Climate
Change

Exploiting reanalyses in studies and services related to climatic variability and trends

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with thanks to Hans Hersbach, Julien Nicolas, Paul Poli and many other colleagues past and present

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Why do we pay special attention to variability and trends?

To qualify the use of ERA5 for climate monitoring by C3S and others

To obtain information for improving future reanalyses, through better

- data assimilation
- observational input
- ancillary datasets for SST, sea ice, aerosol, etc.

particularly related to biases:

- how the various types and numbers of observations change over time
- the biases of the observations, and how well they are detected and corrected
- the biases of the background model
- the weights given to the various observations and the background forecast by the data assimilation system

Additional recent motivation

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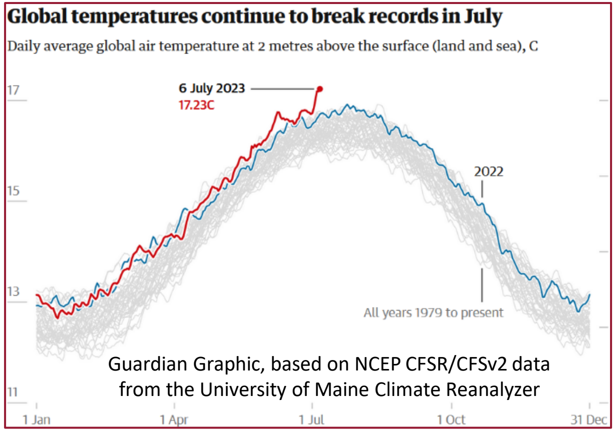
The exceptional warmth of 2023, and the associated media interest and communication challenges

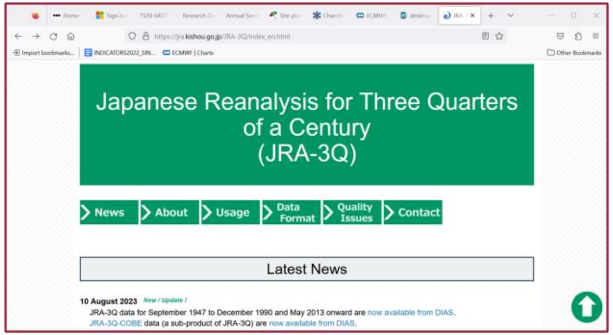
- someone from NOAA tells Associated Press that the NCEP/CFSv2 analyses are model output data that are "not suitable" as substitutes for actual temperatures



Guardian Graphic, based on NCEP CFSR/CFSv2 data from the University of Maine Climate Reanalyzer

Release of JRA-3Q from September 1947 to present

- providing an important new set of reanalysis data with which we can compare ERA5



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The origins of reanalysis

ECMWF (ERA1) and GFDL produced analyses for 1979 from the observations made during the Global Weather Experiment (FGGE)

One year was too short for many purposes, but most of the enhanced observing system deployed for FGGE continued to operate after 1979

The analyses for 1979 were soon supplemented by global analyses from routine weather forecasting for studies of climate

But frequent operational changes clouded the picture, leading to calls for reanalysis (Trenberth & Olson, 1988; Bengtsson & Shukla,1988)

The first multi-year reanalyses followed:

ERA-15 (ERA2; 1979 - 93), NASA/DAO (1980 - 93) and NCEP/NCAR (1948 - …)

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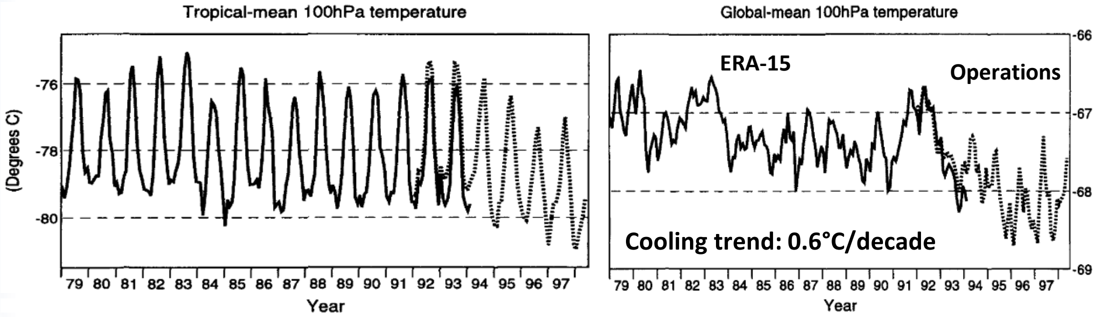
Our first look at a trend using ERA-15 and EC operations



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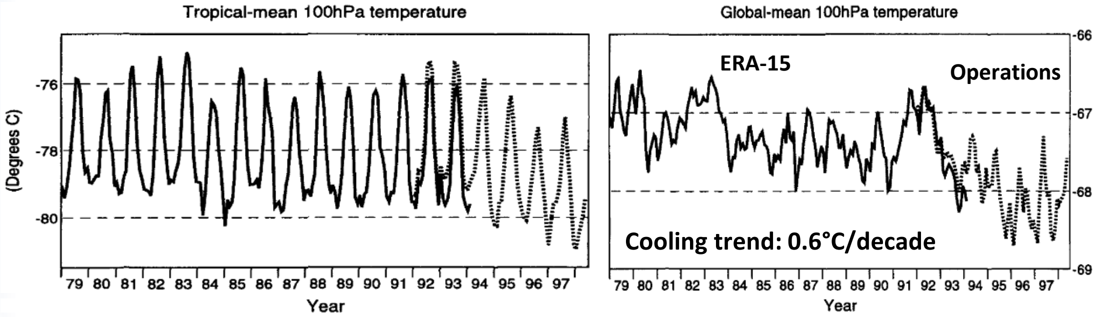

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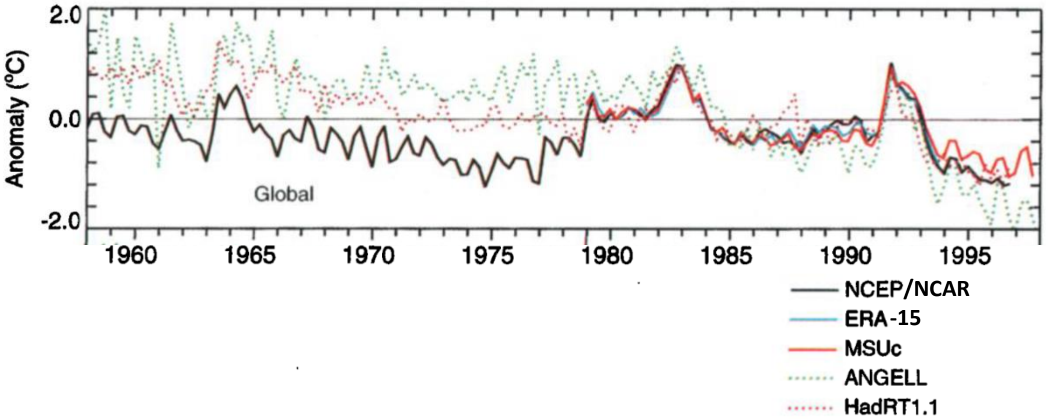

Plate 1. Time series of global- and hemispheric-scale temperature anomalies (degrees Celsius) in the lower stratosphere. Temperatures are estimated from radiosondes (Angell, HadRT1.1), the satellite-based Microwave Sounding Unit (MSU version c, or MSUc) and reanalyses of the European Centre for Medium-Range Weather Forecasts (ERA) and National Center for Environmental Prediction (NCEP). Anomalies are in the

Lower stratospheric (MSU-4 equivalent) temperatures from Santer *et al.* (1999)

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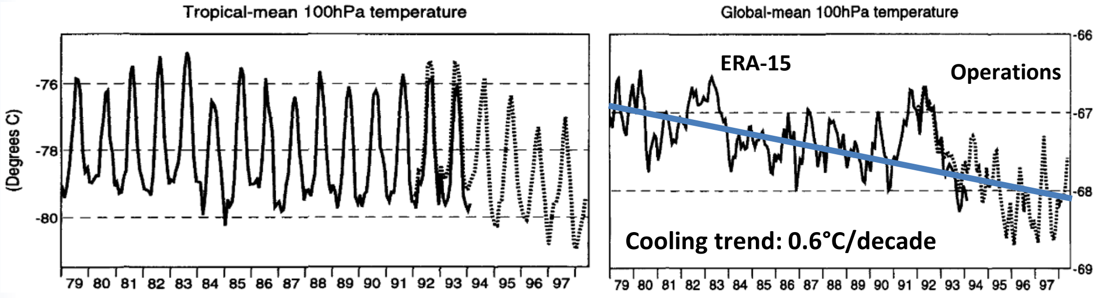
From ERA-15 (ERA2) to ERA5



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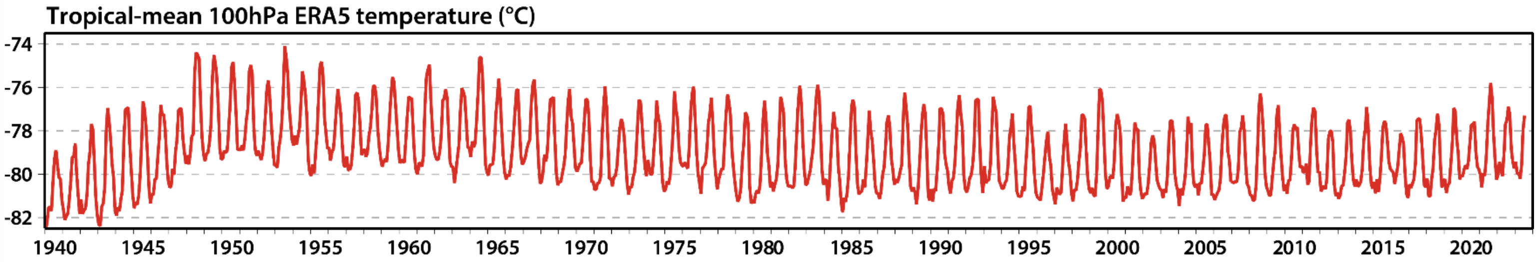

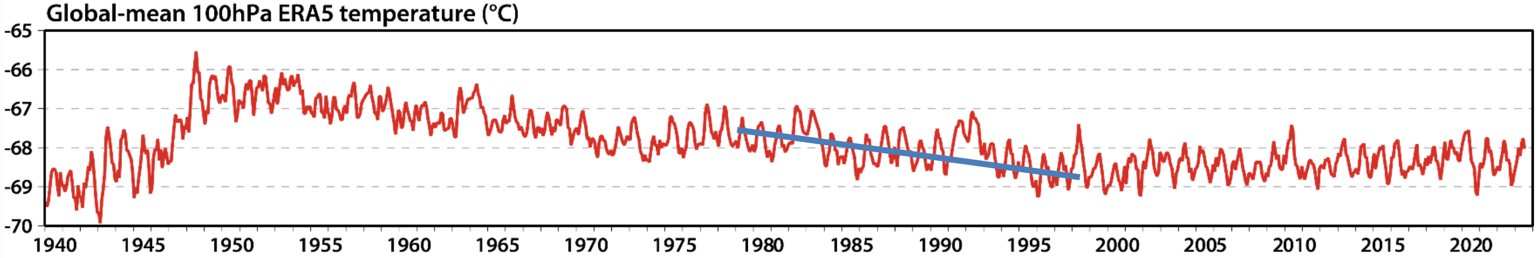

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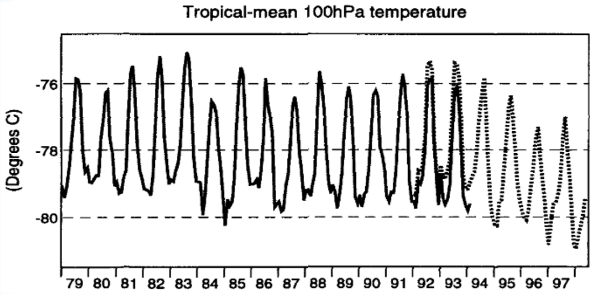
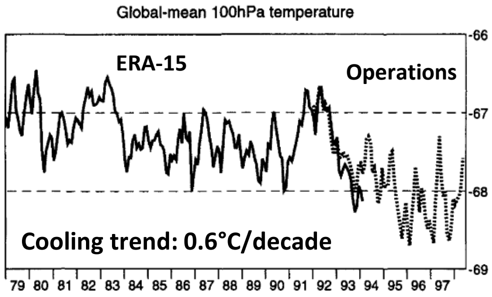
From ERA-15 (ERA2) to ERA5 and JRA-3Q





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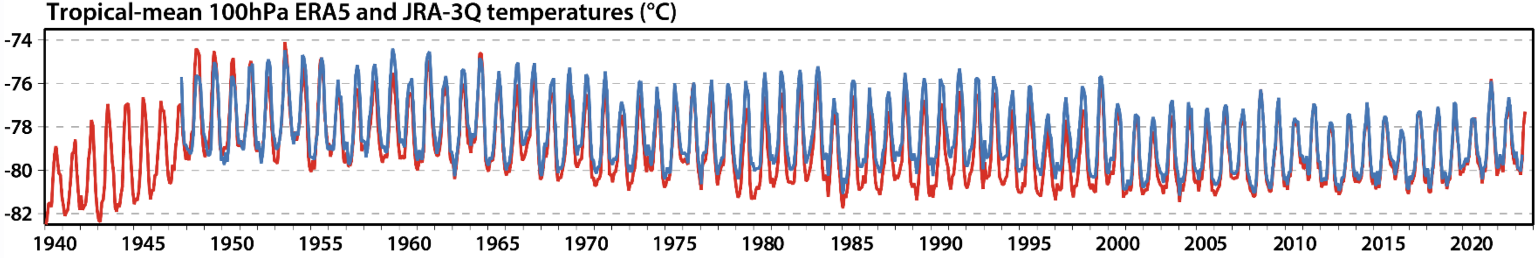

