

Progress in reanalysis at ECMWF: The ERA5 replacement for ERA-Interim

Adrian Simmons

Former Head of Data Division

**Consultant to the Copernicus Climate Change Service
European Centre for Medium-Range Weather Forecasts**

Acknowledgments

From the Copernicus Climate Change Service team:

Paul Berrisford, Gionata Biavati,
Dick Dee, Hans Hersbach,
András Horányi, Joaquin
Munoz-Sabater, Raluca Radu,
Iryna Rozum, Cornel Soci
and Jean-Noël Thépaut

Other contributors to ERA5:

Rossana Dragani, Shoji Hirahara,
Dinand Schepers

and many other colleagues



Enterprise Centre, University of Reading



ECMWF HQ

Global atmospheric reanalyses from ECMWF, JMA, NASA and NOAA

ECMWF and GFDL analysed 1979 data for the Global Weather Experiment

The first multi-year reanalyses were produced in the early to mid 1990s

⊖ ERA-15 (1979 - 93), NASA/DAO (1980 - 93) and NCEP/NCAR (1948 - ...)

A second round of production followed

- ERA-40 (1958 - 2001), JRA-25 (1979 - 2014) and NCEP/DOE (1979 - ...)

And a third

- ERA-Interim (1979 - ...), JRA-55 (1958 - ...), NASA/MERRA (1979 - 2016) and NOAA/CFSR (1979 - 2011; extended to present with CFSv2 system)

A fourth round has begun

- MERRA-2 (1979 - ...) is now up-to-date and continued close to real time
- ERA5 has entered production, under the auspices of Copernicus/ECMWF
- JRA-3Q is planned to enter production in Japanese Fiscal Year 2018

ECMWF reanalyses: Towards an Earth System reanalysis

Atmosphere/land

1979 - 1981
FGGE

1994 - 1996
ERA-15

2001 - 2003
ERA-40

2006 - ...
ERA-Interim

2016 - ...
ERA5

including ocean waves

Ocean

2006
ORAS3

2010 - ...
ORAS4

2016 - ...
ORAS5

including sea ice

Centennial

2013 - 2015
ERA-20CM/20C

2016
CERA-20C

Enhanced land

2012
ERA-Int/Land

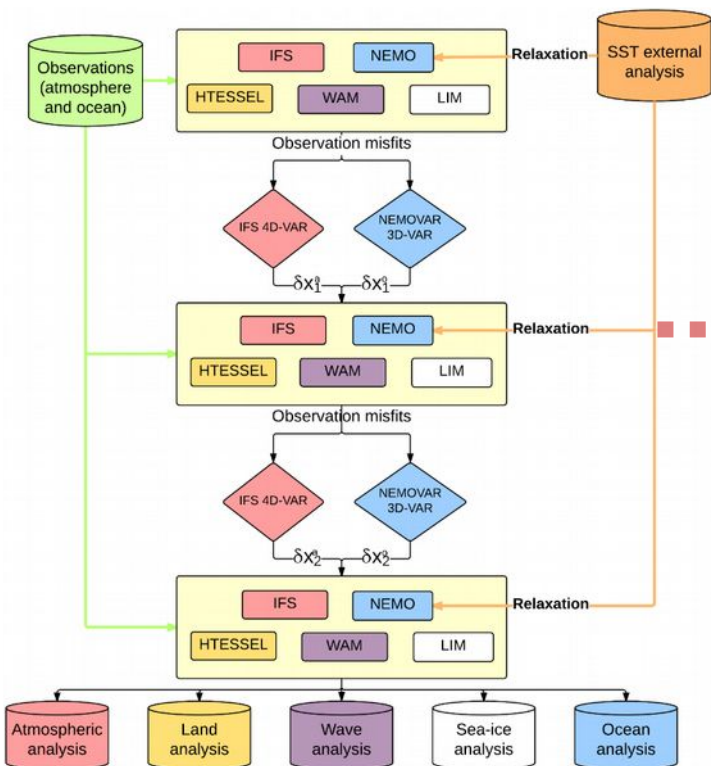
2014
ERA-20C/Land

Atmospheric composition

2008 - 2009
GEMS

2010 - 2011
MACC

2017 - ...
CAMS



Next step for global atmospheric reanalysis: ERA5

Replacement for ERA-Interim, in early stage of production, using:

- ⊖ a 2016 (rather than a 2006) version of the ECMWF data assimilation system
- ⊖ ~30km (rather than ~80km) horizontal resolution and 137 (rather than 60) levels
- ⊖ new analyses of sea-surface temperature and sea-ice concentration
- ⊖ various new and reprocessed satellite data records

providing:

- ⊖ hourly output fields
- ⊖ an observational feedback archive
- ⊖ uncertainty estimates from a 10-member ensemble data assimilation
- ⊖ a land-surface analysis downscaled to ~9km horizontal resolution

from 1979 onwards, with:

