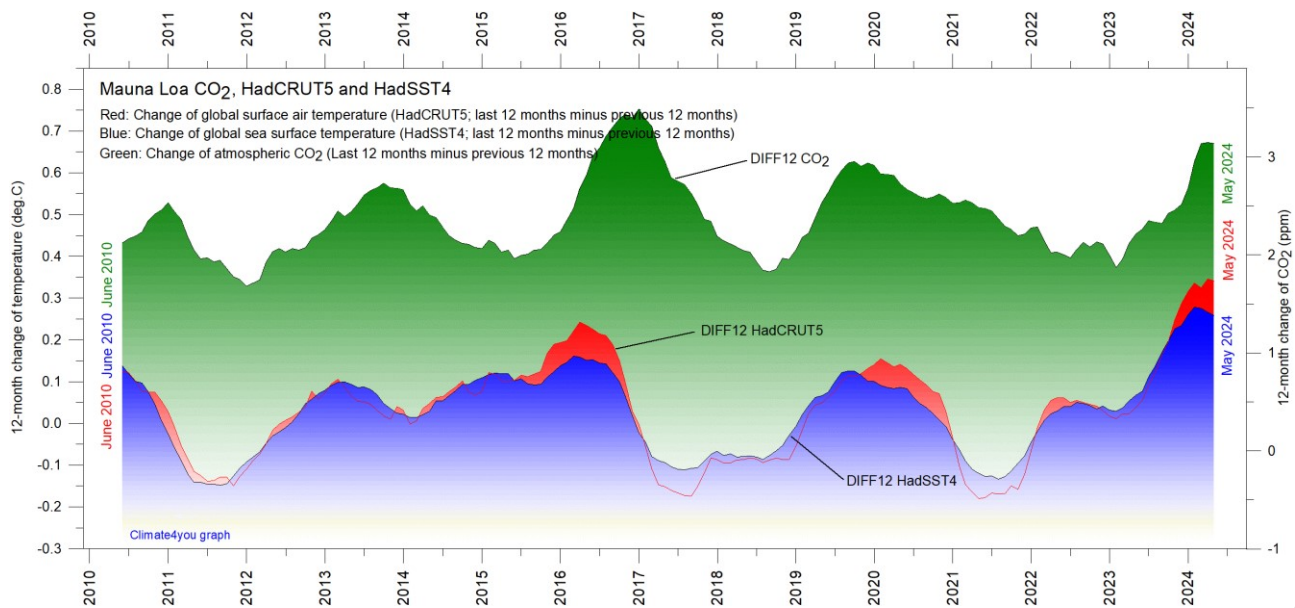
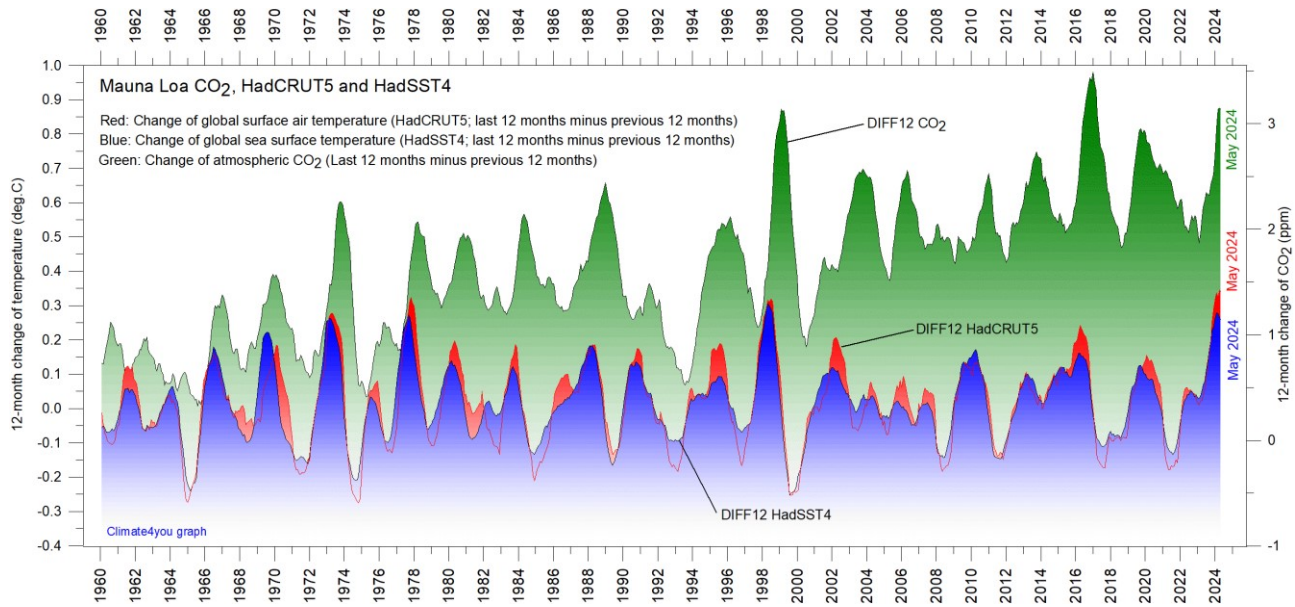
Modern political initiatives usually assume the human influence (mainly the burning of fossil fuels) to represent

the core reason for the observed increase in atmospheric CO<sub>2</sub> since 1958 (diagrams on page 47).

The coronavirus pandemic since January 2020 resulted in a marked reduction in the global consumption of fossil fuels. It is therefore enlightening to follow the effect of this reduction on the amount of atmospheric CO<sub>2</sub>.

However, there is still no clear effect to be seen of the above reduction in release of CO<sub>2</sub> from fossil fuels. Presumably, the main explanation for this is that the human contribution is too small compared to the numerous natural sources and sinks for atmospheric CO<sub>2</sub> to appear in diagrams showing the amount of atmospheric CO<sub>2</sub>.

## The phase relation between atmospheric CO<sub>2</sub> and global temperature, updated to May 2024



month change of global atmospheric CO<sub>2</sub> concentration ([Mauna Loa](#); green), global sea surface temperature ([HadSST4](#); blue) and global surface air temperature ([HadCRUT5](#); red dotted). Entire data series since 1958 in upper figure, and last 15 years in lower figure, to enhance modern dynamics. All graphs are showing monthly values of DIFF12, the difference between the average of the last 12 month and the average for the previous 12 months for each data series.