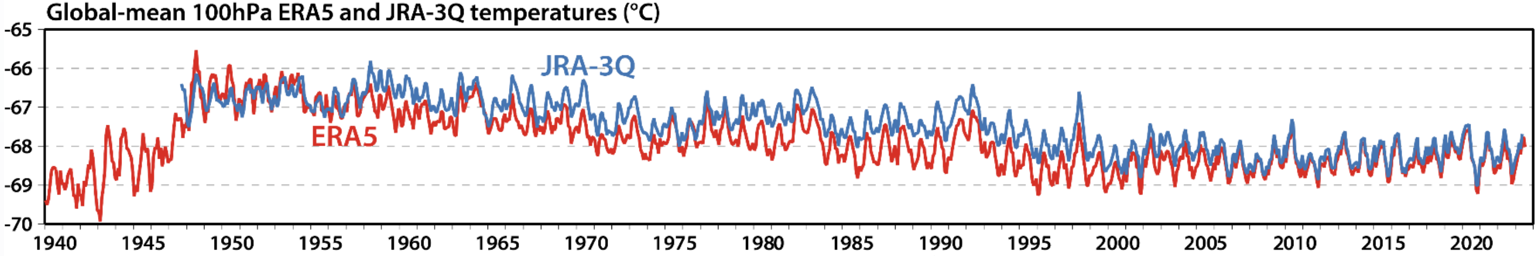

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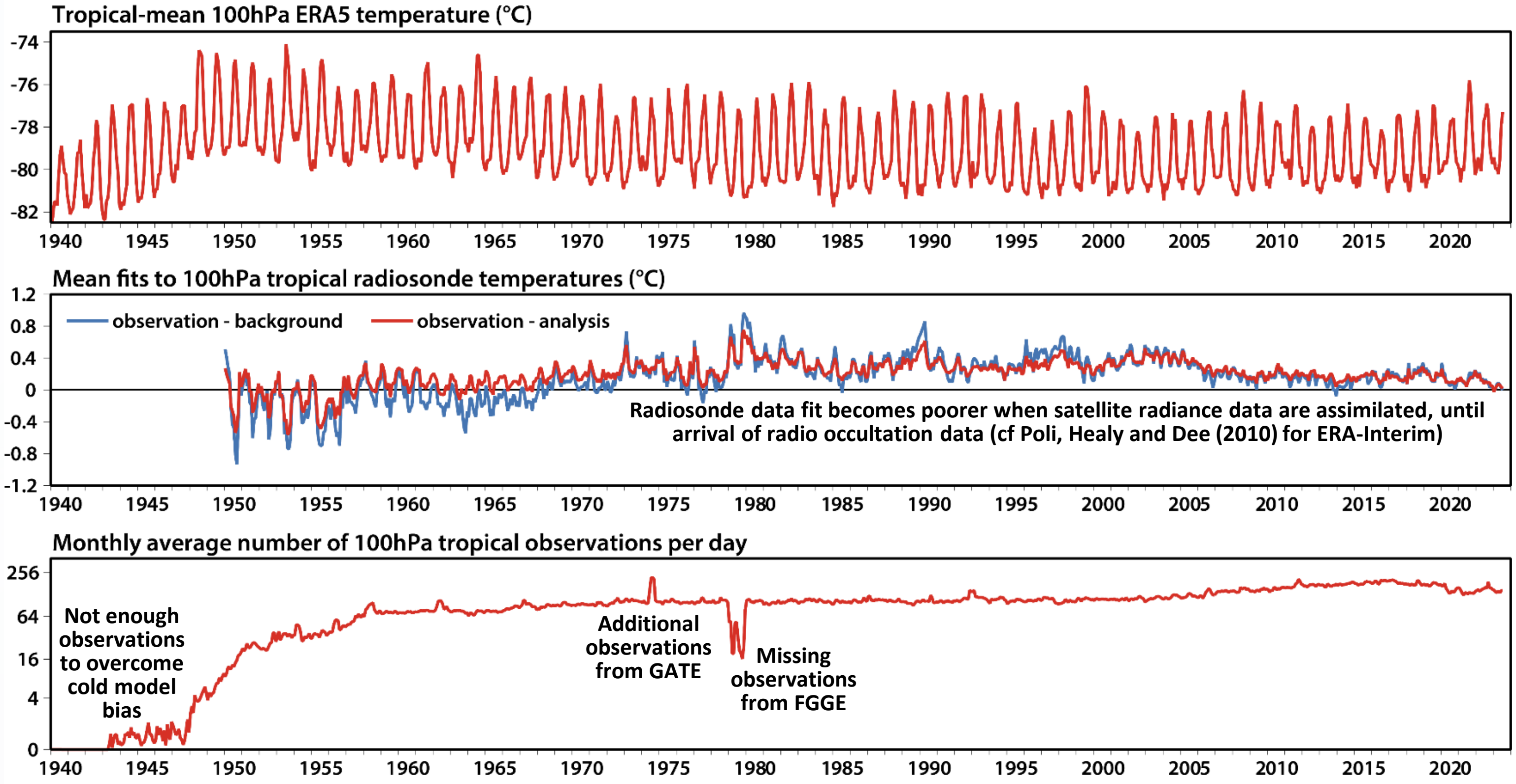
Tropical averages at 100hPa from ERA5



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Lower stratospheric temperature change from ERA-40

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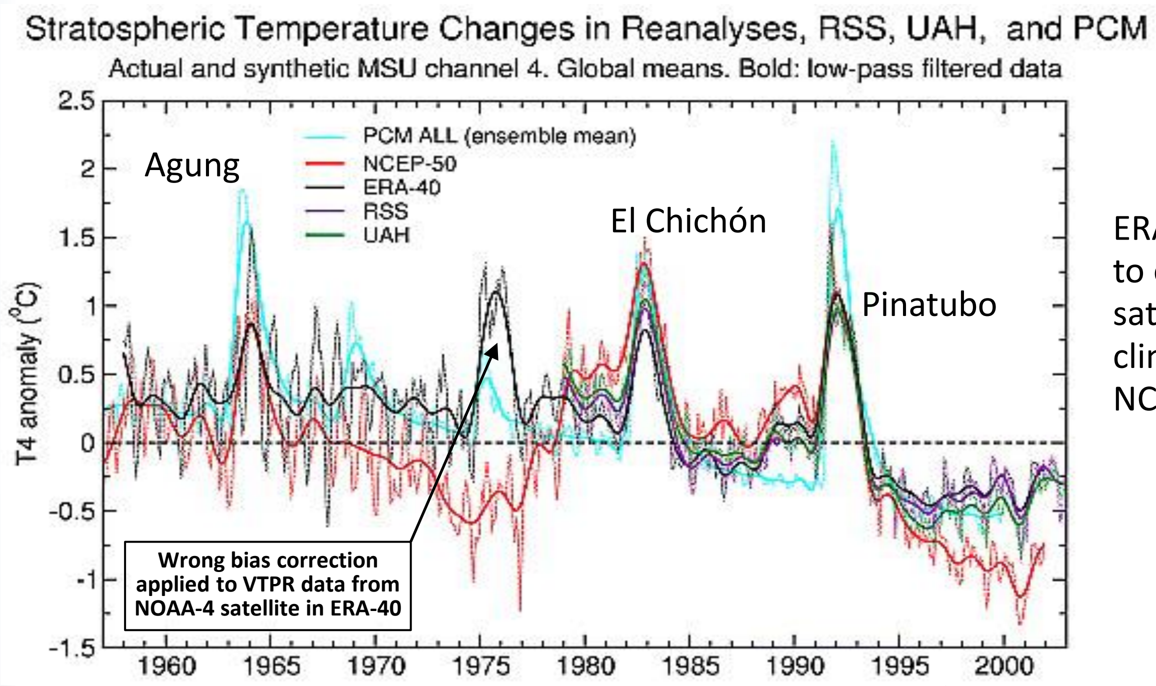
From Santer, Wigley, Simmons, Kållberg, Kelly, Uppala et al. (2004):
Identification of anthropogenic climate change using a second-generation reanalysis



ERA-40 is generally closer to estimates from MSU-4 satellite data and a climate model than the NCEP/NCAR reanalysis is

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Temperatures at 50 hPa from 1940 to 2023

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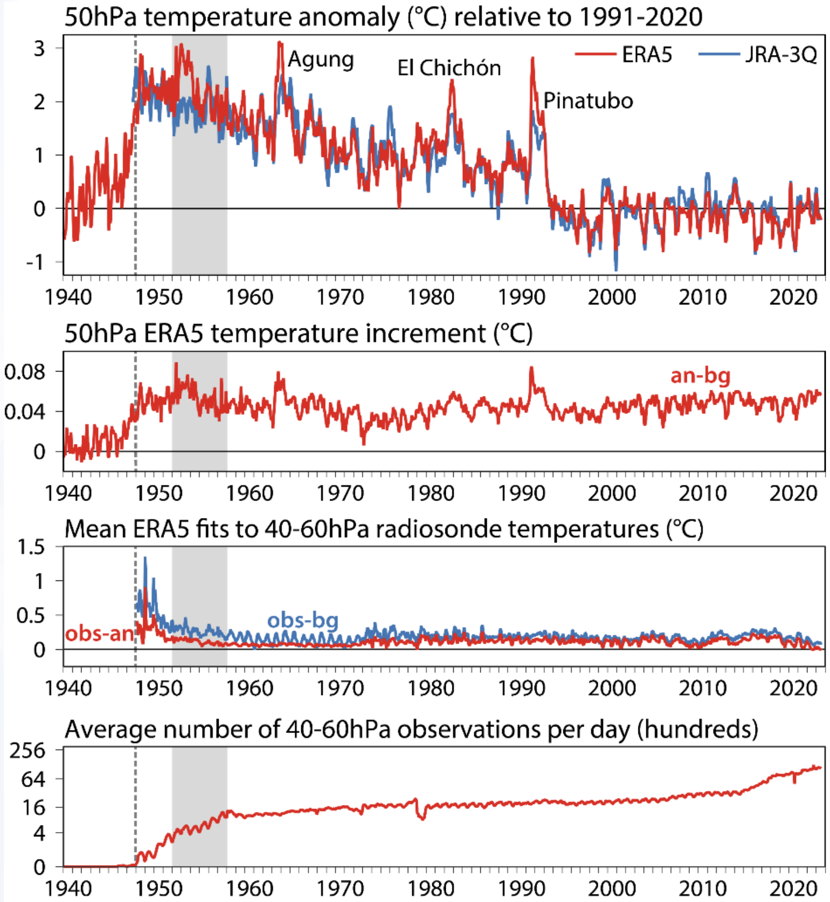
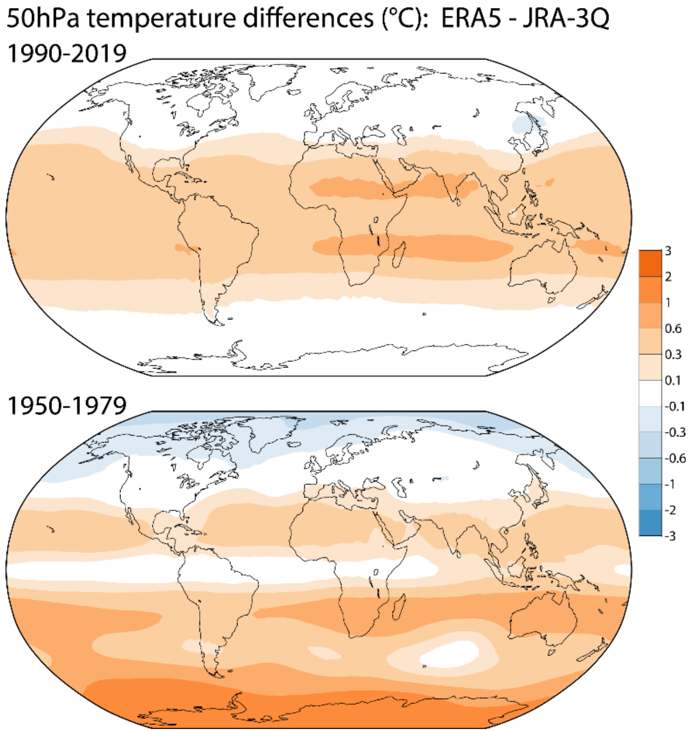
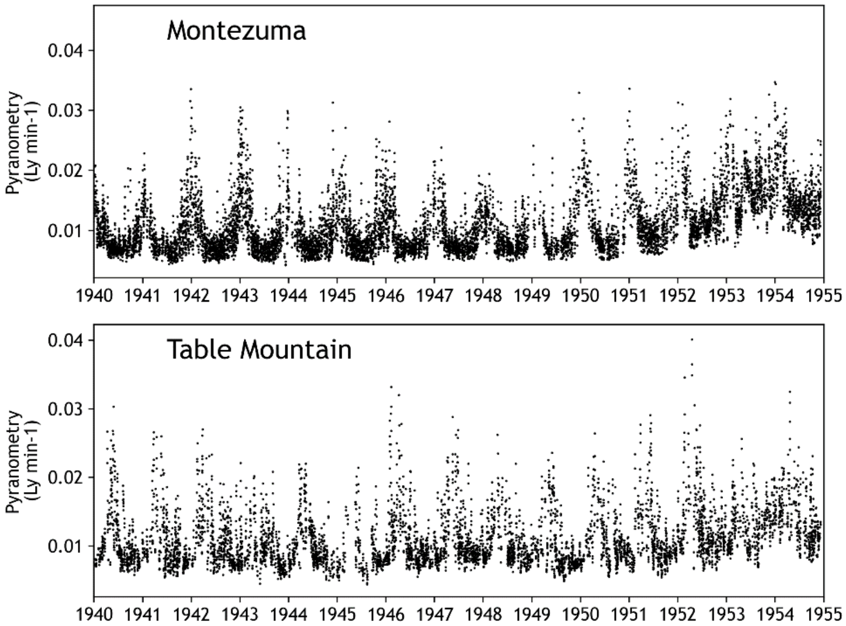




Was surface solar radiation lower than normal 1952-1954?