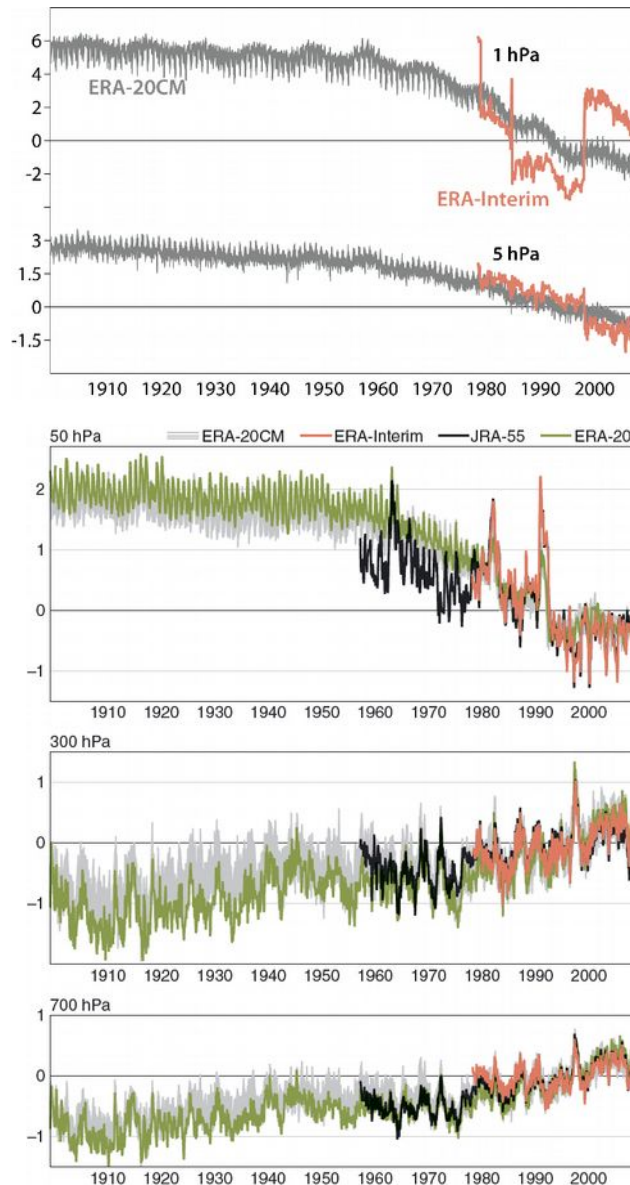
- ⊖ prompt operational extension forward in time
- ⊖ a subsequent extension to cover the period from around 1950

ERA5 model includes CMIP5 forcings

Forcings in the radiation scheme of the assimilating ERA5 model follow CMIP5 recommendations for:

- ⊖ greenhouse gases
- ⊖ solar input
- ⊖ ozone
- ⊖ aerosols

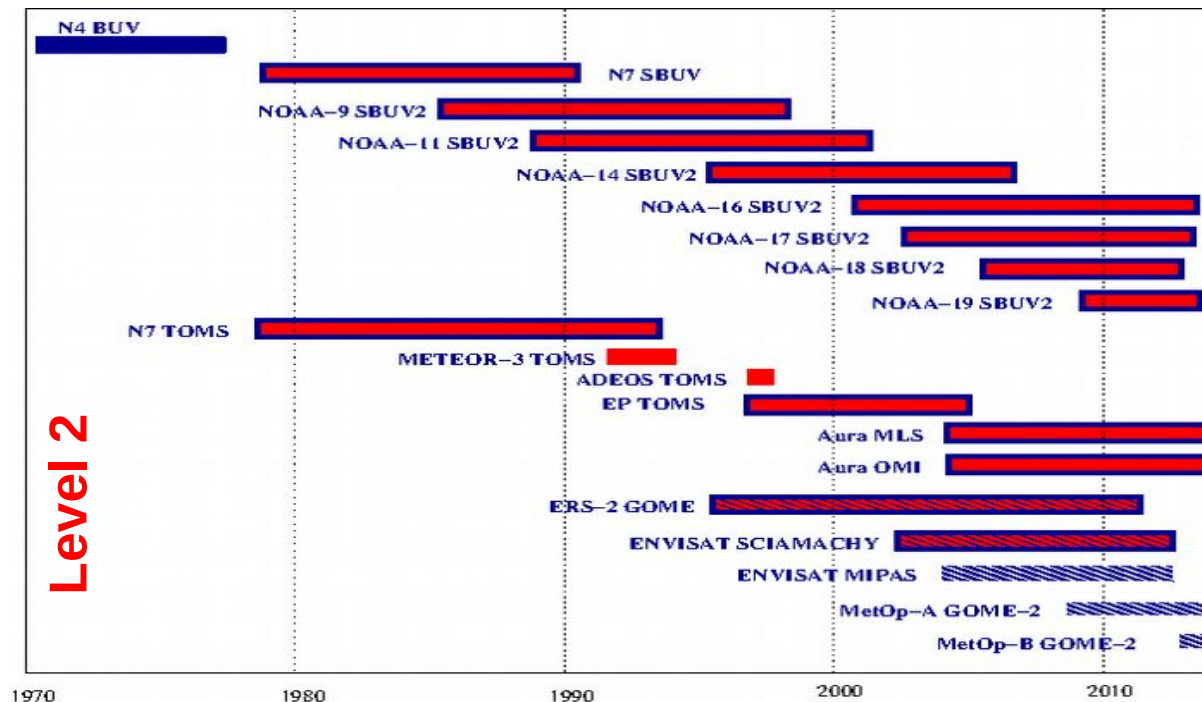
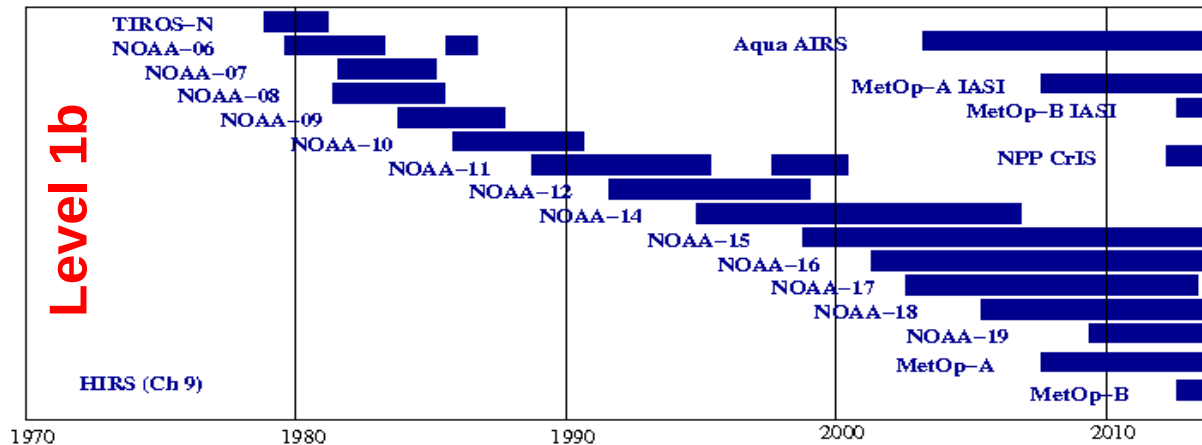
as used in ERA-20CM model simulations and centennial ERA-20C and CERA-20C reanalyses



Discontinuities near the stratopause should be reduced in ERA5, but analysis in this region remains challenging

Using the CMIP5 forcing and prescribing SST ensures that the underlying model (as in ERA-20CM) already captures observed trends and low-frequency variability reasonably well; data assimilation should then correct for the remaining deficiencies

ERA5 uses additional data streams, and reprocessed versions of data used in ERA-Interim, shown here for ozone



ERA5 also applies variational bias correction to ozone data

Other improvements to input data

Other newly reprocessed satellite datasets

- ⊖SSM/I and Meteosat radiances
- ⊖Atmospheric Motion Vectors from Meteosat, GMS, GOES, MTSAT and AVHRR
- ⊖soil moisture from ERS 1/2 and ASCAT-A
- ⊖radio occultation data from Metop, COSMIC, CHAMP, GRACE, SAC-C and TERRASAR-x