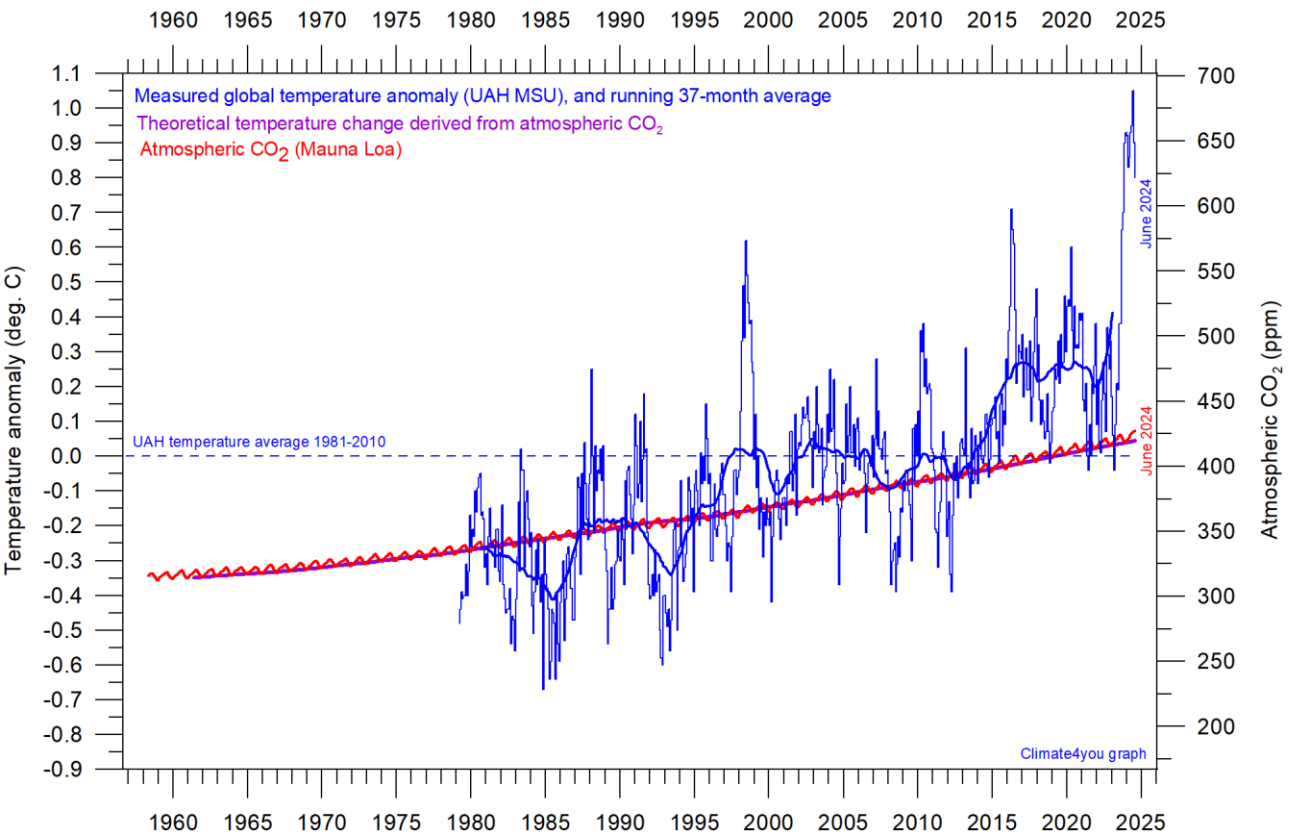
The typical sequence of events is seen to be that changes in the global atmospheric CO<sub>2</sub> follow changes in global surface air temperature, which again follow changes in global ocean surface temperatures. Thus, changes in global

atmospheric CO<sub>2</sub> usually are lagging 9.5–10 months behind changes in global air surface temperature, and 11–12 months behind changes in global sea surface temperature.

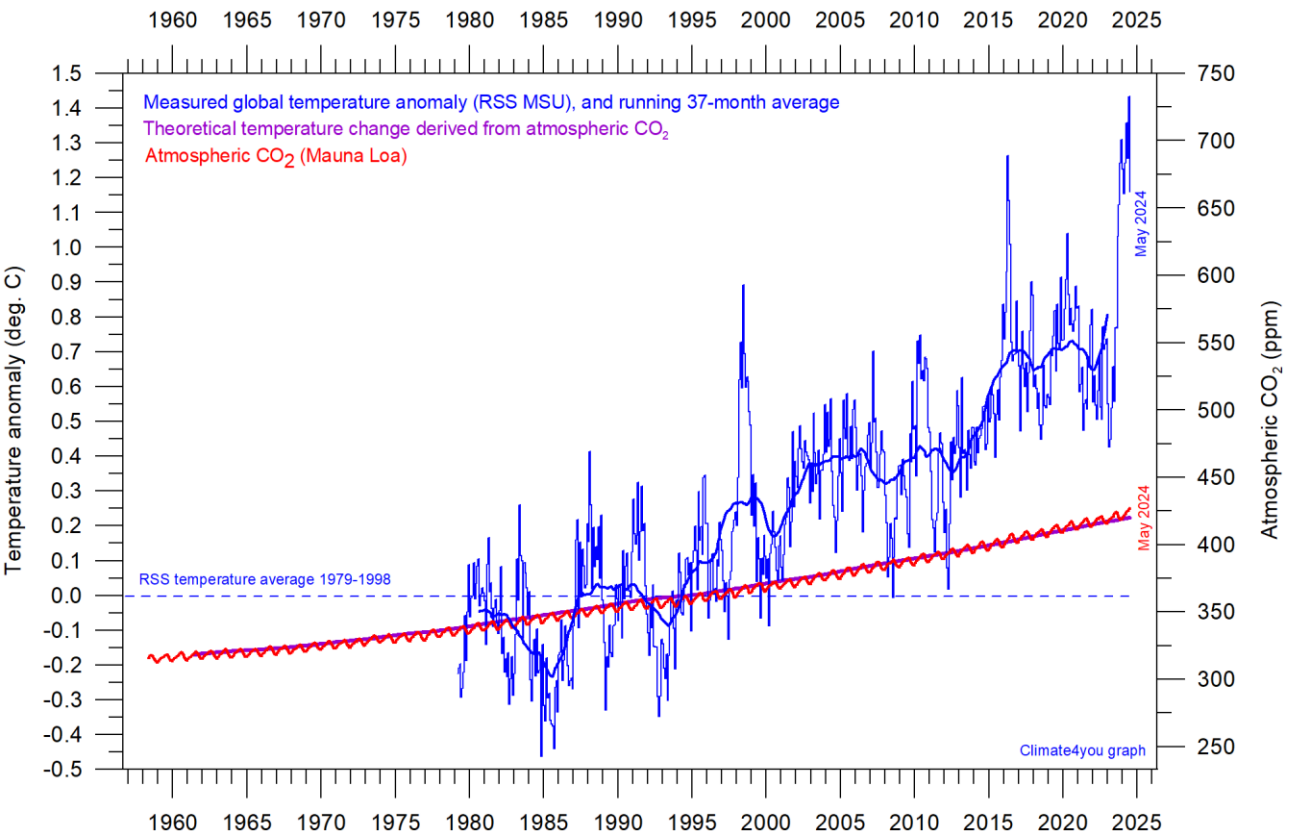
Reference: Humlum, O., Stordahl, K. and Solheim, J-E. 2012. The phase relation between atmospheric carbon dioxide and global temperature. *Global and Planetary Change*, August 30, 2012.