Time series (1940-1955) of measurements from Chile and California of scattered solar light (Paul Poli, after Roosen and Angione, 1984)

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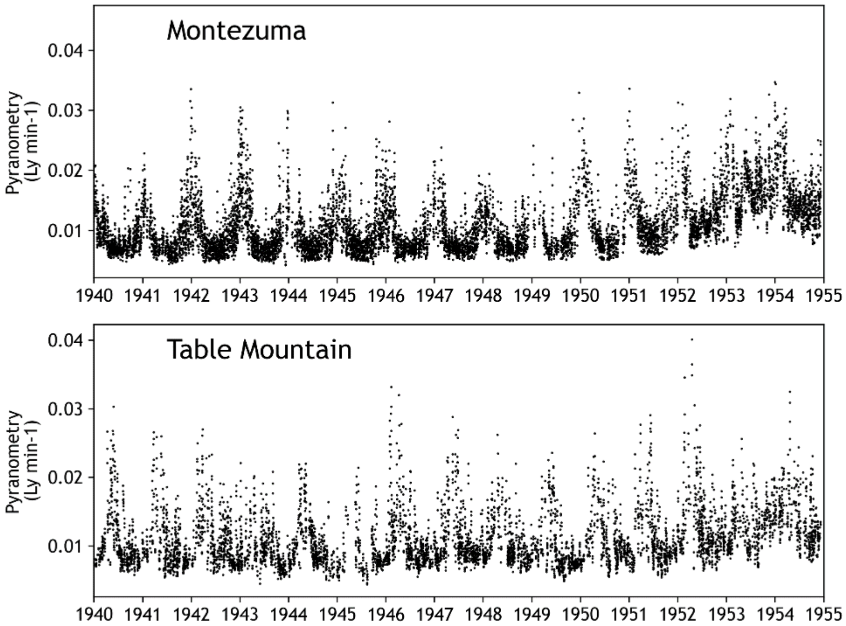

Time series (1940-1955) of measurements from Chile and California of scattered solar light (Paul Poli, after Roosen and Angione, 1984)

"Ivy Mike" nuclear test 31 Oct 1952 (UTC)

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Temperatures at 500hPa from 1940 to 2023

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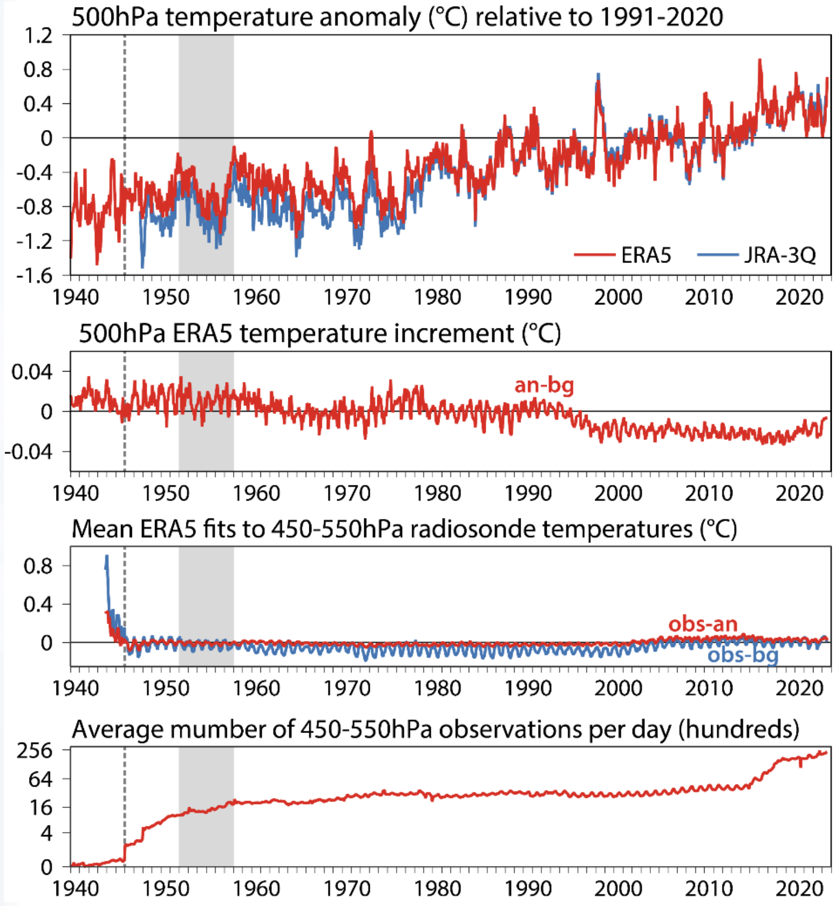

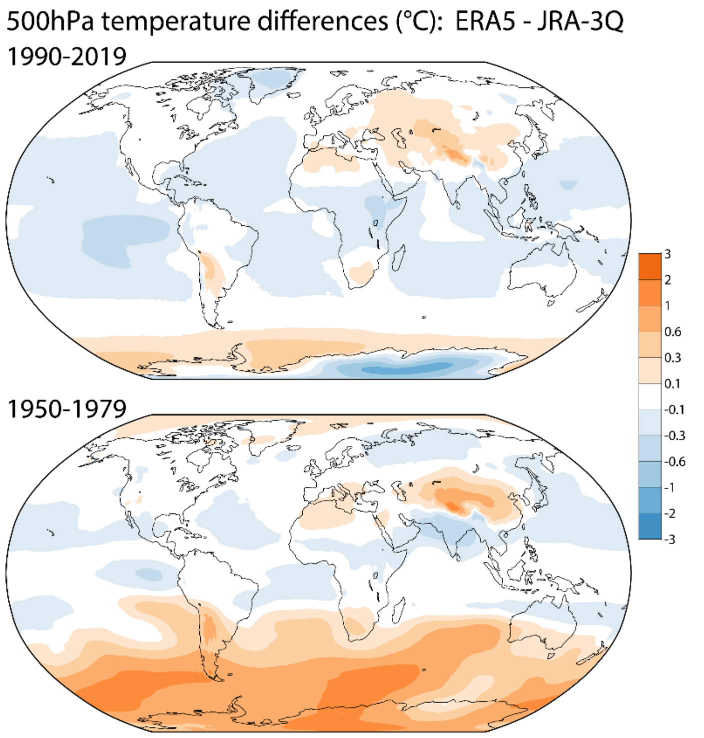

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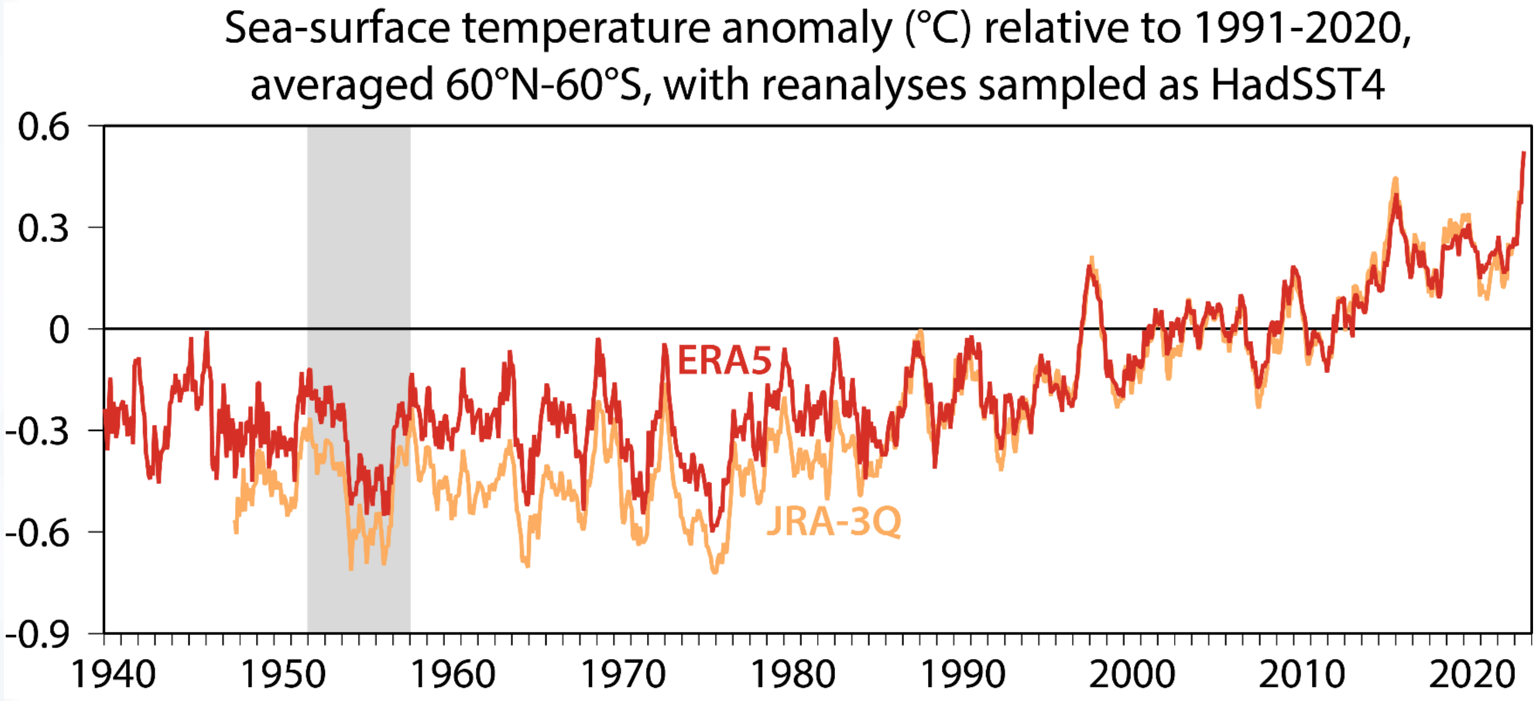
ERA5 SST analysis is likely too warm prior to the 1980s



JRA-3Q uses COBE-SST2 to May 1985, and MGDSST from June 1985

ERA5 uses HadISST2

ERA5 SST analysis is likely too warm prior to the 1980s

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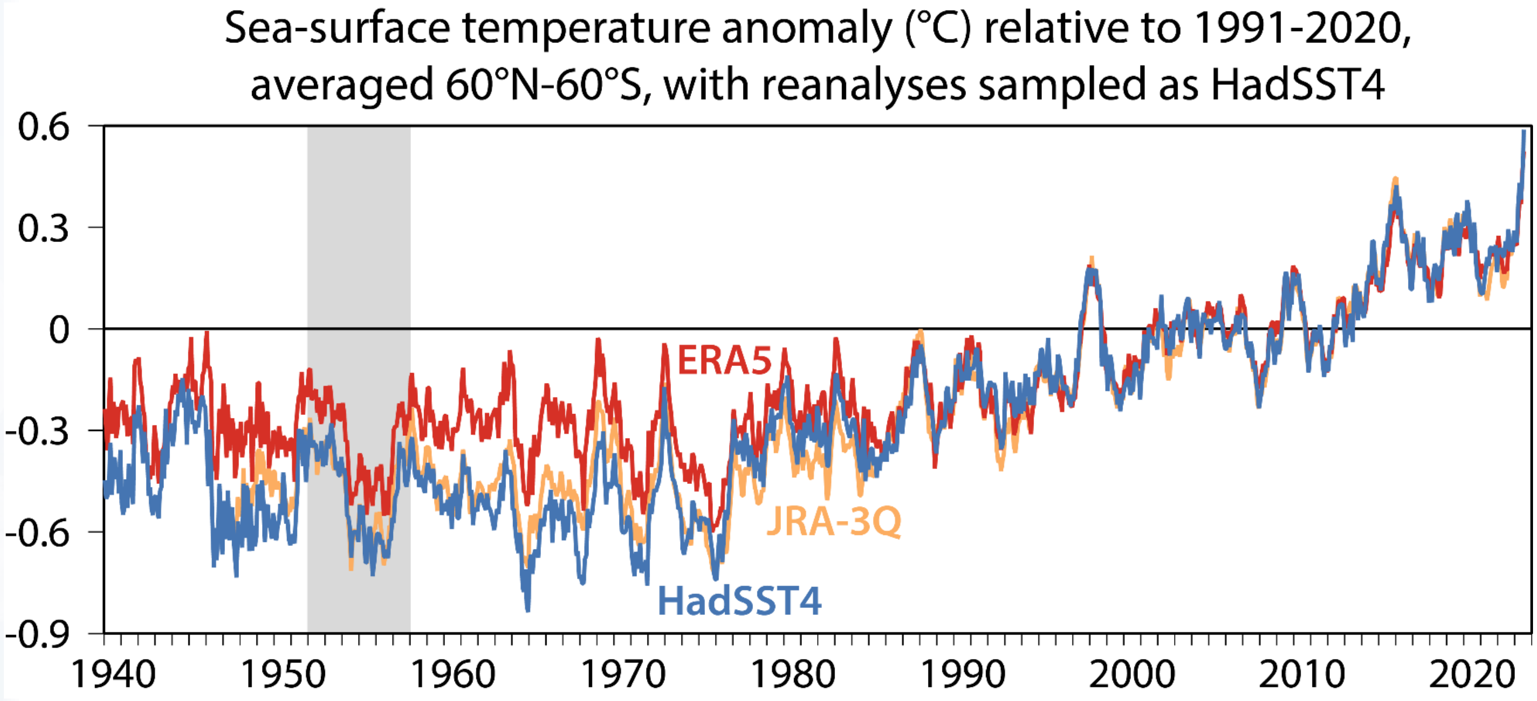