Newer satellite datasets not used in 2006 system fixed for ERA-Interim

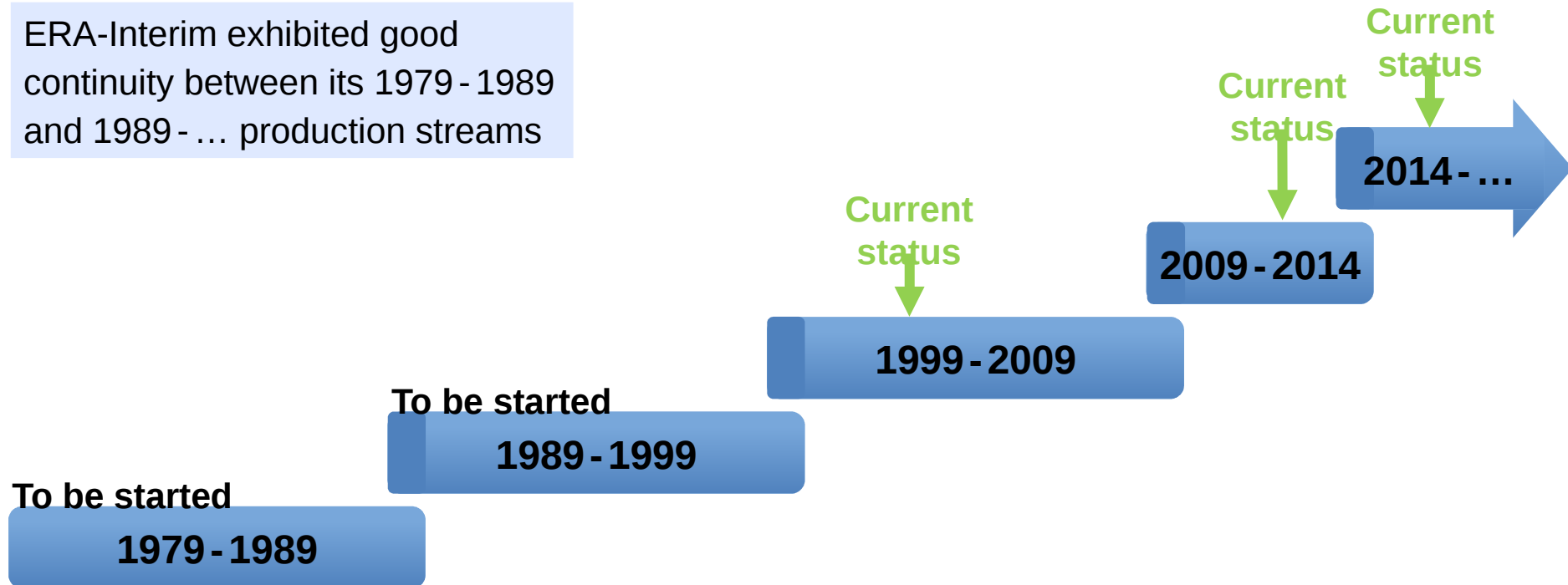
- ⊖ASCAT, ATMS, CrIS, FY-3, IASI and Himawari

Improved usage of data

- ⊖“all-sky” assimilation of microwave imager data
- ⊖upgraded radiative transfer modelling for simulating observations, including variable atmospheric CO₂, and variable CO₂-cell pressures for SSU data
- ⊖bias correction of aircraft data and improved correction of radiosonde biases

ERA5 production streams

ERA-Interim exhibited good continuity between its 1979 - 1989 and 1989 - ... production streams



Test data for January-February 2016 have been released

It is planned to release data from 2010 onwards early in 2017 and to supply data for 2017 and subsequent years in close to real time

Data from 1979 to 2009 are planned for release in 2018

ERA-Interim is difficult to maintain, and production is likely to cease in 2018

Atmospheric reanalysis: for monitoring impacts of changes in forecasting and observing systems

Operational improvement from 1980 to 2000 comes mainly from better forecasting systems

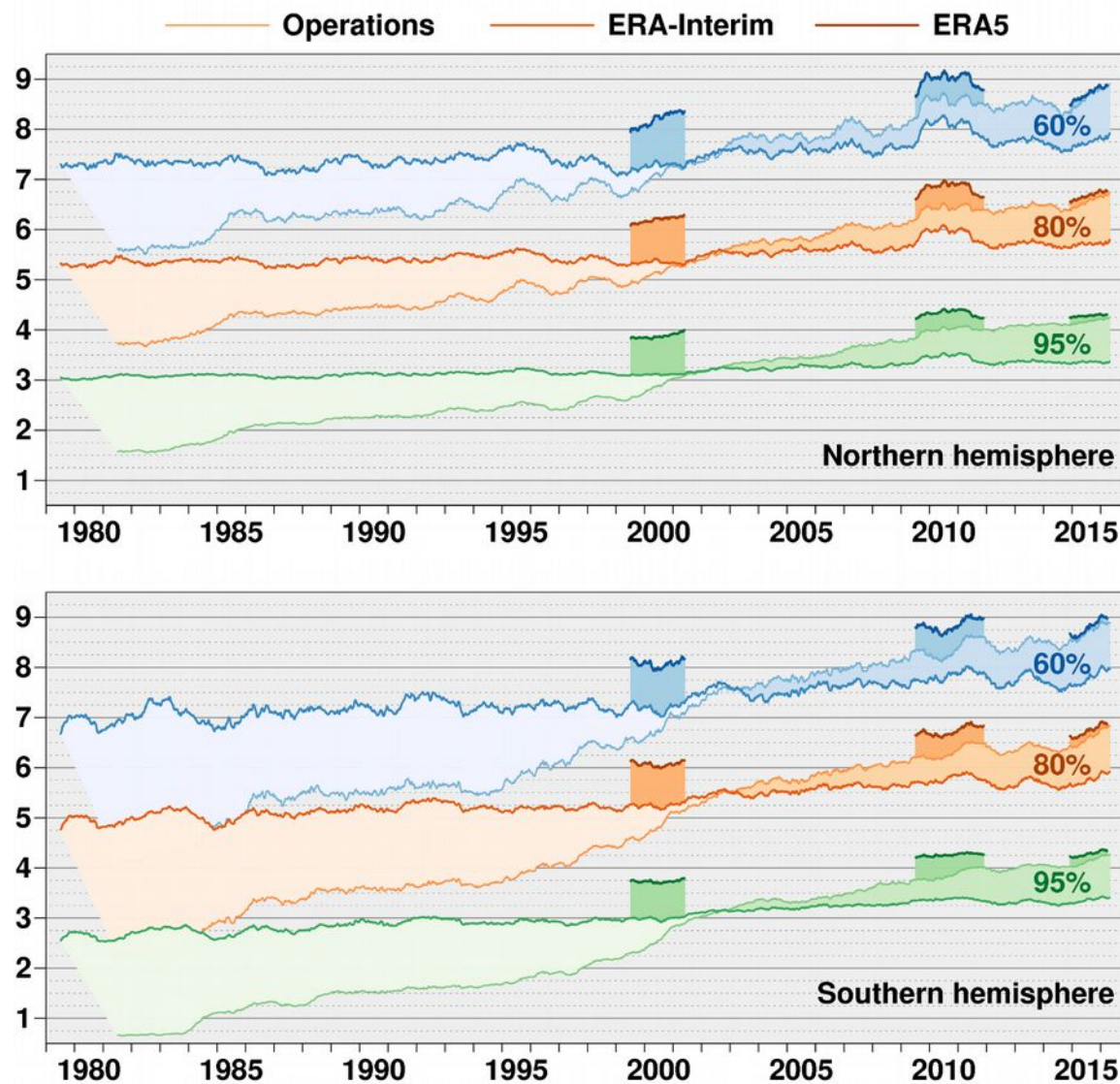
Improvement since 2000 comes from better forecasting systems and better observations