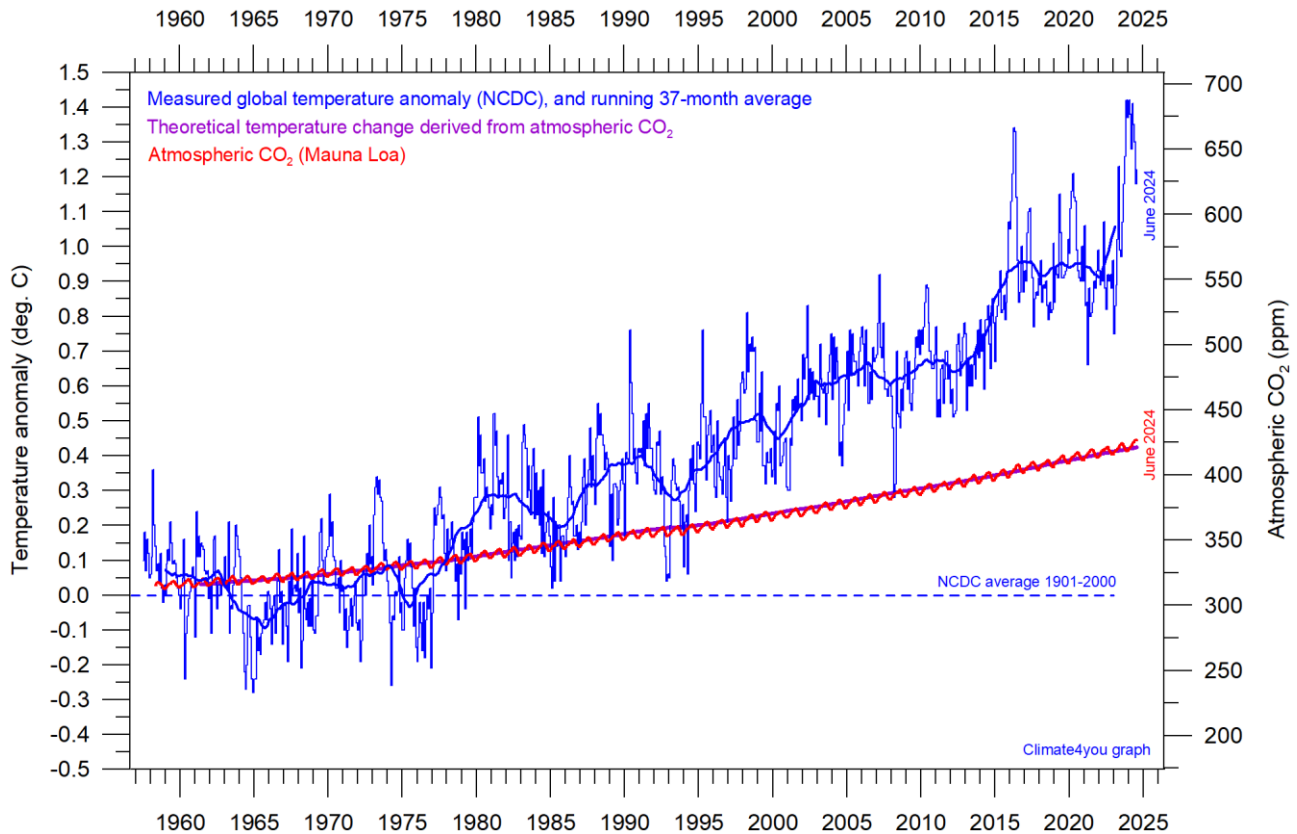
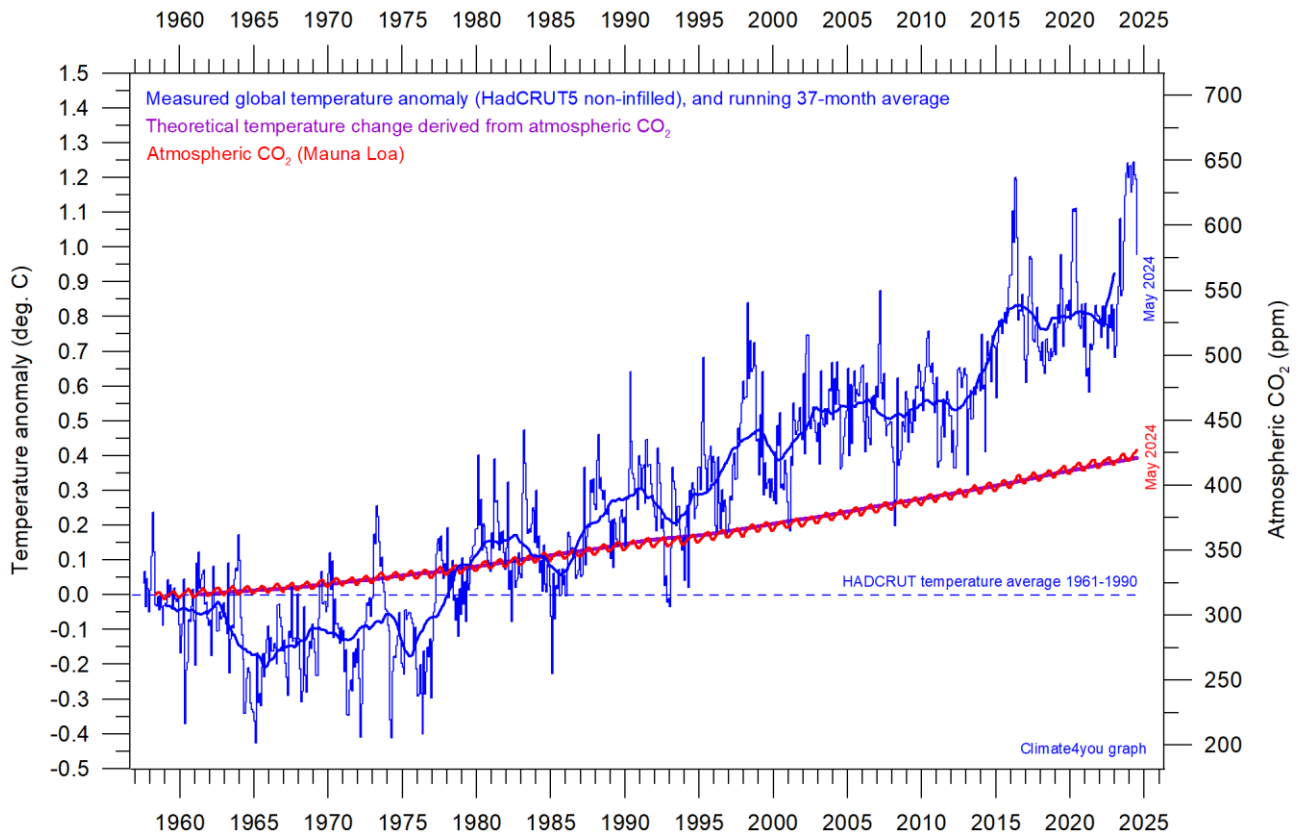
<http://www.sciencedirect.com/science/article/pii/S0921818112001658?v=s5>

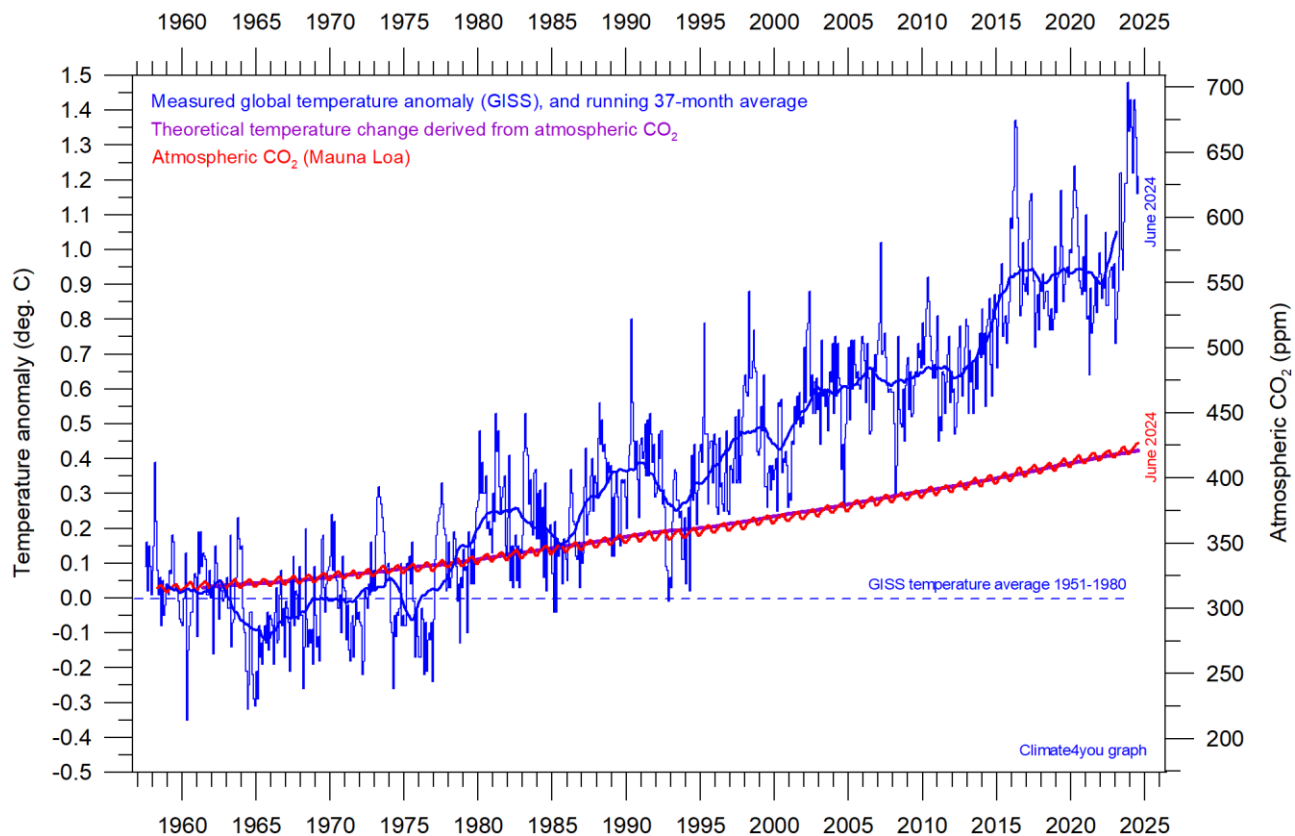
Global air temperature and atmospheric CO<sub>2</sub>, updated to June 2024



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Diagrams showing UAH, RSS, HadCRUT5, NCDC and GISS monthly global air temperature estimates (blue) and the monthly atmospheric CO<sub>2</sub> content (red) according to the [Mauna Loa Observatory](#), Hawaii. Purple line (running along red CO<sub>2</sub> curve) shows theoretical temperature change due to changing atmospheric CO<sub>2</sub>. The Mauna Loa data series begins in March 1958, and 1958 was therefore chosen as starting year for all diagrams above. Reconstructions of past atmospheric CO<sub>2</sub> concentrations (before 1958) are not incorporated in this diagram, as such past CO<sub>2</sub> values are derived by other means (ice cores, stomata, or older measurements using different methodology), and therefore are not directly comparable with direct atmospheric measurements.