JRA-3Q uses COBE-SST2 to May 1985, and MGDSST from June 1985

ERA5 uses HadISST2, which pre-dates HadSST4

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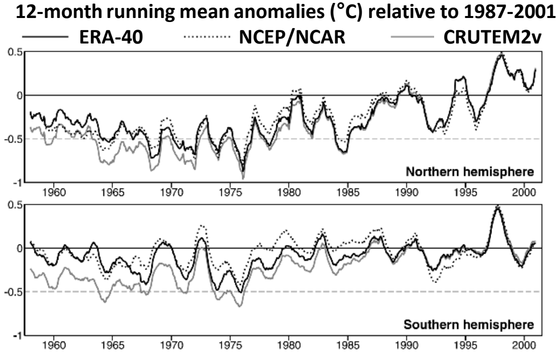
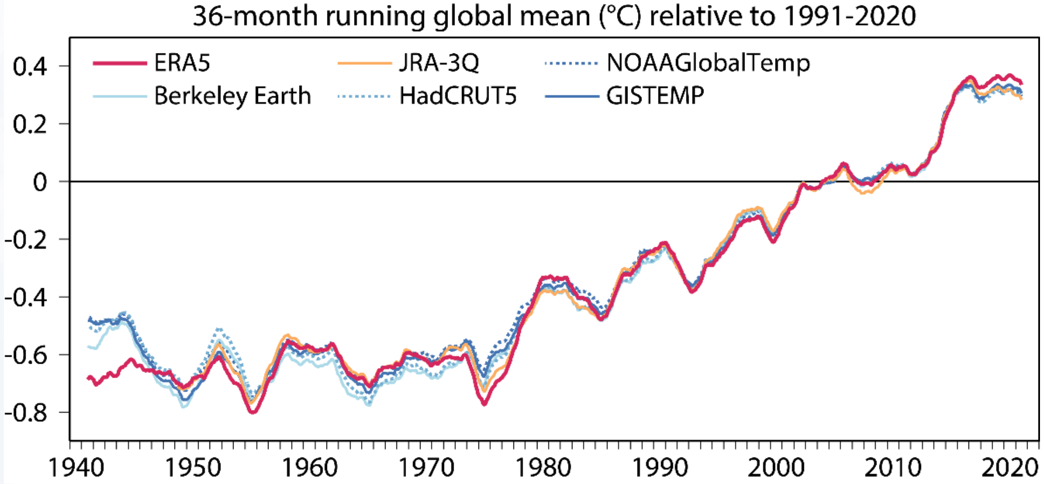
Trends in surface temperature anomalies



The first study of ERA two-metre temperature trends over land (Simmons, Jones *et al.* , 2004) was encouraging, and has been followed by several others



Berkeley Earth, GISTEMP. HadCRUT5 and Berkeley Earth are based on analysis of monthly anomalies at observing stations, and SST analyses

Berkley Earth and HadCRUT5 use HadSST4

GISTEMP and NOAAGlobalTemp use ERSSTv5

Trends in surface temperature anomalies: Europe

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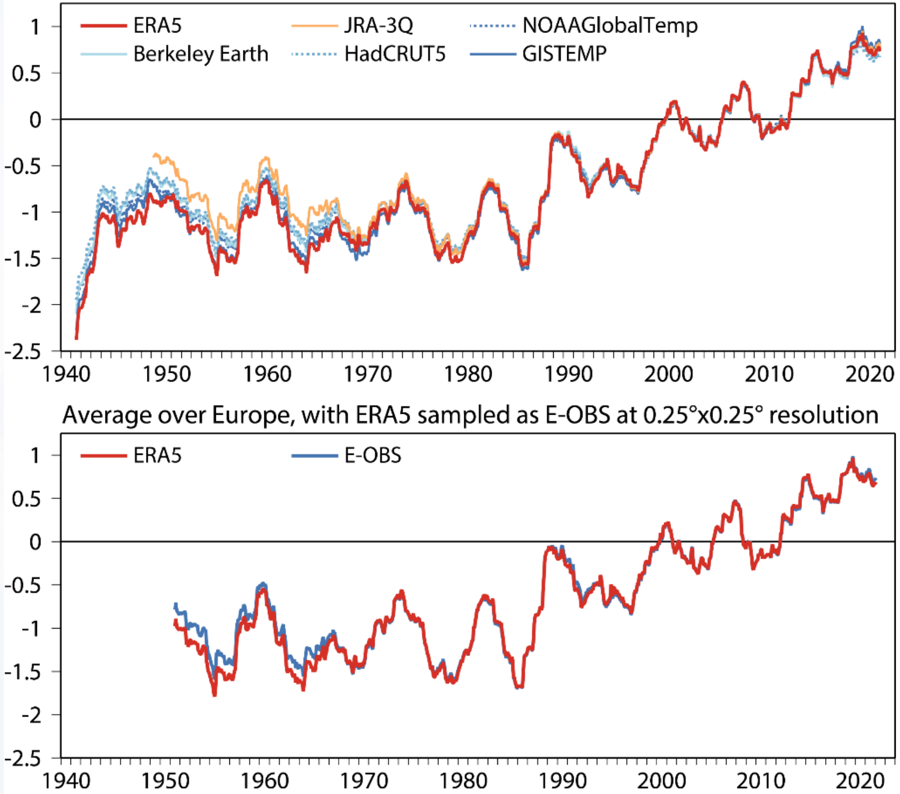
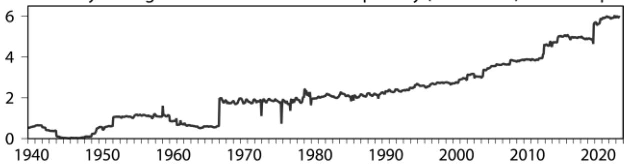


JRA-3Q data have been downloaded only at 1.25°x1.25° resolution

Coarse spatial resolution and missing data values may have a small influence on results from some datasets

ERA5 captures the essence of the cold early 1940s



ERA5 has some substantial gaps in observational coverage before 1967

ERA5 appears to be biased cold then, and JRA-3Q biased warm

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Differences between ERA5 and JRA-3Q over Antarctica

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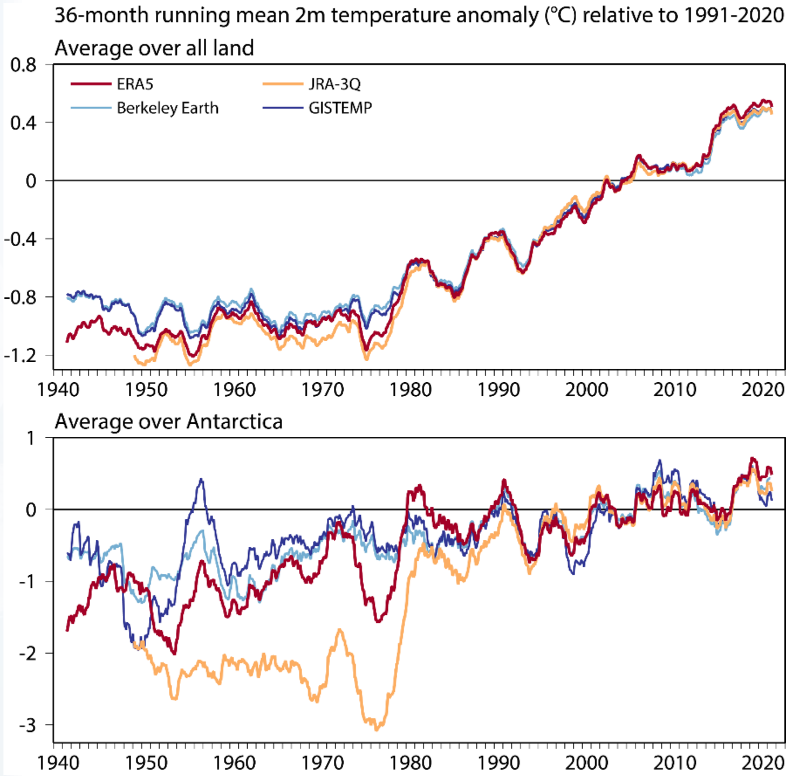

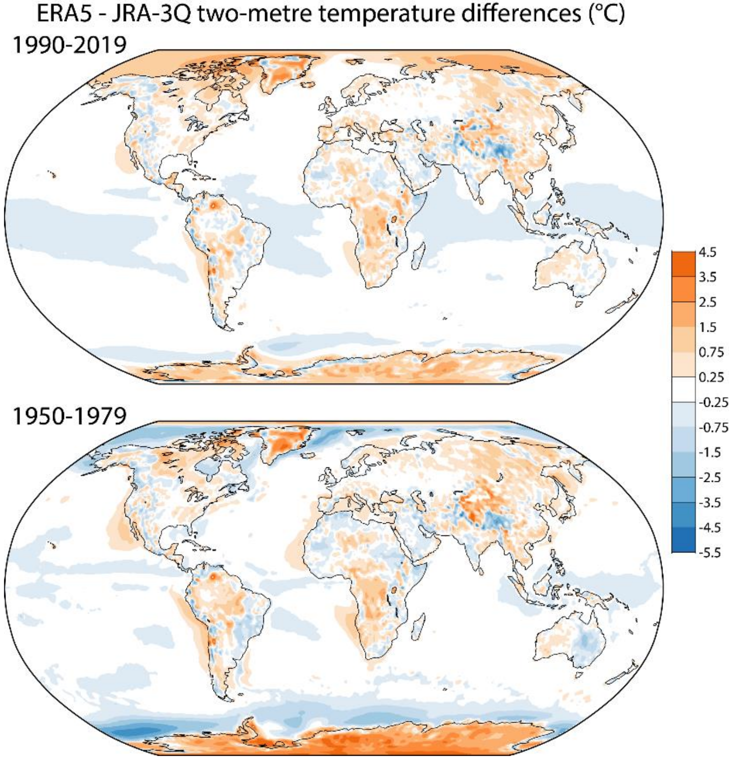

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All-land averages related to the ERA5 T2m analysis

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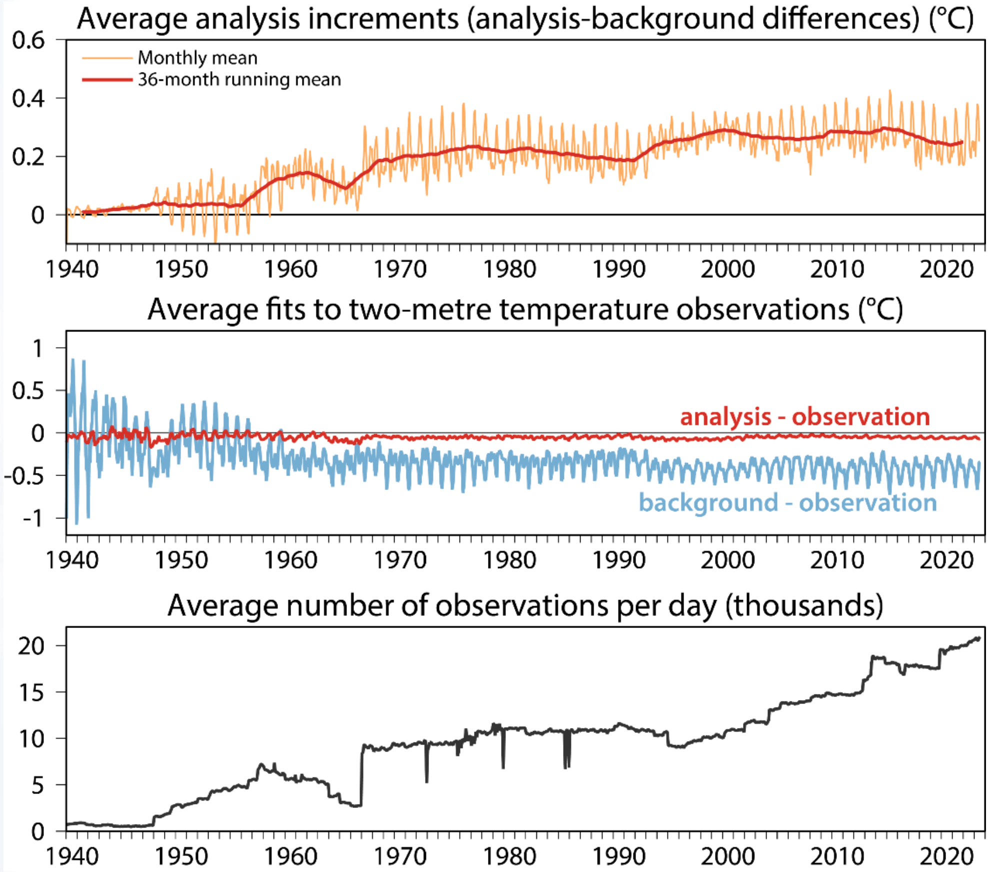

Analysis increments mirror observation numbers in the 1960s, but not in the late 1940s and early 1950s

Increments increase in the early 1990s, when mean background fits worsen

The analysis fits the observations closely throughout

Statistics are for a subset of observations; the total number of observations increases more rapidly in later years, mainly due to more frequent reporting