The ERA-Interim system was fixed in 2006 - some newer types of data are not used

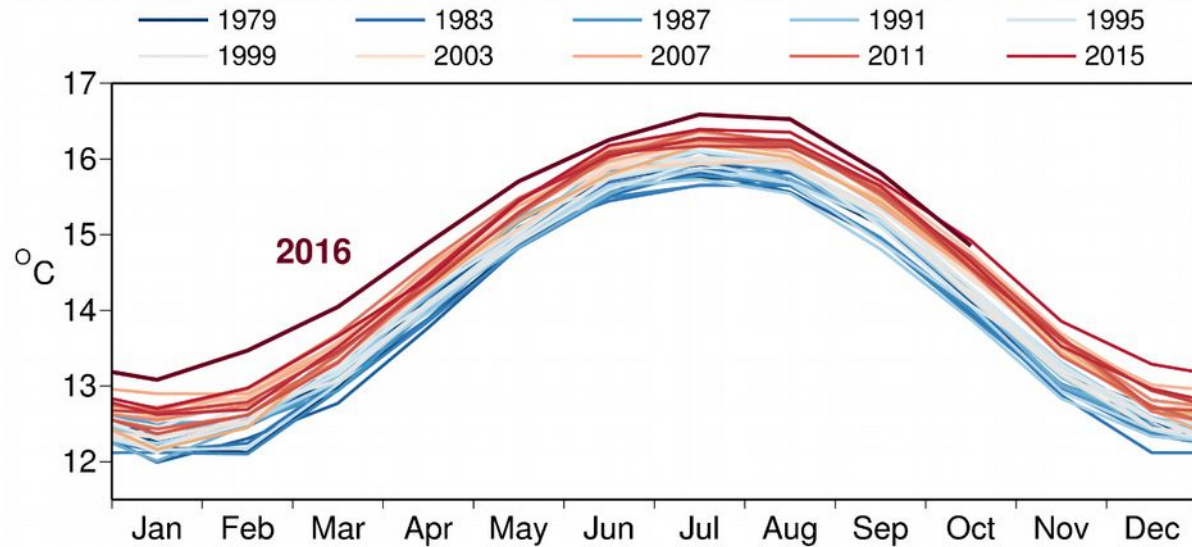
ERA5 uses data an extra six hours into the future, but has lower horizontal resolution than current operations

ERA5's forecasts improve more than ERA-Interim's from 2001 to 2009 - due to better and more extensive use of new satellite data, or a 1999-2001 problem?