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From a theoretical point of view, it is generally agreed that the atmospheric temperature effect  $\Delta T$  of increasing atmospheric CO<sub>2</sub> may be expressed as (see, e.g. Myhre et al. 1998 and IPCC Third Assessment Report, section 6.1):

$$\Delta T = \Delta F * \lambda$$

where  $\Delta F = 5,35 \ln(C1/Co)$  W/m<sup>2</sup>, and where Co and C1 indicates the concentration of atmospheric CO<sub>2</sub> at the beginning and end of the time interval considered. The factor  $\lambda$  is a so-called climate sensitivity parameter (expressing the global mean surface temperature response to the imposed radiative CO<sub>2</sub> forcing). This factor has been determined to about 0,26°CW<sup>-1</sup>m<sup>2</sup>. The relation shows that as the concentration of atmospheric CO<sub>2</sub> increases, its

theoretical greenhouse effect increases in a logarithmic fashion, not linear. Therefore, for each increase in CO<sub>2</sub> concentration, the effect on temperature is smaller and smaller.

If all other effects in the real world are ignored, the above relation shows that any doubling of atmospheric CO<sub>2</sub> concentration produces a temperature increase of nearly 1°C (0.96°C), no matter how high the initial concentration of CO<sub>2</sub>.

The purple line in the above diagrams (p.50-52) is calculated using the observed concentration of atmospheric CO<sub>2</sub> since March 1958. The axis for CO<sub>2</sub> is adjusted to show overlap between CO<sub>2</sub> (red) and the



calculated accumulated temperature effect (purple). In all graphs, the temperature anomaly axis has been adjusted to position the initial calculated effect of CO<sub>2</sub> roughly at the average for the beginning of the observed temperature graph (blue). This is done to make it possible to compare the theoretical CO<sub>2</sub> temperature development (purple) with the observed development (blue).

All these diagrams show the observed temperature development to be much more complicated than the theoretical development from atmospheric CO<sub>2</sub> alone. With exception of the UAH diagram, the overall observed temperature increases since 1958 is much larger than calculated from CO<sub>2</sub> alone. In addition, the observed temperature development is characterised by recurrent intervals characterised by increasing and decreasing temperatures, respectively, a development extremely different from the calculated temperature (purple graph). Clearly many other factors than only CO<sub>2</sub> is in control of the real-world atmospheric temperature.

In contrast to this real-world observation, climate models are programmed to give the greenhouse gas carbon dioxide CO<sub>2</sub> a leading role on control on the global air temperature.

The fact that the observed real-world temperature has been changing much more than expected just from CO<sub>2</sub>, is usually ascribed to an added greenhouse effect of atmospheric water vapour in the upper Troposphere, the concentration of which by the models is expected to increase along with CO<sub>2</sub> (see, e.g. Schneider et. al. 1999).

However, measurements of water vapour in the upper Troposphere apparently show this assumption to be mistaken (see, e.g., diagram on p.46). Therefore, the quite substantial difference between modelled and observed atmospheric temperature must be caused by other factors (see, e.g., Koutsoyiannis and Vournas 2023). In addition, the very dynamic change pattern displayed by the observed temperature also needs to be explained before a sound understanding of global climate dynamics can be claimed.

All temperature-CO<sub>2</sub> diagrams (p.50-52) shows both atmospheric temperature and atmospheric CO<sub>2</sub> to be increasing since 1959. However, this fact does not demonstrate that temperature is controlled by CO<sub>2</sub>. In fact, it might just as well demonstrate the opposite relation (temperature controlling CO<sub>2</sub>), or, that both temperature and CO<sub>2</sub> is controlled by a third factor.

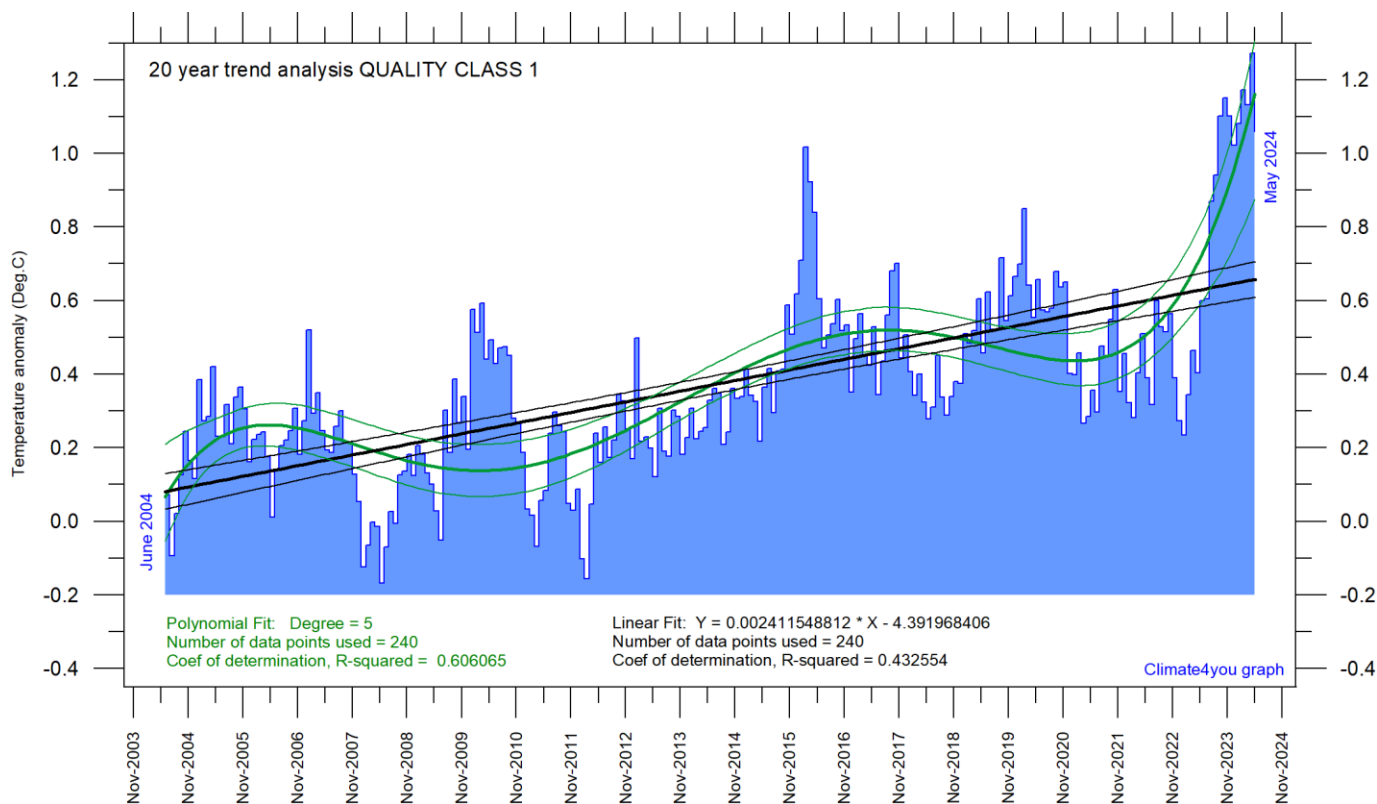
#### Litterature:

Demetris Koutsoyiannis & Christos Vournas 2023. *Revisiting the greenhouse effect – a hydrological perspective*. Hydrological Sciences Journal, doi: 10.1080/02626667.2023.2287047

Myhre, G., E. Highwood, K. Shine, and F. Stordal 1998. *New estimates of radiative forcing due to well mixed greenhouse gases*, Geophys. Res. Lett., 25(14), 2715–2718, doi:10.1029/98GL0190

Schneider, E.K., Kirtman, B.P., and Lindzen, R.S. 1999. *Tropospheric Water Vapor and Climate Sensitivity*. Journal of the Atmospheric Sciences, 56, 1649-1658.