T2m analysis does not adjust for elevation mismatches

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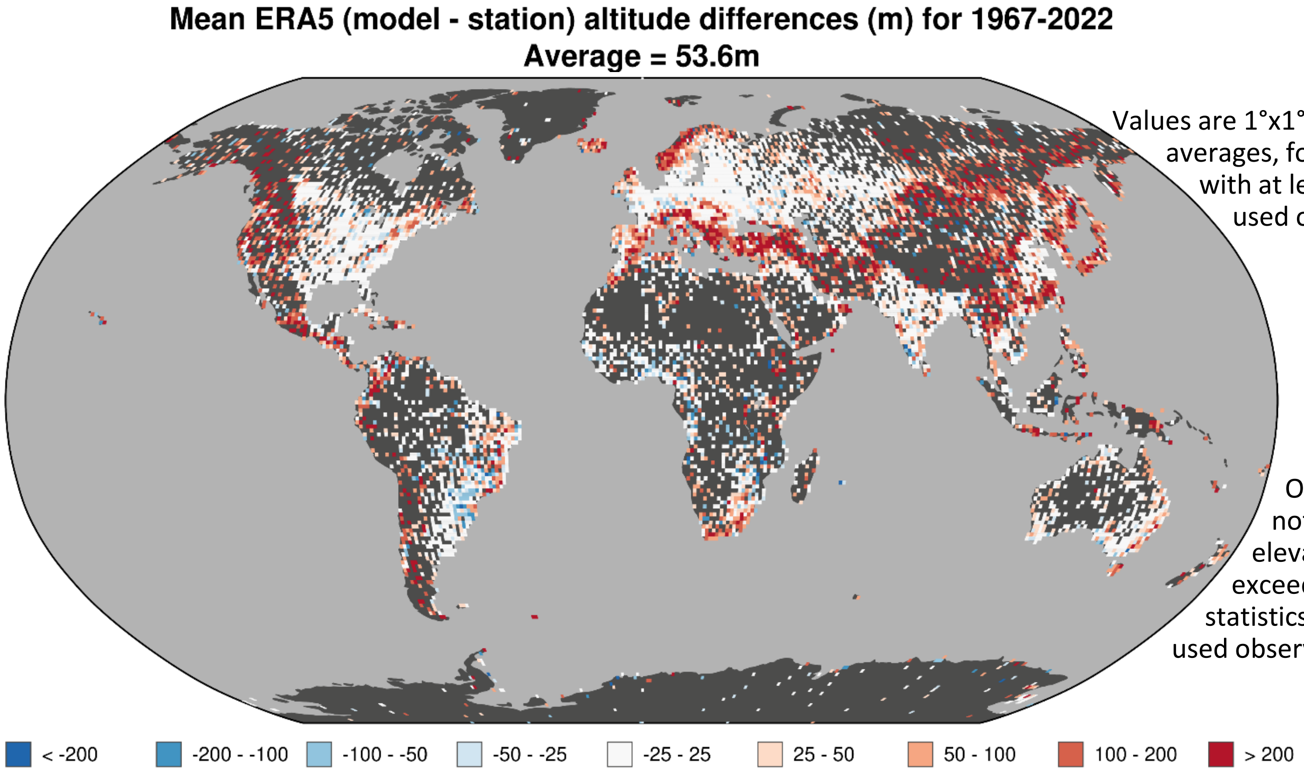

Values are 1°x1° grid-box averages, for grid boxes with at least 100 used observations

Observations are not used where elevation differences exceed 300m; these statistics are based on used observations.

Observing stations tend to be located at lower elevations than are typical of their surroundings, especially in mountainous regions

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Analysis – background two-metre temperatures (°C)

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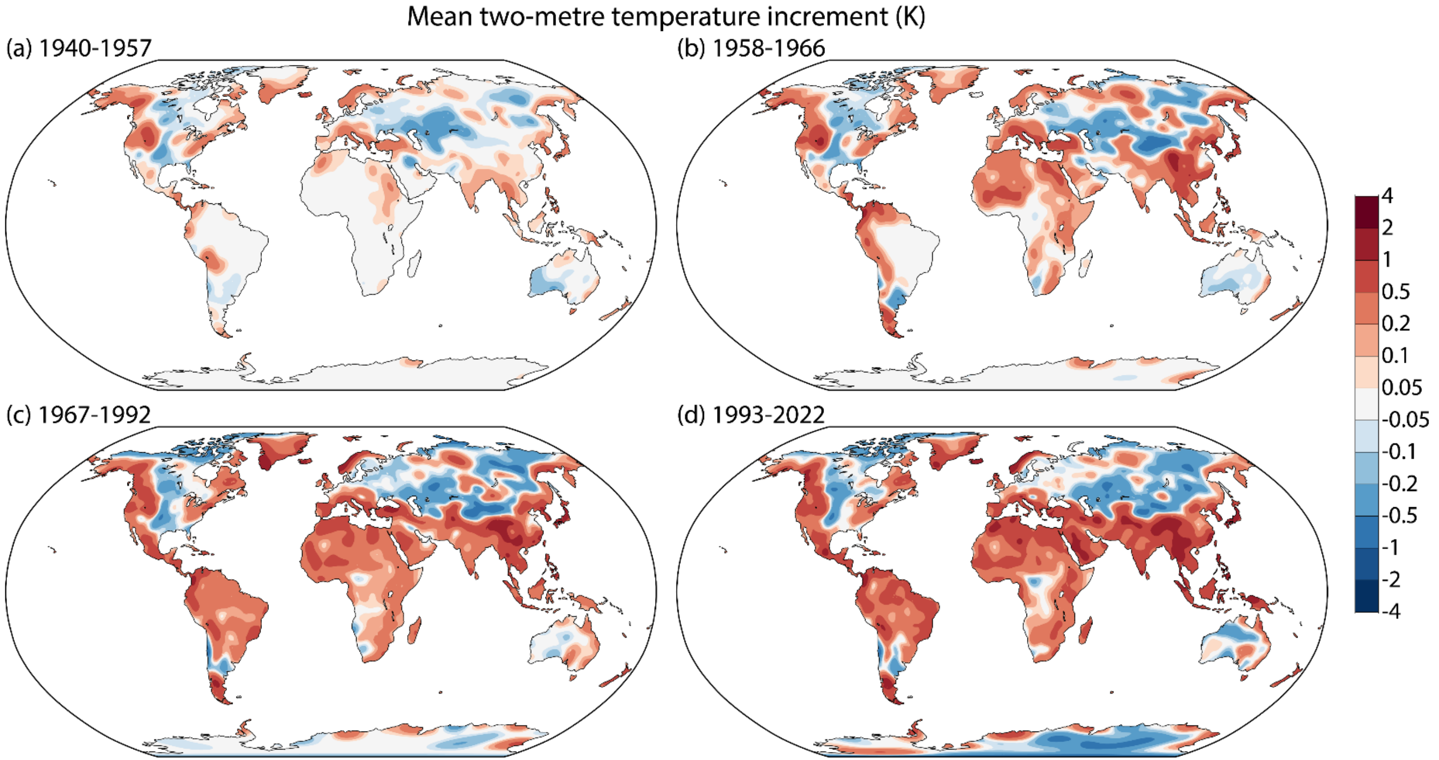

The ERA5 analysis scheme increases background temperatures in mountainous regions because of the mismatch in elevations. This spurious warming increases as the number of observations increases in the early decades

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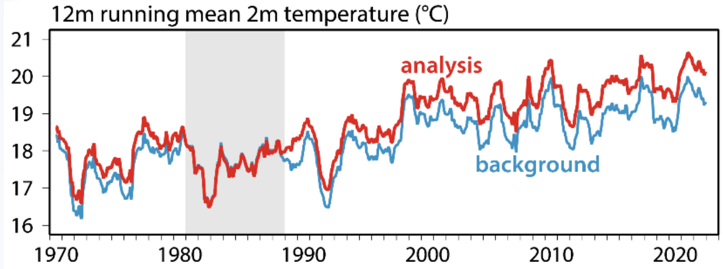
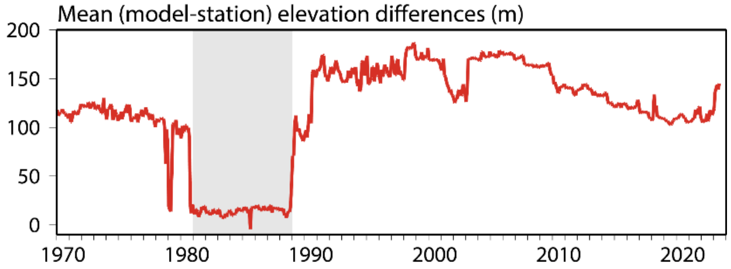
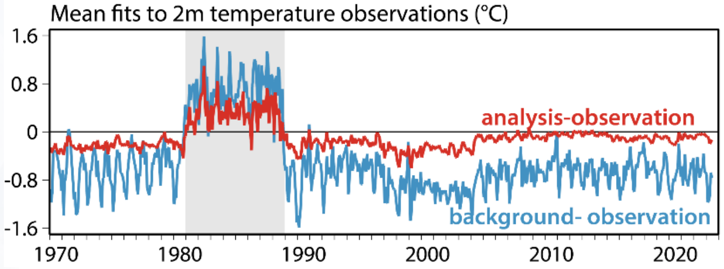
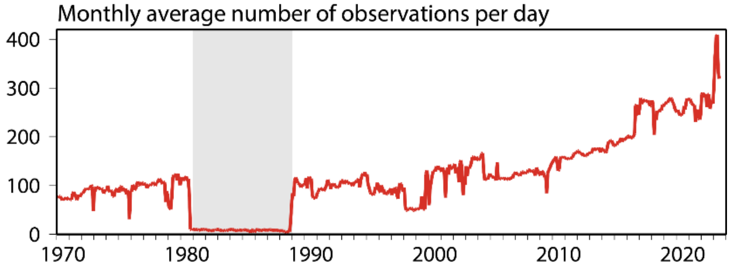
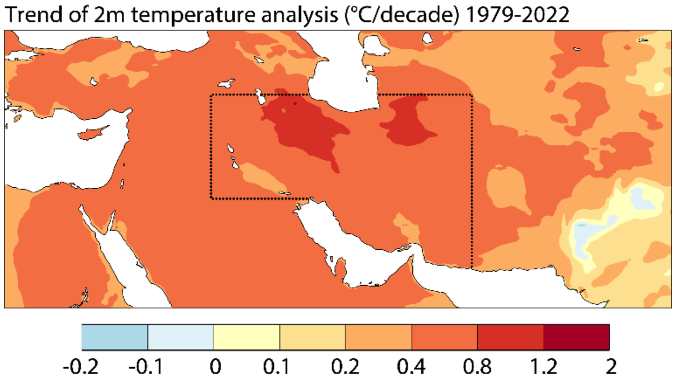
Few observations from Iran and Iraq 1981-1988











The warming trend from 1979 is overestimated for this region because analysed temperatures are relatively low when observations are missing during the 1980s

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Comparisons back to 1850 provide context for August 2023

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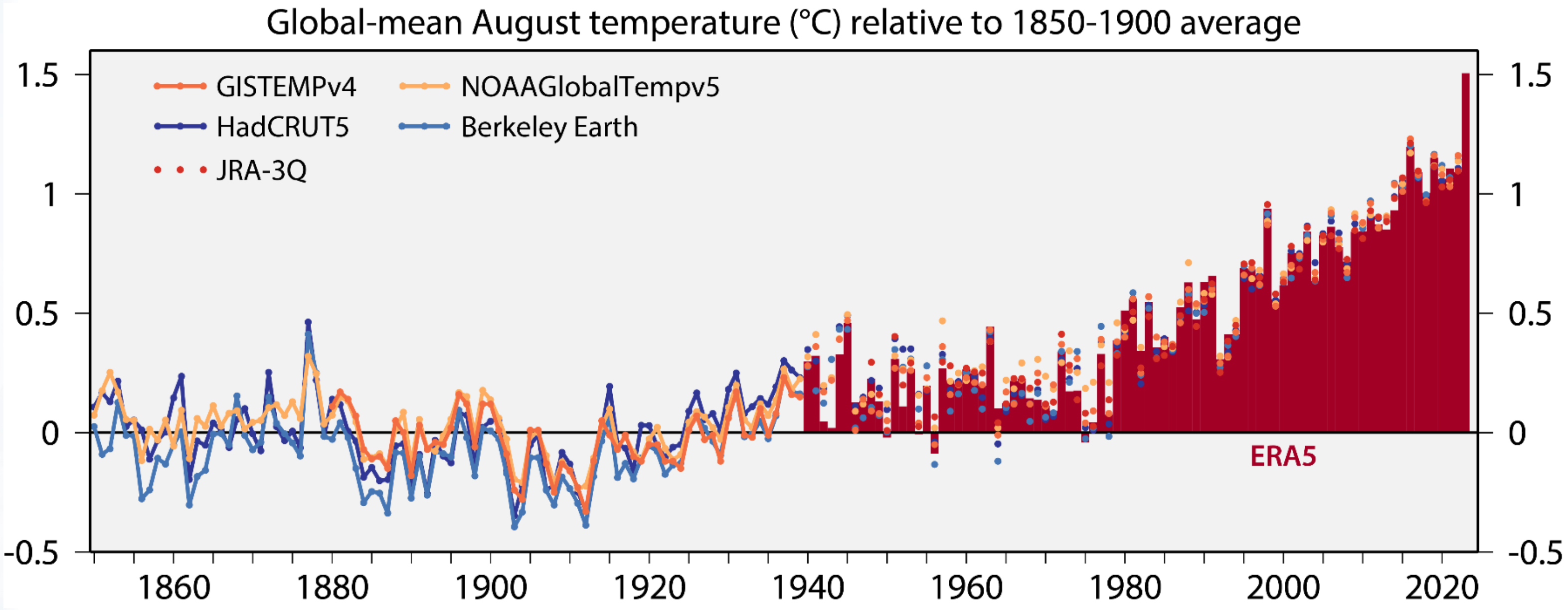

August 2023 temperature is about 1.5°C higher than the 1850-1900 average for August

The gap between August 2023 and the next warmest August is large

The (El Niño) year 1877 also stands out, as does 1998

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Daily trends and exceptional values in June-August 2023