Range (days) when 365-day mean 500hPa height AC (%) falls below threshold

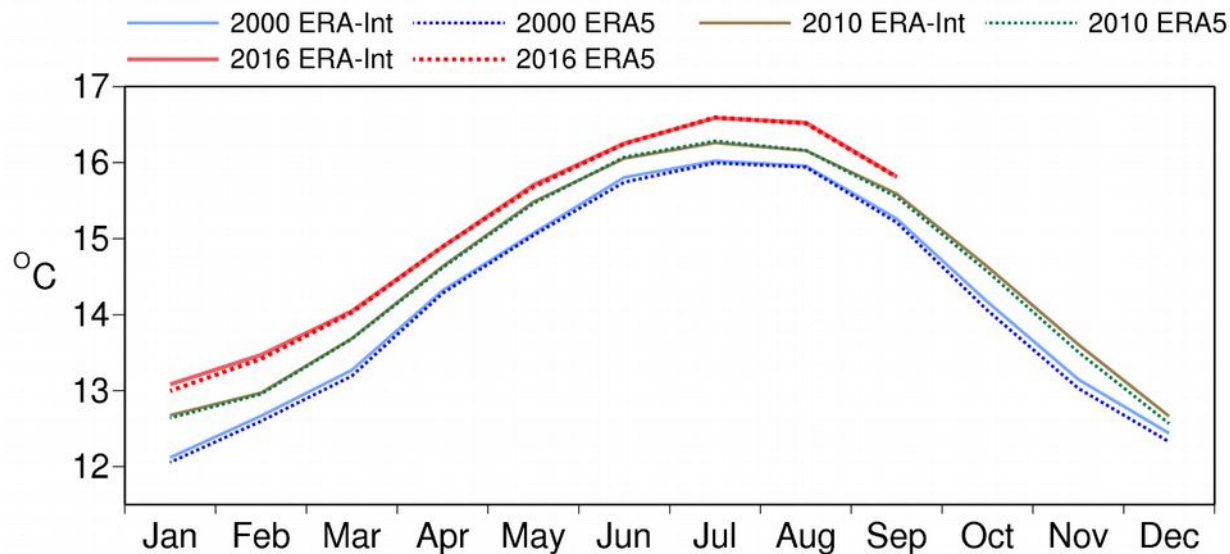


Monthly global-mean surface air temperatures



ERA-Interim shows warming over the period since 1979, and the widely reported exceptional values over the past twelve months

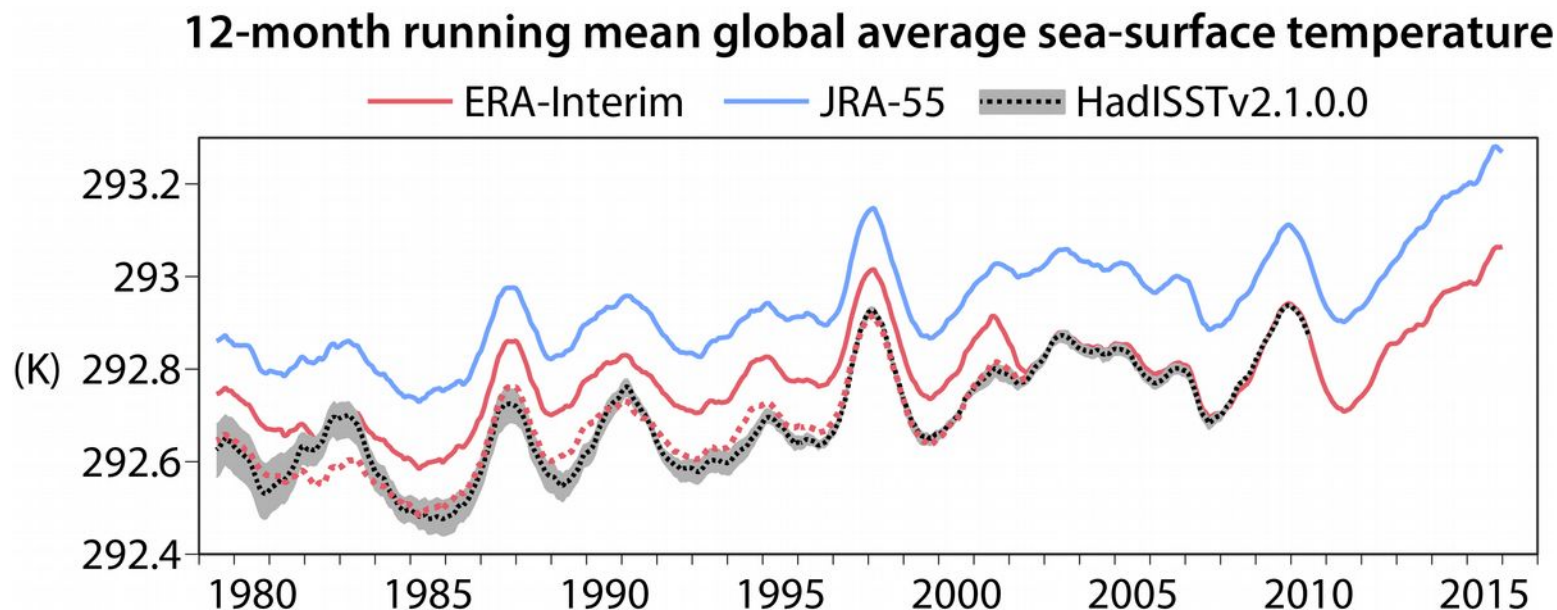
Values are adjusted prior to 2002 to compensate for relatively warm sea surface temperature analyses



ERA5 values obtained to date are in quite good agreement with the adjusted ERA-Interim values

Background values are used over sea for both reanalyses, as analysed surface air temperatures are unreliable there