## Latest 20-year QC1 global monthly air temperature changes, updated to May 2024



Last 20 years' global monthly average air temperature according to Quality Class 1 (UAH and RSS; see p.6 and 9) global monthly temperature estimates. The thin blue line represents the monthly values. The thick black line is the linear fit, with 95% confidence intervals indicated by the two thin black lines. The thick green line represents a 5-degree polynomial fit, with 95% confidence intervals indicated by the two thin green lines. A few key statistics are given in the lower part of the diagram (please note that the linear trend is the monthly trend).

In the enduring scientific climate debate, the following question is often put forward: Is the surface air temperature still increasing or has it basically remained without significant changes during the last 15-16 years?

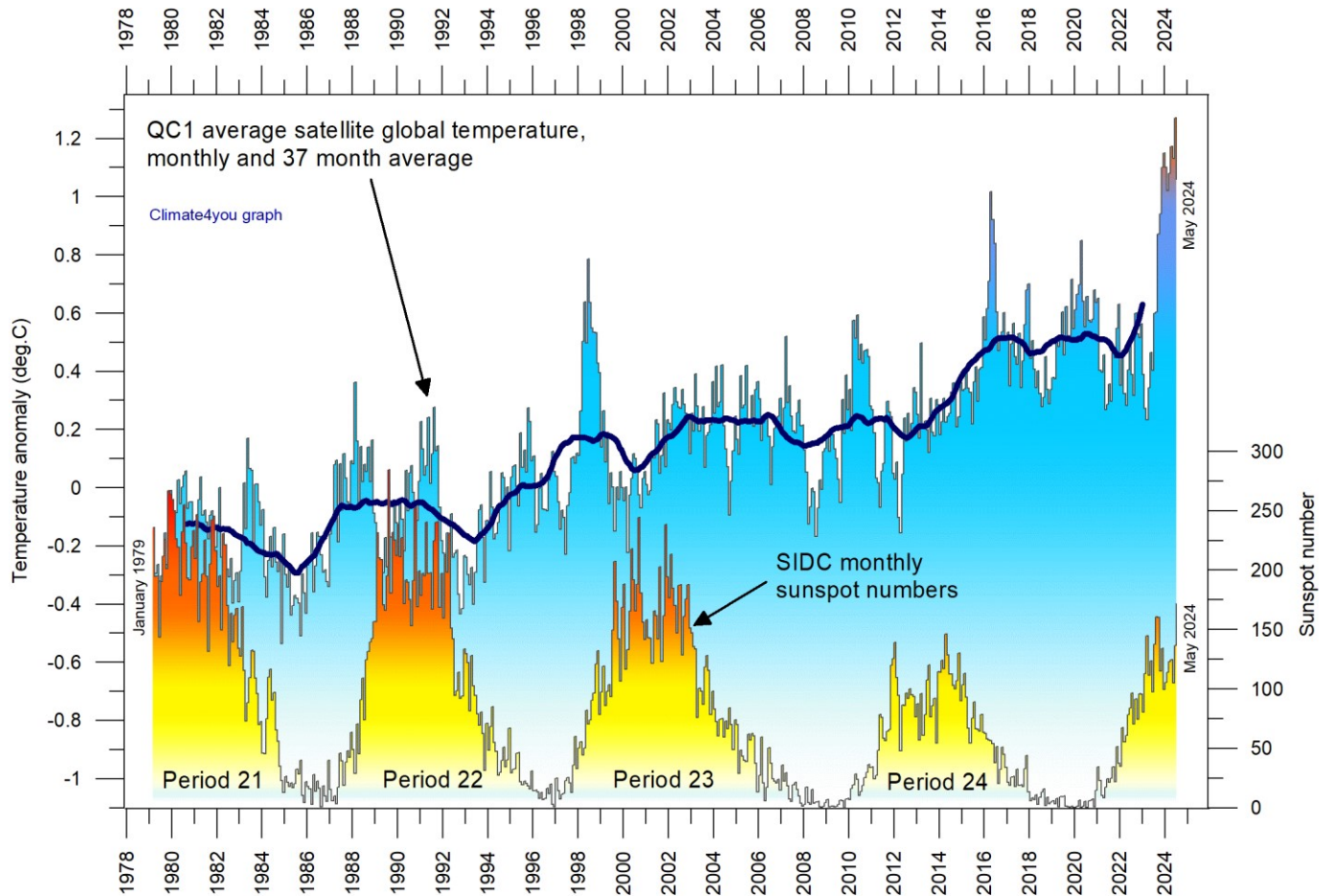
The diagram above may be useful in this context and demonstrates the differences between two often used statistical approaches to determine recent temperature trends. Please also note that such fits only attempt to describe the past, and usually have small, if any, predictive power.

In addition, before using any linear trend (or other) analysis of time series a proper statistical model should be chosen, based on statistical justification.

For global temperature time series, there is no *a priori* physical reason why the long-term trend should be linear in time. In fact, climatic time series often have trends for which a straight line is not a good approximation, as is clearly demonstrated by several of the diagrams shown in the present report.

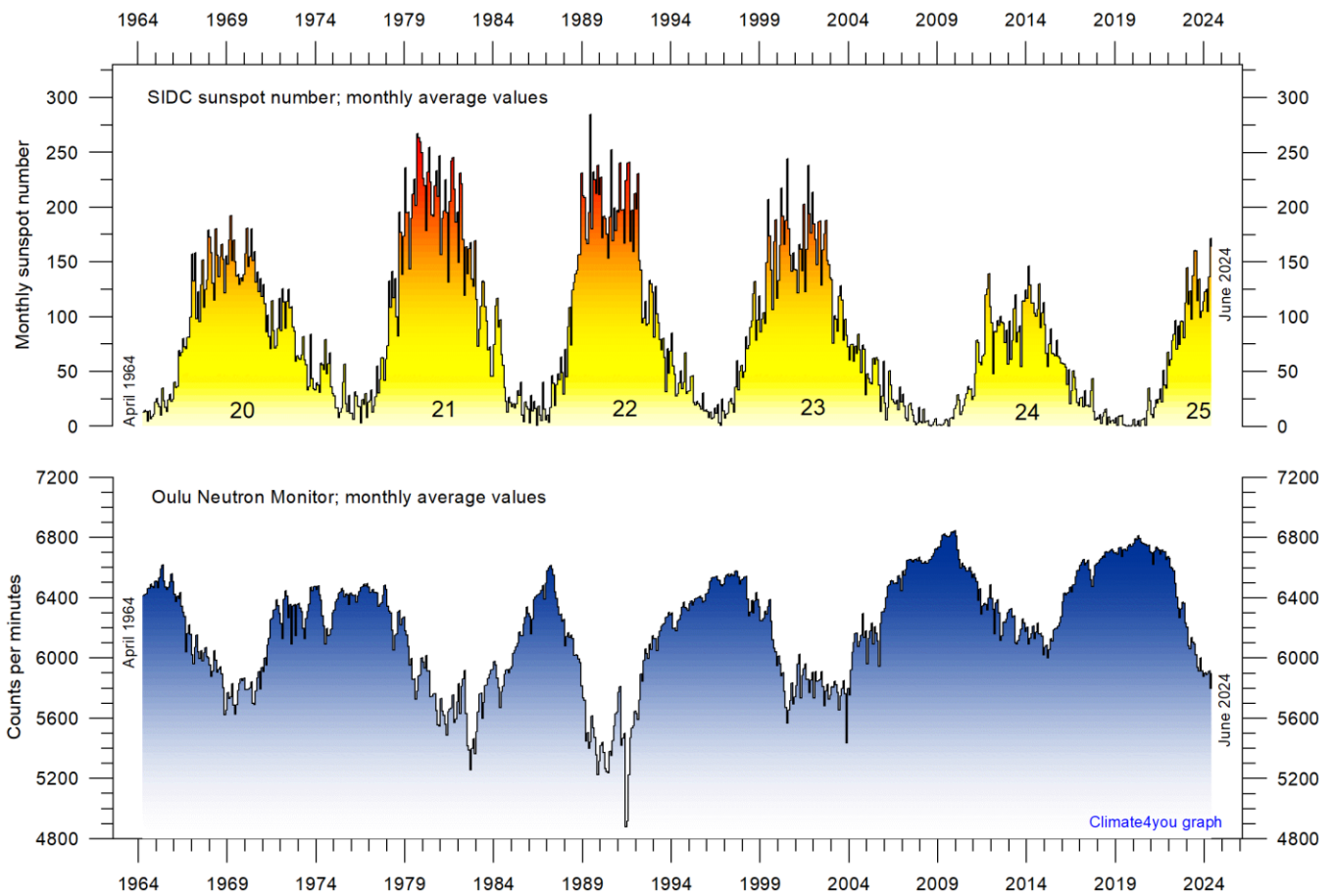
For an commendable description of problems often encountered by analyses of temperature time series analyses, please see [Keenan, D.J. 2014: Statistical Analyses of Surface Temperatures in the IPCC Fifth Assessment Report](#).