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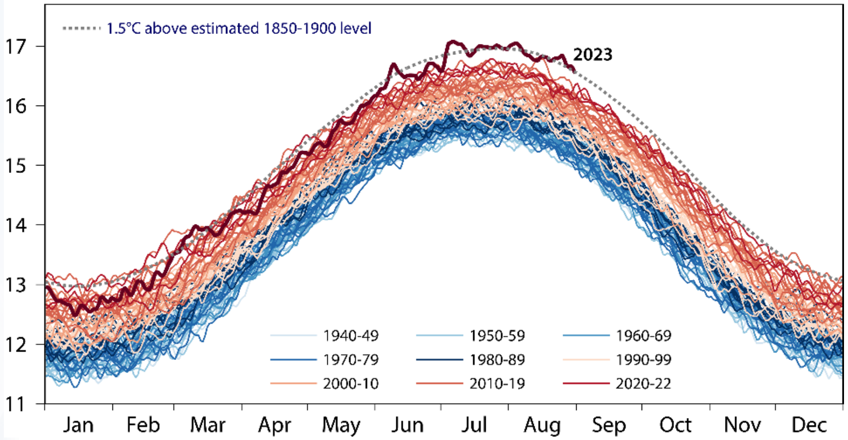
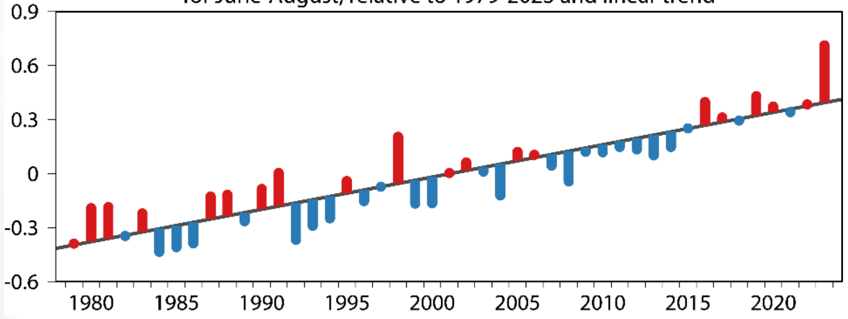
Daily global-average surface air temperature (°C) 1940-2023



Global-mean surface air temperature anomalies (°C)
for June-August, relative to 1979-2023 and linear trend



Variability of daily values is largest in boreal winter

Warming trend is a little larger then

2023 is first year with boreal summer values around 1.5°C higher than the (rather uncertain) 1850-1900 reference

Linear trend is 0.18°C/decade

Deviation from linear trend is larger for June-August 2023 than for any other boreal summer in the years from 1979

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Daily trends and exceptional values in 2023

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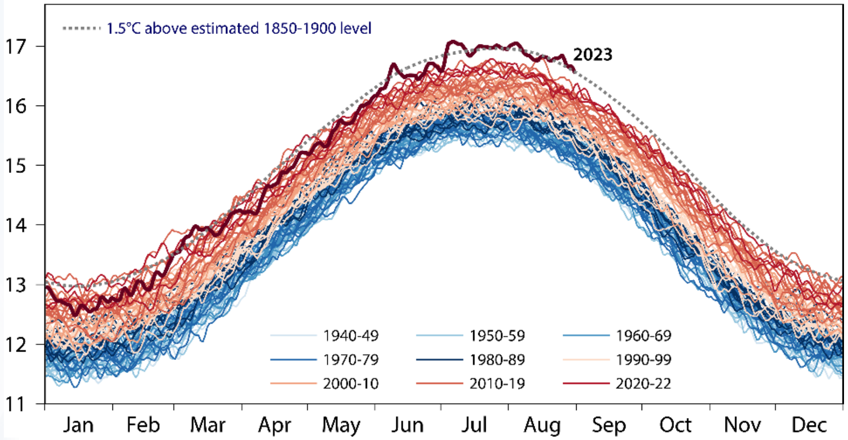
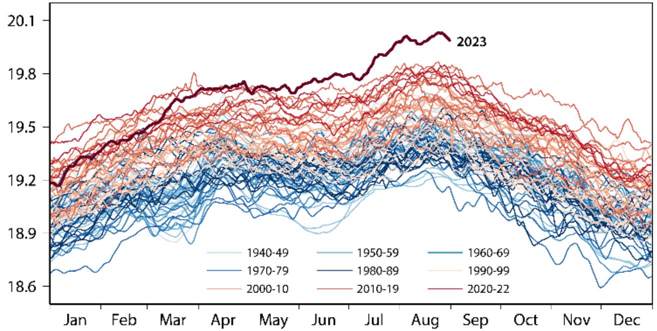


Daily global-average sea-surface temperature (°C) 1940-2023



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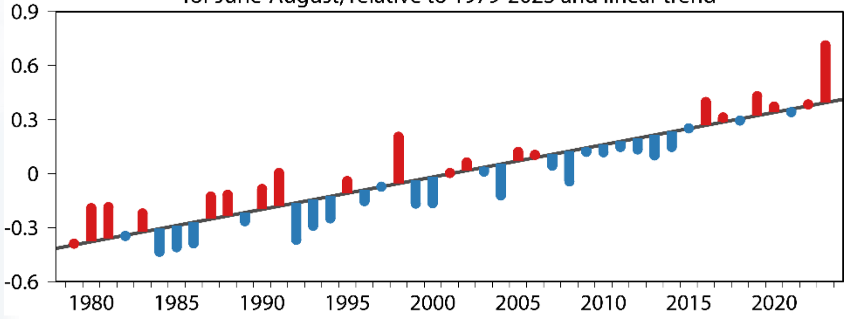
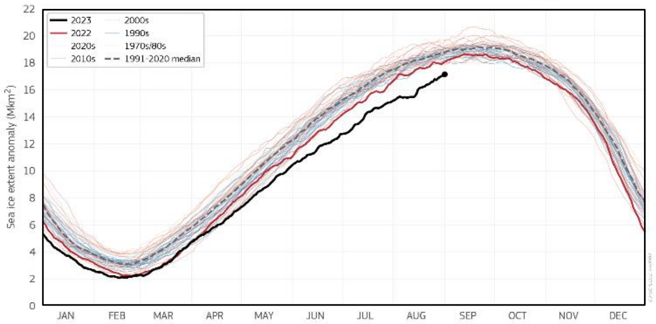


DAILY ANTARCTIC SEA ICE EXTENT

EUMETSAT OSI SAF

Data: OSI SAF Sea Ice Index v2.2 • Last data: 01 Sep 2023 • Credit: C3S/ECMWF/EUMETSAT



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ERA5 daily temperatures

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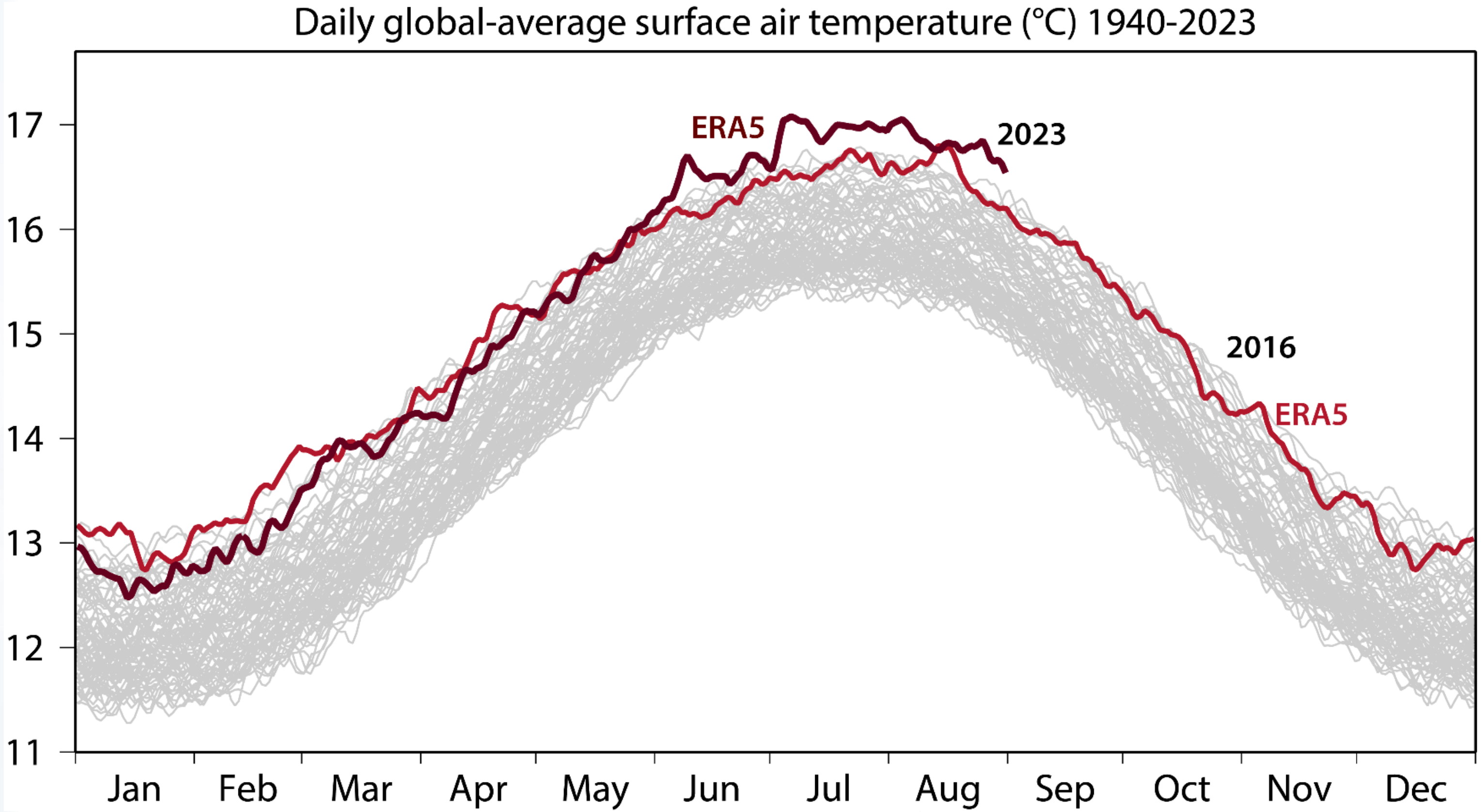

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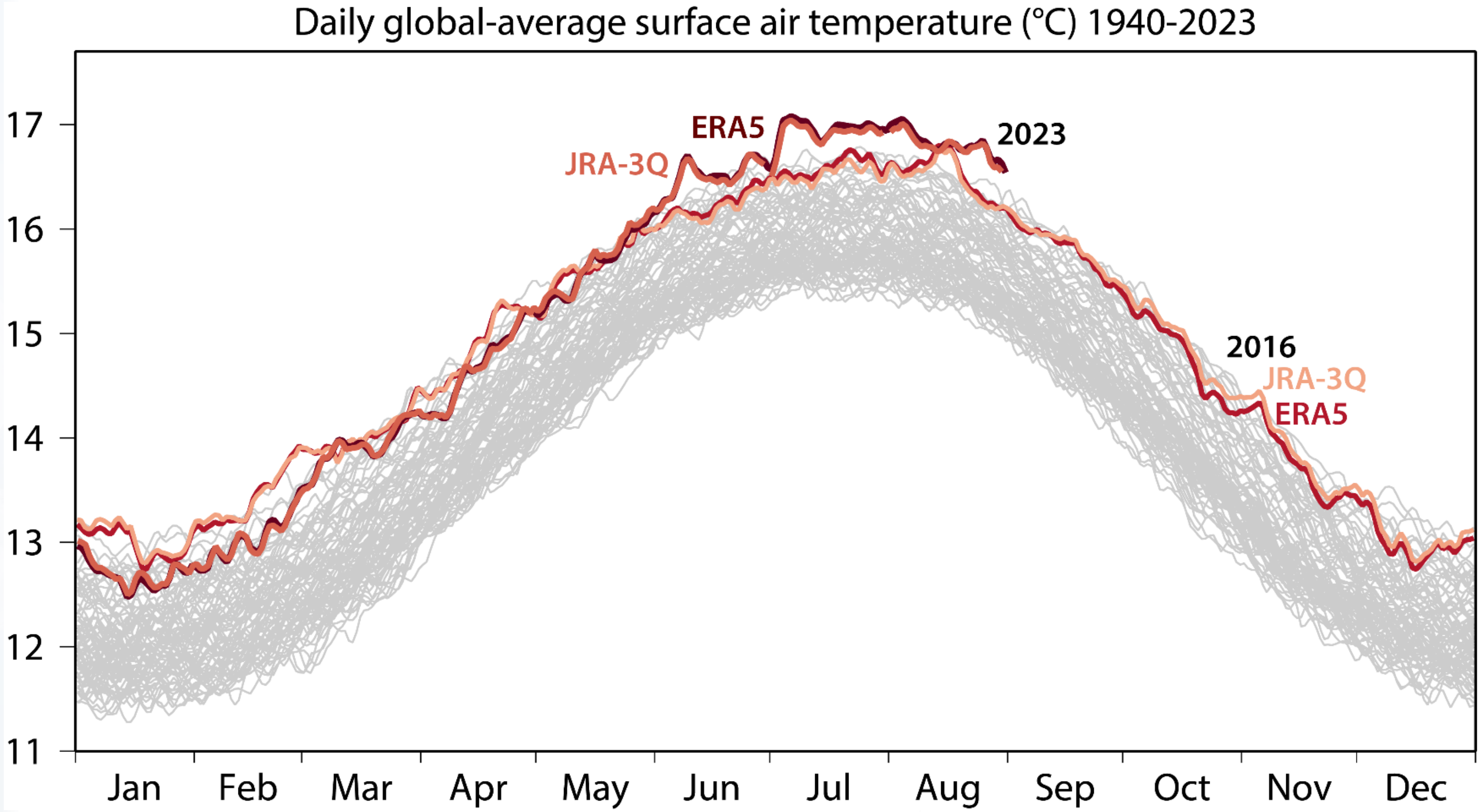
ERA5 and JRA-3Q daily temperatures