Sea-surface temperature analyses



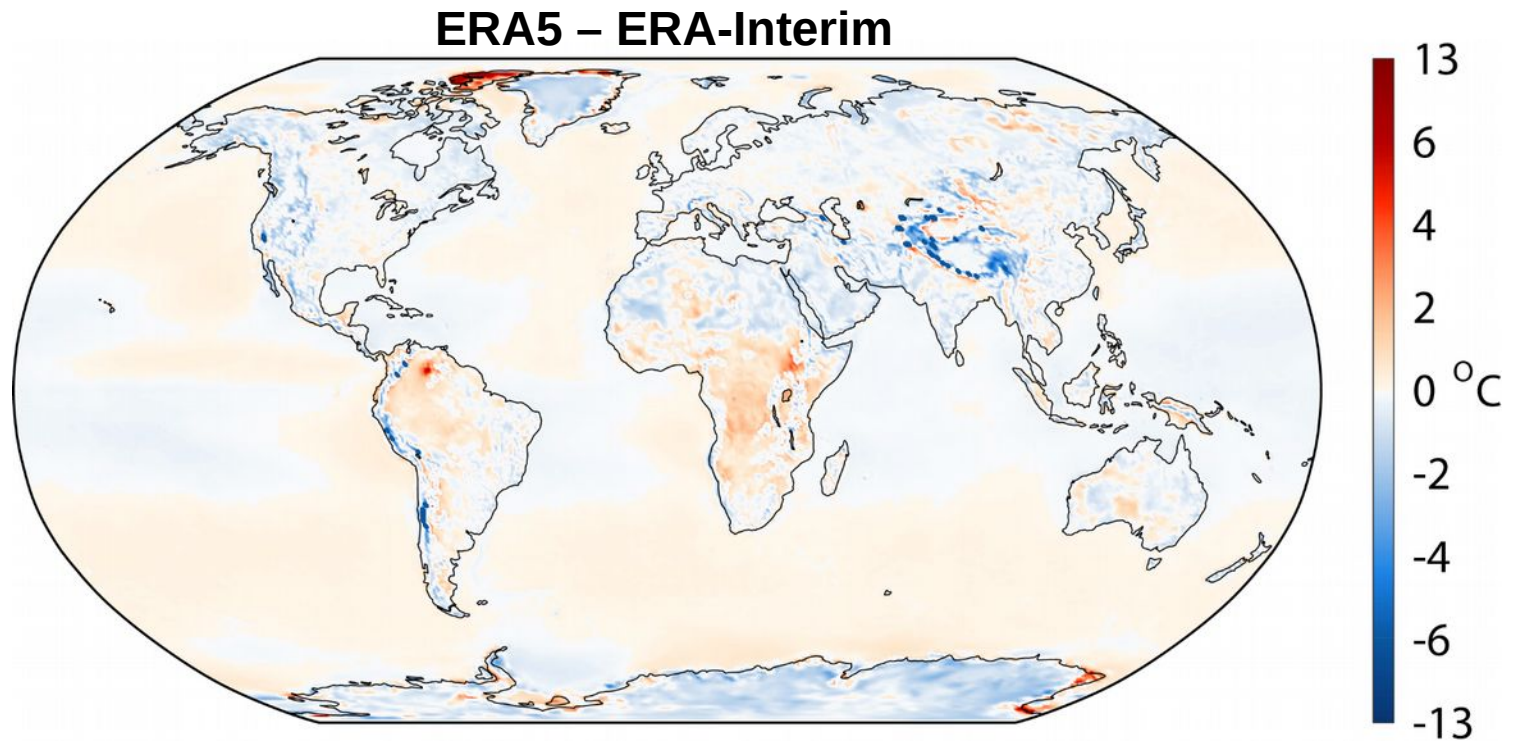
ERA-Interim used several sources of SST analysis.

SSTs were consistently cooler by about 0.1°C from January 2002 onwards relative to other datasets such as JRA-55. Difference did not vary much geographically.

A version of the HadISST2 ensemble (plus OSTIA) is being used in ERA5. The ensemble mean (dotted) and 10-member range (grey) of an earlier version of HadISST2 are shown.

For monitoring global-mean temperature, ERA-Interim SSTs and its closely related surface air (2-metre) temperatures over sea are reduced by 0.1°C prior to January 2002 (red dotted).

Mean difference in surface air temperature for 2010



Background values are used over sea; the 2m temperature analysis is suppressed there

Largest difference is over Ellesmere Island: mean background error (background-observation) at Alert Climate station is -5.8°C for ERA-Interim and -2.0°C for ERA5