## Sunspot activity (SIDC) and QC1 average satellite global air temperature, updated to May 2024



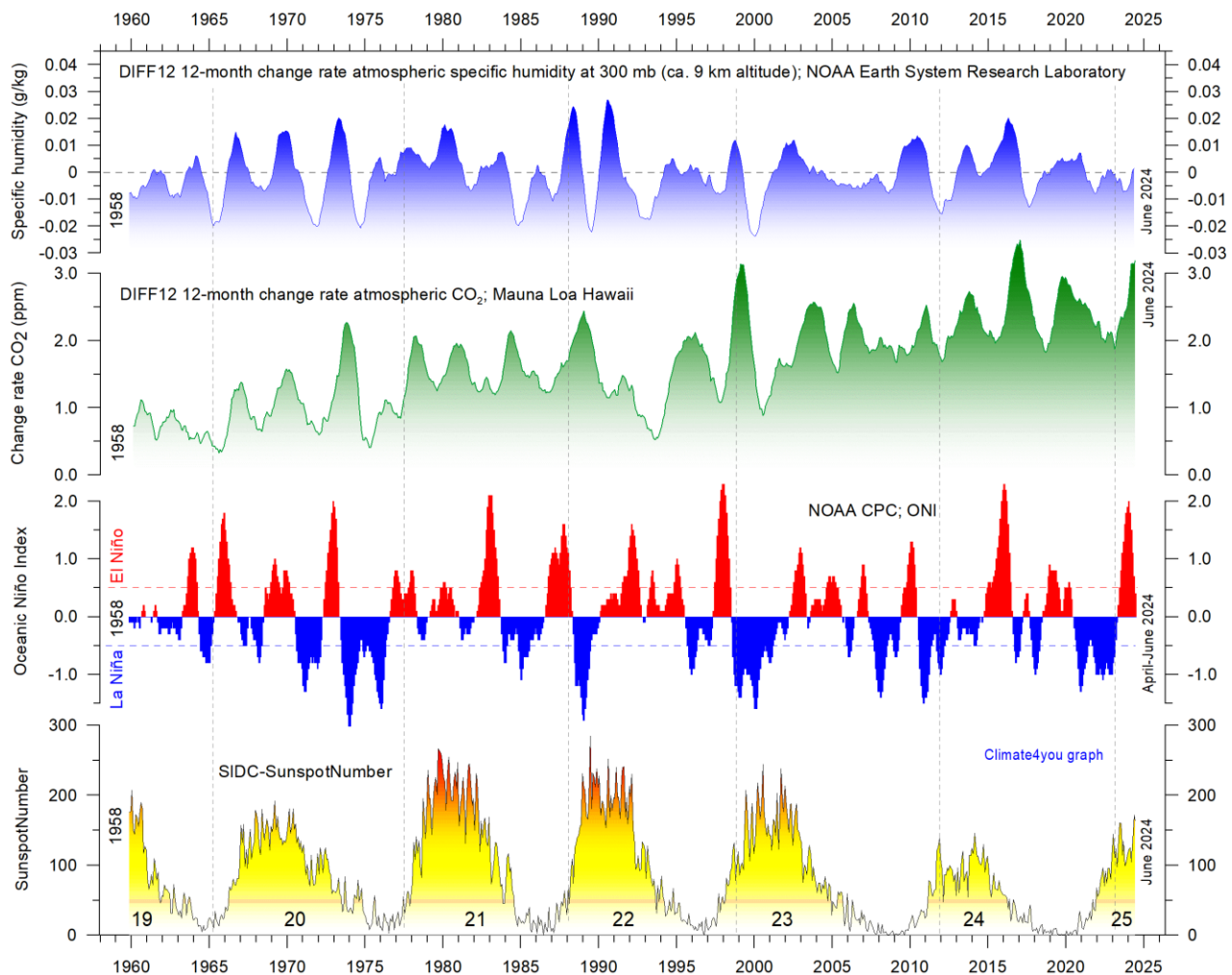
Variation of global monthly air temperature according to Quality Class 1 (UAH and RSS; see p.4) and observed sunspot number as provided by the Solar Influences Data Analysis Center (SIDC), since 1979. The thin lines represent the monthly values, while the thick line is the simple running 37-month average, nearly corresponding to a running 3-year average. The asymmetrical temperature 'bump' around 1998 is influenced by the oceanographic El Niño phenomenon in 1998, as is the case also for 2015-16. Temperatures in year 2019-20 was influenced by a moderate El Niño. In summer 2023 a new El Niño episode has begun (see diagram on p.25).

## Monthly sunspot activity (SIDC) and average neutron counts (Oulu, Finland), updated to June 2024



Observed monthly sunspot number (Solar Influences Data Analysis Center (SIDC) since April 1964, and (lower panel) monthly average counts of the Oulu (Finland) neutron monitor, adjusted for barometric pressure and efficiency.

## Monthly sunspot activity (SIDC), Oceanic Niño Index (ONI), and change rates of atmospheric CO<sub>2</sub> and specific humidity, updated to June 2024