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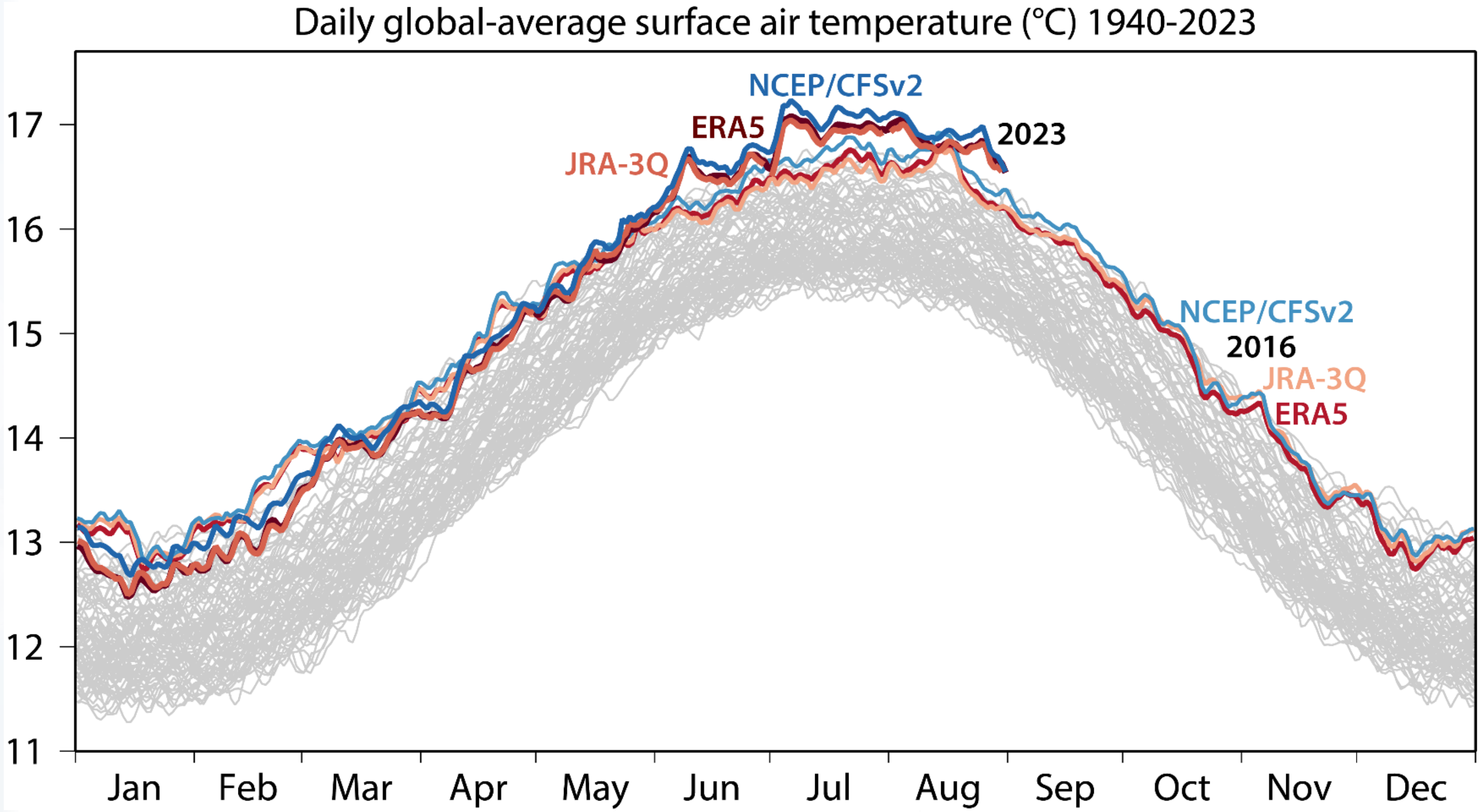
ERA5, JRA-3Q and NCEP daily temperatures



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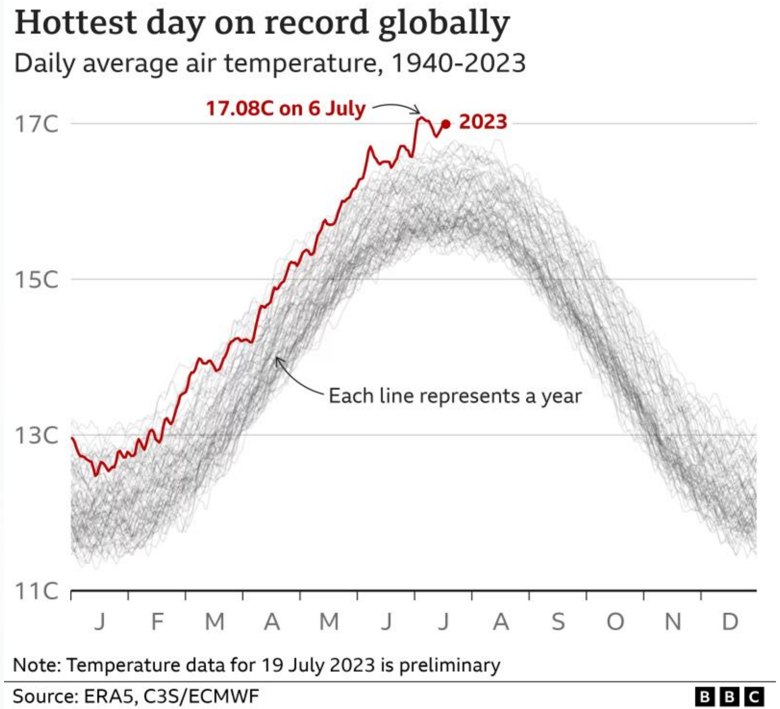
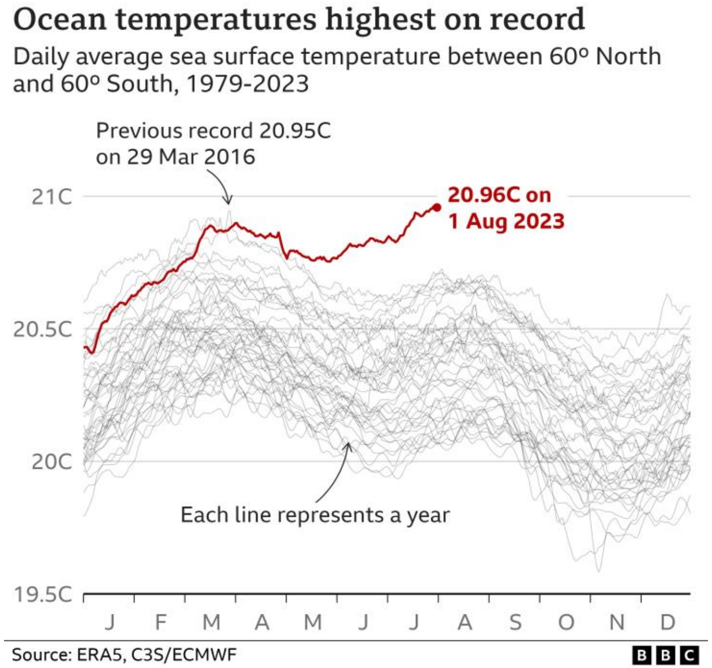
One digit or two after the decimal point?





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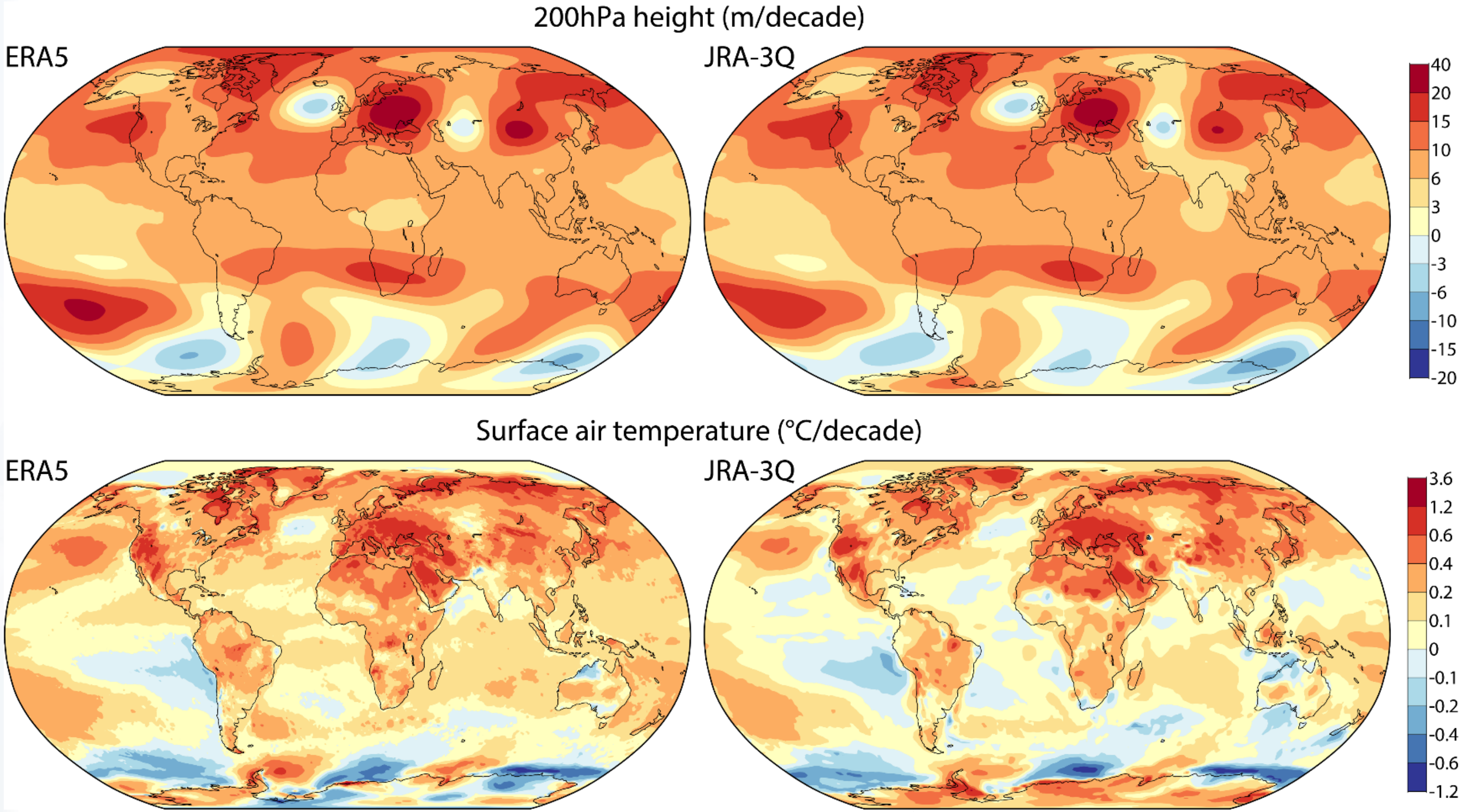
Linear trends for June-August, 1979-2022



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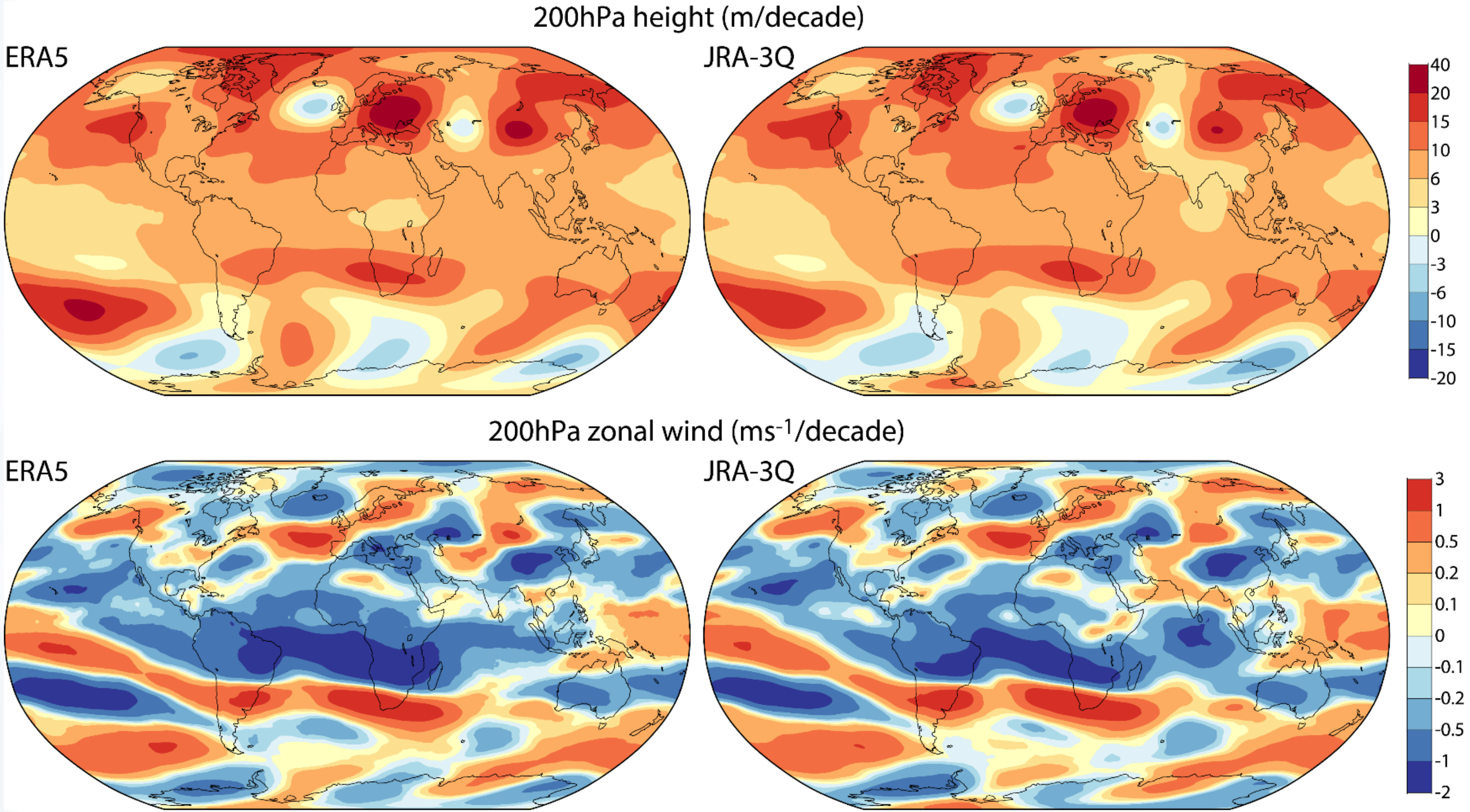