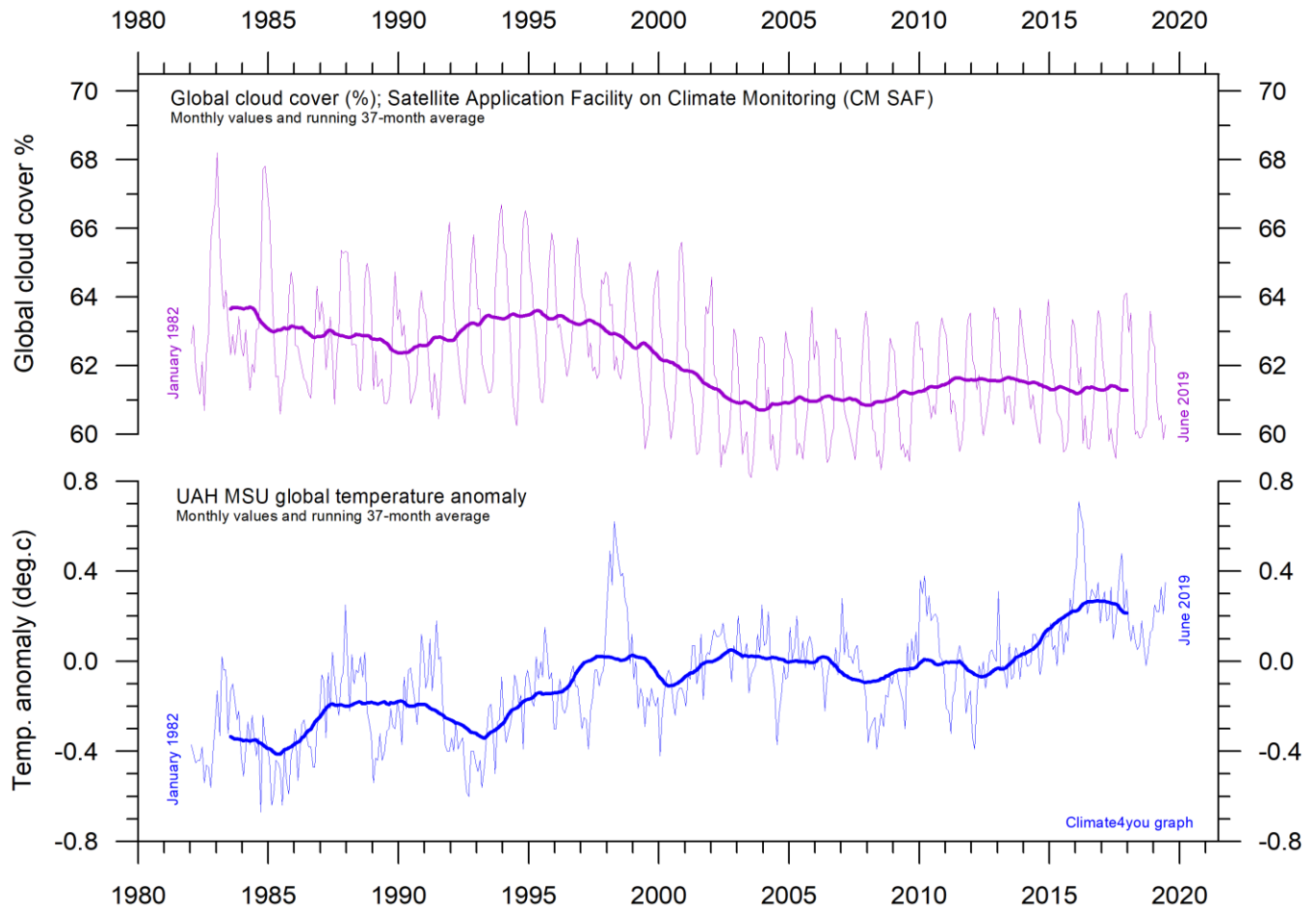


Visual association since 1958 between (from bottom to top) Sunspot Number, Oceanic Niño Index (ONI) and annual change rate of atmospheric CO<sub>2</sub> and specific humidity at 300 mb (ca. 9 km altitude). Upper two panels: Annual (12 month) change rate of atmospheric CO<sub>2</sub> and specific humidity at 300 mb since 1959, calculated as the average amount of atmospheric CO<sub>2</sub>/humidity during the last 12 months, minus the average for the preceding 12 months (see also diagrams on page 43+44). Niño index panel: Warm ( $>+0.5^{\circ}\text{C}$ ) and cold ( $<0.5^{\circ}\text{C}$ ) episodes for the Oceanic Niño Index (ONI), defined as 3 month running mean of ERSSTv4 SST anomalies in the Niño 3.4 region ( $5^{\circ}\text{N}$ - $5^{\circ}\text{S}$ ,  $120^{\circ}$ - $170^{\circ}\text{W}$ ). For historical purposes cold and warm episodes are defined when the threshold is met for a minimum of 5 consecutive over-lapping seasons. Anomalies are centred on 30-yr base periods updated every 5 years. Thin vertical stippled lines indicate the visually estimated timing of sunspot minima. The typically sequence following a sunspot minimum appears to be a warm El Niño episode followed by a cold La Niña episode. Effects on change rates of atmospheric CO<sub>2</sub> and atmospheric specific humidity are visually apparent, with ONI variations being followed by changes in first humidity, and then (last) by CO<sub>2</sub>.

The above diagram is inspired by the Leamon et al. 2021 publication: Robert J. Leamon, Scott W. McIntosh, Daniel R. Marsh. Termination of Solar Cycles and Correlated Tropospheric Variability. *Earth and Space Science*, 2021; 8 (4) DOI: [10.1029/2020EA001223](https://doi.org/10.1029/2020EA001223)



## Monthly lower troposphere temperature (UAH) and global cloud cover, updated to April 2021

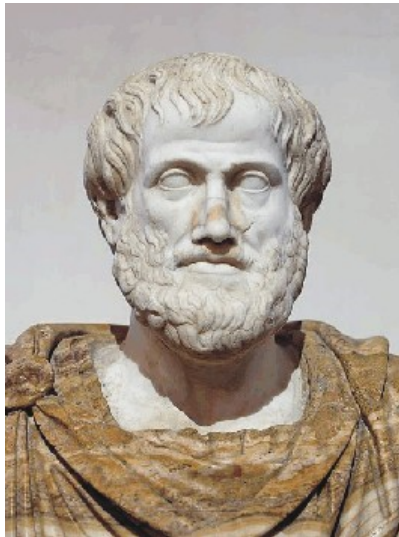


Lower tropospheric air temperature and global cloud cover. Upper panel: Global cloud cover according to Satellite Application Facility on Climate Monitoring. Lower panel: Global monthly average lower troposphere temperature (thin line) since 1979 according to [University of Alabama](https://climate4you.com/) at Huntsville, USA. The thick lines represent the simple running 37-month average. Reference period for UAH is 1991-2020.

Cloud cover data citation: Karlsson, Karl-Göran; Anttila, Kati; Trentmann, Jörg; Stengel, Martin; Solodovnik, Irina; Meirink, Jan Fokke; Devasthale, Abhay; Kothe, Steffen; Jääskeläinen, Emmihenna; Sedlar, Joseph; Benas, Nikos; van Zadelhoff, Gerd-Jan; Stein, Diana; Finkensieper, Stephan; Håkansson, Nina; Hollmann, Rainer; Kaiser, Johannes; Werscheck, Martin (2020): CLARA-A2.1: CM SAF cCloud, Albedo and surface RAdiation dataset from AVHRR data - Edition 2.1, Satellite Application Facility on Climate Monitoring, DOI:10.5676/EUM\_SAF\_CM/CLARA\_AVHRR/V002\_01, [https://doi.org/10.5676/EUM\\_SAF\\_CM/CLARA\\_AVHRR/V002\\_01](https://doi.org/10.5676/EUM_SAF_CM/CLARA_AVHRR/V002_01).

## Climate and history; one example among many

### 384-322 BC; Aristotle's views on weather and climate



Marble bust of Aristotle (left). Roman copy after a Greek bronze original by [Lysippus](#) c. 330 BC. Geocentric celestial spheres (center); Peter Apian's *Cosmographia* (Antwerp, 1539). Right picture: Plato (left) and Aristotle (right), a detail of [The School of Athens](#), a fresco by [Raphael](#). Aristotle gestures to the earth, representing his belief in knowledge through empirical observation and experience, while holding a copy of his [Nicomachean Ethics](#) in his hand, whilst Plato gestures to the heavens, representing his belief in [The Forms](#).

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Aristotle (384-322 BC) was a Greek philosopher, a student of [Plato](#) and later teacher of [Alexander the Great](#). Aristotle is one of the most important founding figures in Western philosophy, and his views on the physical sciences profoundly shaped medieval scholarship, and their influence extended well into the Renaissance, although they were ultimately replaced by Newtonian physics. Much of the summary below is adopted from different sources in [Wikipedia](#) and from [Rasmussen 2010](#), from where additional information is available.

Aristotle was born in Stageira in 384 BC, about 55 km east of the modern-day city Thessalonika. His father Nicomachus was the personal physician to [King Amyntas of Macedon](#). Aristotle was trained and educated as a member of the aristocracy. At about the age of eighteen, he went to Athens to continue his education at [Plato's Academy](#). Aristotle remained at the academy for nearly twenty years before quitting Athens in 348/47 BC, and traveling to Asia Minor, where he studied botany and zoology. In 343

BC Aristotle was invited by [Philip II of Macedon](#) to become the tutor to his son [Alexander the Great](#). Aristotle was appointed as the head of the royal academy of Macedon and gave lessons not only to Alexander, but also to two other future kings: [Ptolemy](#) and [Cassander](#). By 335 BC he had returned to Athens, establishing his own school there known as the [Lyceum](#), where he conducted courses at for the next twelve years. It is during this period in Athens from 335 to 323 BC when Aristotle is believed to have composed many of his works.

Aristotle studied almost every subject possible at the time, and made significant contributions to most of them. In physical science, Aristotle studied anatomy, astronomy, embryology, geography, geology, meteorology, physics and zoology. In philosophy, he wrote on aesthetics, ethics, government, metaphysics, politics, economics, psychology, rhetoric and theology. He also studied education, foreign customs, literature and poetry. His combined works constitute a virtual encyclopedia of Greek

knowledge. It has been suggested that Aristotle was probably the last person to know everything there was to be known in his own time. Like his teacher Plato, Aristotle's philosophy was aiming at the universal. Aristotle, however, found the universal in particular things, which he called the essence of things. Aristotle's method is both inductive and deductive, while Plato's is essentially deductive from a priori principles.

In 350 BC Aristotle wrote a treatise entitled '[Meteorologica](#)', which probably is the first attempt ever to make a comprehensive about the earth sciences, including [meteorology](#). '[Meteorologica](#)' consists of four books, including early accounts of water evaporation, weather phenomena, and earthquakes, and was considered a benchmark publication for more than 2000 years. Interesting enough, Aristotle expected clouds to consist of water. In chapter (part) nine in his first book, he directly states that '*air condensing into water is cloud*'.

In '[Meteorologica](#)' Aristotle presents a number of interesting interpretations concerning different phenomena related to the Earth, atmosphere, clouds weather, climate and climate change effects:

#### Earth, Sun and atmosphere

- *The earth is surrounded by water, just as that is by the sphere of air, and that again by the sphere called that of fire.*
- *...four bodies are fire, air, water, earth.*
- *Fire occupies the highest place among them all, earth the lowest, and two elements correspond to these in their relation to one another, air being nearest to fire, water to earth.*
- *...the motion of these latter bodies [of four] being of two kinds: either from the centre or to the centre.*
- *Fire, air, water, earth, we assert, originate from one another, and each of them exists potentially in each, as all things do that can be resolved into a common and ultimate substrate.*

- *The efficient and chief and first cause is the circle in which the sun moves. For the sun as it approaches or recedes, obviously causes dissipation and condensation and so gives rise to generation and destruction.*

#### Clouds and rain

- *Now the earth remains but the moisture surrounding it is made to evaporate by the sun's rays and the other heat from above, and rises. But when the heat which was raising it leaves it, in part dispersing to the higher region, in part quenched through rising so far into the upper air, then the vapour cools because its heat is gone and because the place is cold, and condenses again and turns from air into water. And after the water has formed it falls down again to the earth.*
- *Since water is generated from air, and air from water, why are clouds not formed in the upper air? They ought to form there the more, the further from the earth and the colder that region is. For it is neither appreciably near to the heat of the stars, nor to the rays reflected from the earth. It is these that dissolve any formation by their heat and so prevent clouds from forming near the earth. For clouds gather at the point where the reflected rays disperse in the infinity of space and are lost. To explain this we must suppose either that it is not all air which water is generated, or, if it is produced from all air alike, that what immediately surrounds the earth is not mere air, but a sort of vapour, and that its vaporous nature is the reason why it condenses back to water again.*
- *However, it may well be that the formation of clouds in that upper region is also prevented by the circular motion. For the air round the earth is necessarily all of it in motion, except that which is cut off inside the circumference which makes the earth a complete sphere. In the case of winds it is actually observable that they originate in*

*marshy districts of the earth; and they do not seem to blow above the level of the highest mountains. It is the revolution of the heaven which carries the air with it and causes its circular motion, fire being continuous with the upper element and air with fire. Thus its motion is a second reason why that air is not condensed into water.*

- *The exhalation of water is vapour: air condensing into water is cloud. Mist is what is left over when a cloud condenses into water, and is therefore rather a sign of fine weather than of rain; for mist might be called a barren cloud. So we get a circular process that follows the course of the sun. For according as the sun moves to this side or that, the moisture in this process rises or falls. We must think of it as a river flowing up and down in a circle and made up partly of air, partly of water. When the sun is near, the stream of vapour flows upwards; when it recedes, the stream of water flows down: and the order of sequence, at all events, in this process always remains the same. So if 'Oceanus' had some secret meaning in early writers, perhaps they may have meant this river that flows in a circle about the earth.*
- *So the moisture is always raised by the heat and descends to the earth again when it gets cold. These processes and, in some cases, their varieties are distinguished by special names. When the water falls in small drops it is called a drizzle; when the drops are larger it is rain.*

#### Water vapour, dew and hoar-frost

- *Some of the vapour that is formed by day does not rise high because the ratio of the fire that is raising it to the water that is being raised is small*
- *Both dew and hoar-frost are found when the sky is clear and there is no wind. For the vapour could not be raised unless the sky were clear, and if a wind were blowing it could not condense.*

- *...hoar-frost is not found on mountains contributes to prove that these phenomena occur because the vapour does not rise high. One reason for this is that it rises from hollow and watery places, so that the heat that is raising it, bearing as it were too heavy a burden cannot lift it to a great height but soon lets it fall again.*

#### Weather

- *When there is a great quantity of exhalation and it is rare and is squeezed out in the cloud itself we get a thunderbolt.*
- *So the whirlwind originates in the failure of an incipient hurricane to escape from its cloud: it is due to the resistance which generates the eddy, and it consists in the spiral which descends to the earth and drags with it the cloud which it cannot shake off. It moves things by its wind in the direction in which it is blowing in a straight line, and whirls round by its circular motion and forcibly snatches up whatever it meets.*

#### Climate change effects:

- *So it is clear, since there will be no end to time and the world is eternal, that neither the Tanais nor the Nile has always been flowing, but that the region whence they flow was once dry: for their effect may be fulfilled, but time cannot. And this will be equally true of all other rivers. But if rivers come into existence and perish and the same parts of the earth were not always moist, the sea must needs change correspondingly. And if the sea is always advancing in one place and receding in another it is clear that the same parts of the whole earth are not always either sea or land, but that all this changes in course of time.*

Aristotle's writings were never to influence directly on practical meteorology. For many centuries people relied instead on a few weather rules of thumb, sometimes blended with the assumption of a certain

degree of divine interference. One of Aristotle's students, Theophrastus (371-287 BC) succeeded him as a director of the Lyceum in Athens. He took over the philosophy of Aristotle in parts reshaping, commenting, and developing it in an original way. His thinking leads to empiricism by means of observation, collection, and classification.

Theophrastus was years the director of the Lyceum around 35 years and he was a teacher of up to 2000 students. Today he is often considered the "father of botany". In addition, he probably was the first in Europe to discover Sunspots (although observed also independently and much earlier in China). However,

he also continued Aristotle's work on meteorology, formulating about 80 weather rules, based entirely on observations. This indicates that empirical meteorology already at this time had reached an advanced stage in Greek science ([Rasmussen 2010](#)).

Later, much of the scientific knowledge acquired and formulated by Aristotle and his students was sadly ignored and forgotten in Europe, and it was not before 1000-1100 AD that it was rediscovered by European scientist, after surviving among Arabian scientists. By this, with a delay of at least 1300 years, the theories and explanations set forth by Aristotle were to gain huge impact on the later European scientific development.

#### References:

Rasmussen, E.A. 2010. *Vejret gennem 5000 år* (Weather through 5000 years). Meteorologiens historie. Aarhus Universitetsforlag, Århus, Denmark, 367 pp, ISBN 978 87 7934 300 9.

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All diagrams in this report, along with any supplementary information, including links to data sources and previous issues of this newsletter, are freely available for download on [www.climate4you.com](http://www.climate4you.com)

Yours sincerely,

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20 July 2024.

Planned publication of next newsletter: around 24 August 2024.