Trends and obs fits, 200hPa tropical easterlies, 1979-2022

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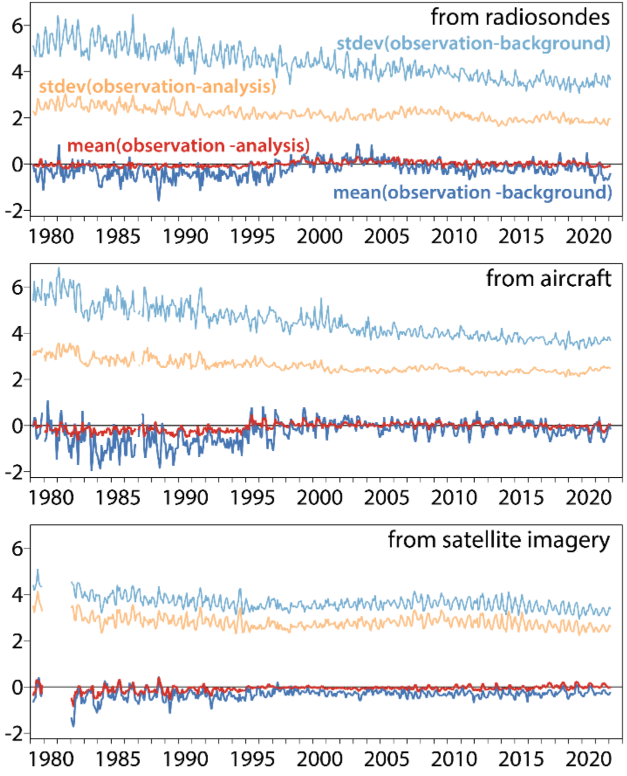
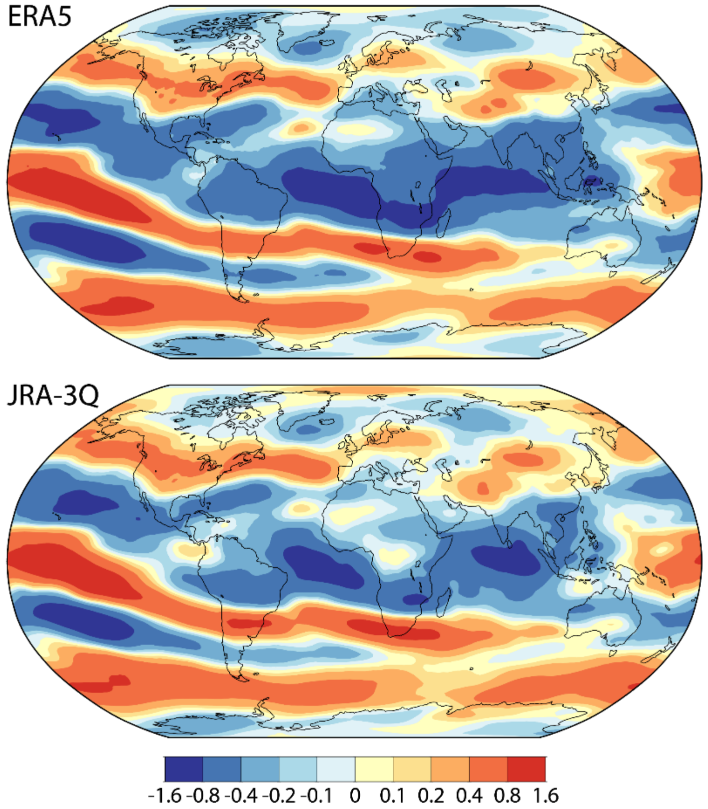
ERA5 fits to zonal wind (ms^{-1}) observations
(175-225hPa, 10°S-10°N, 90°W-150°E)



200hPa zonal wind (ms^{-1}/decade)



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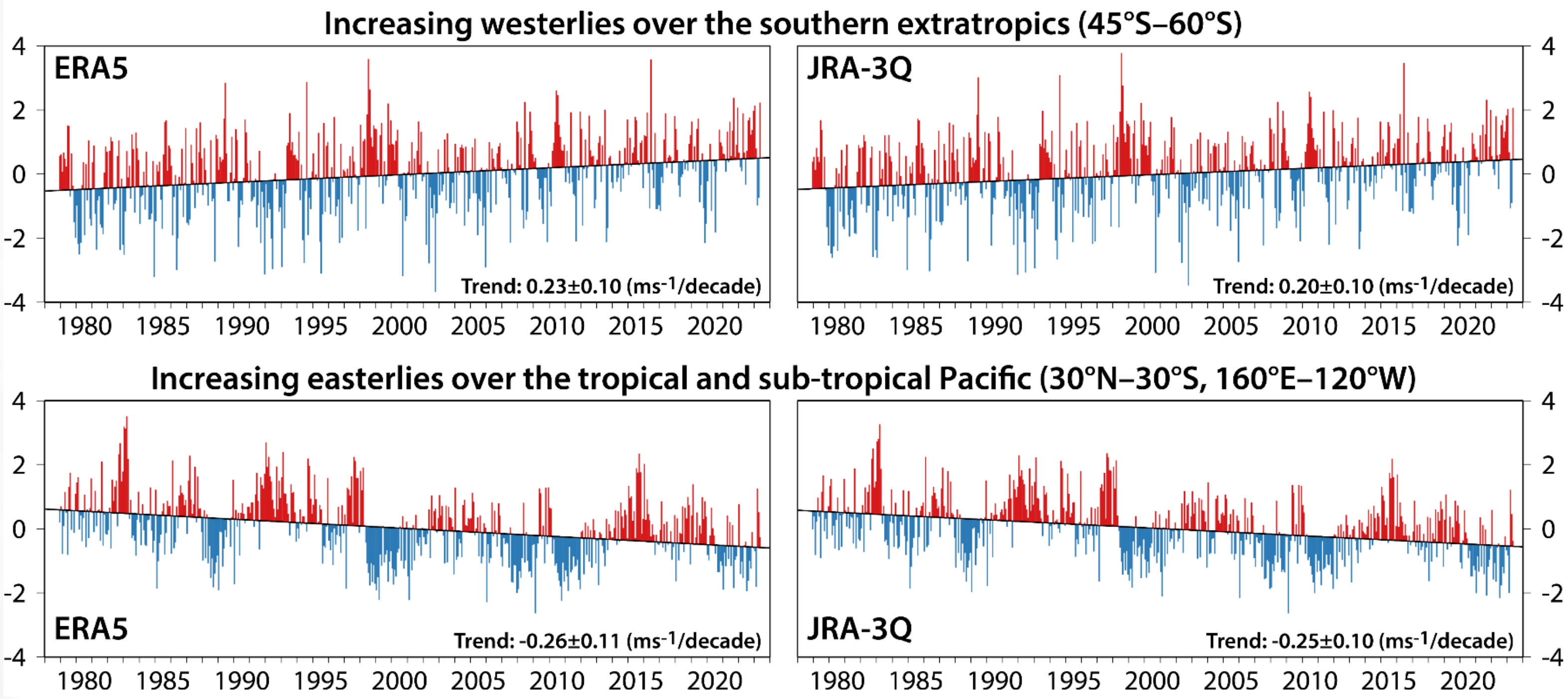
Trends in monthly-mean 850hPa zonal wind anomaly (ms^{-1})



Linear trends are shown with 95% confidence levels

Mean precipitation rates from ERA5, JRA-3Q and GPCC

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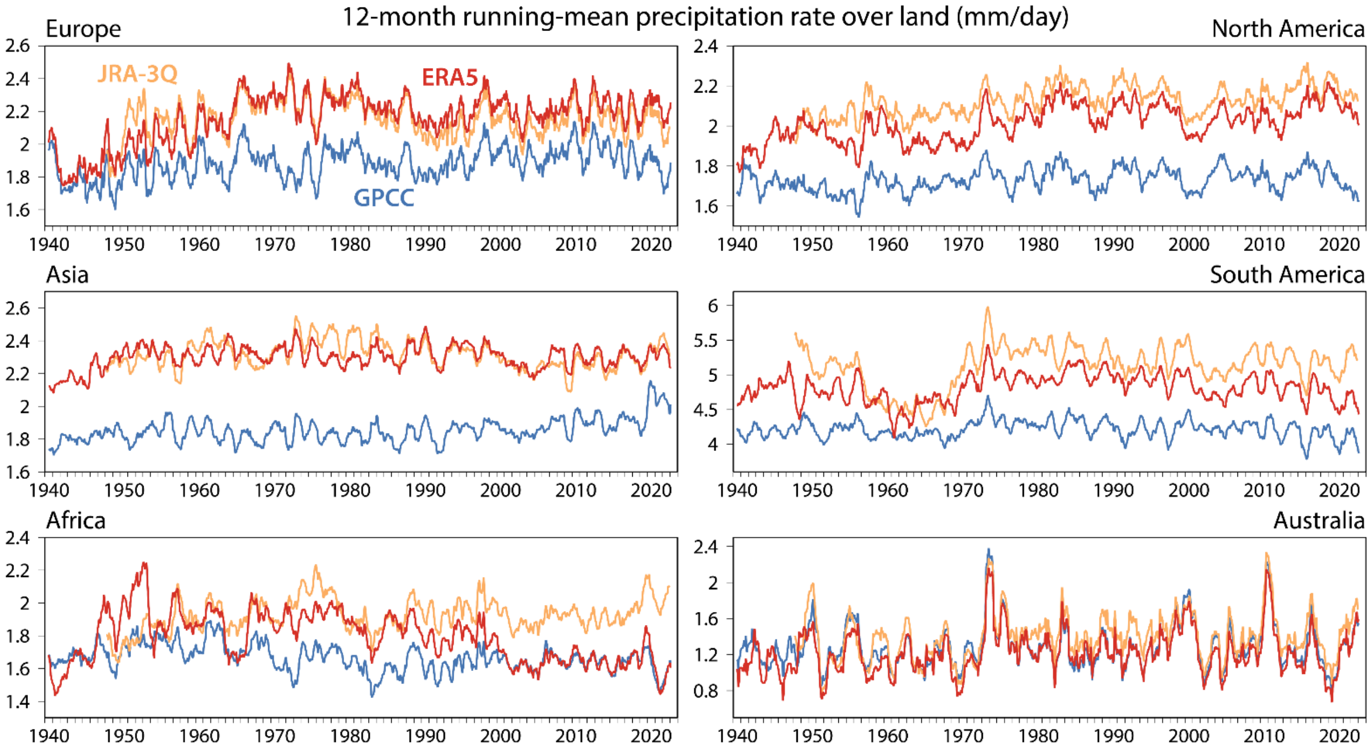

Short-term variability over land is mostly reasonable; longer-term variability is generally poor

Values over sea still have considerable room for improvement, despite some progress

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Concluding remarks

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The suitability of newer generations of reanalysis for documenting climatic variability and trends is now quite well established, even if not accepted by all

Performance is quite reasonable for atmospheric temperature, circulation and some aspects of the hydrological cycle

Reanalysis data must nevertheless be used with care, especially for local applications

Comparisons of contemporary reanalyses with each other and with their assimilated observations are vital for promoting appropriate use of these reanalyses, and for assessing what is needed for future improvement

The exceptional conditions during the boreal spring and summer 2023 have brought challenges at many levels

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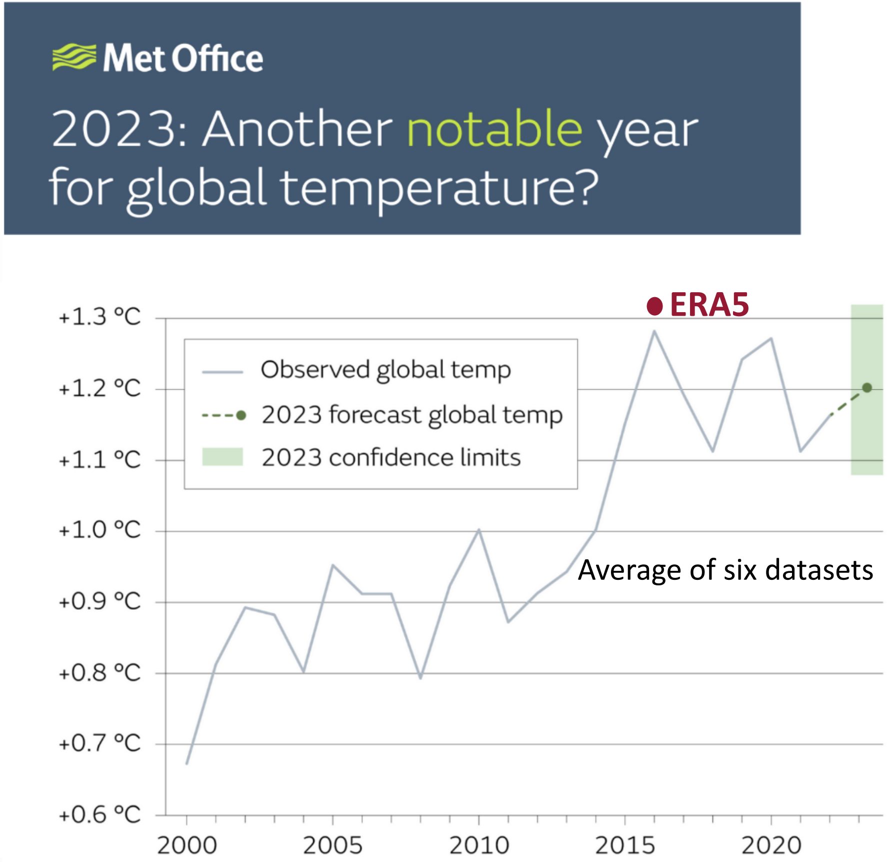
Climate Change

Concluding remarks



Jan-Aug 2023 average is 1.36°C according to ERA5

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