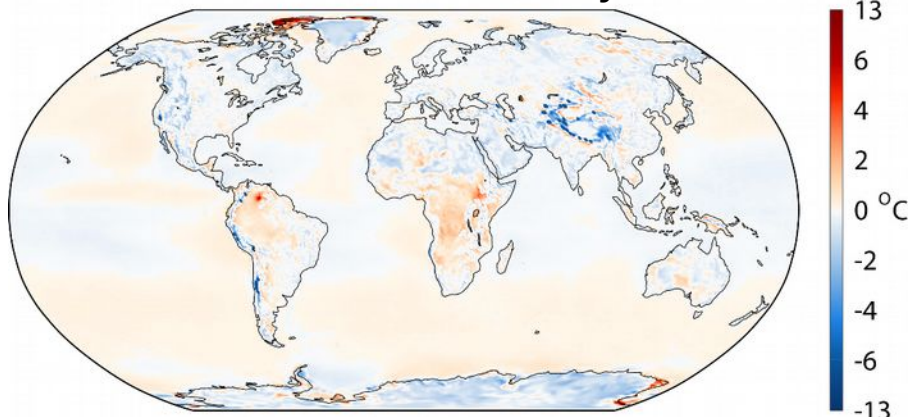
Background error for Longyearbyen, Svalbard, is -5.3°C for ERA-Interim and -1.4°C for ERA5

ERA5 is colder over Antarctic plateau, where ERA-Interim has warm bias (Fréville *et al.*, 2014)

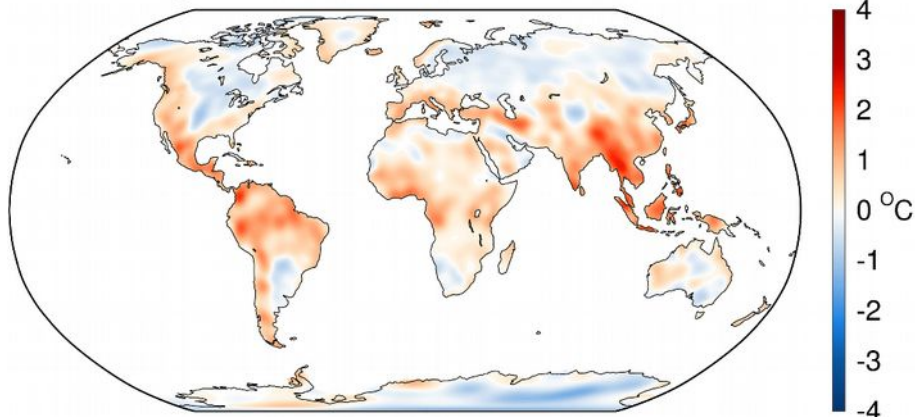
Other differences are still to be investigated

Mean differences and increments of stand-alone analysis of surface air temperature for 2010

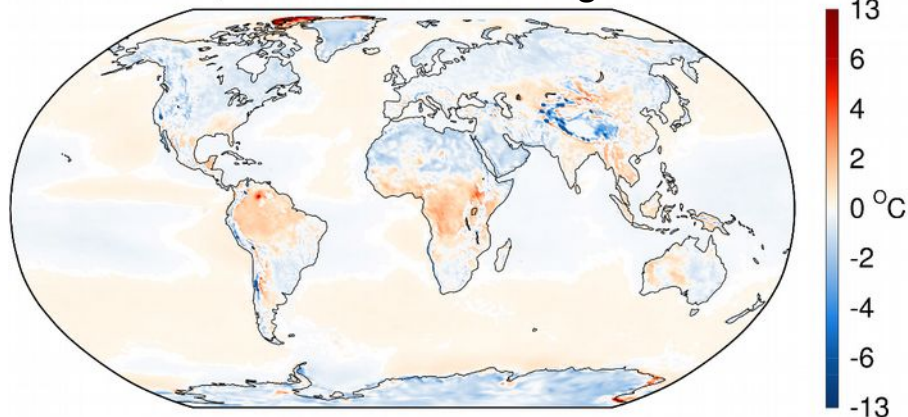
ERA5 – ERA-Interim analysis



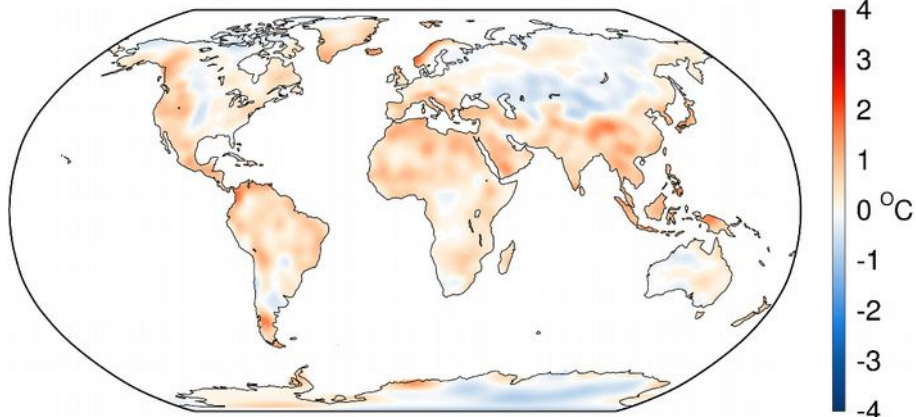
ERA-Interim increment



ERA5 – ERA-Interim background



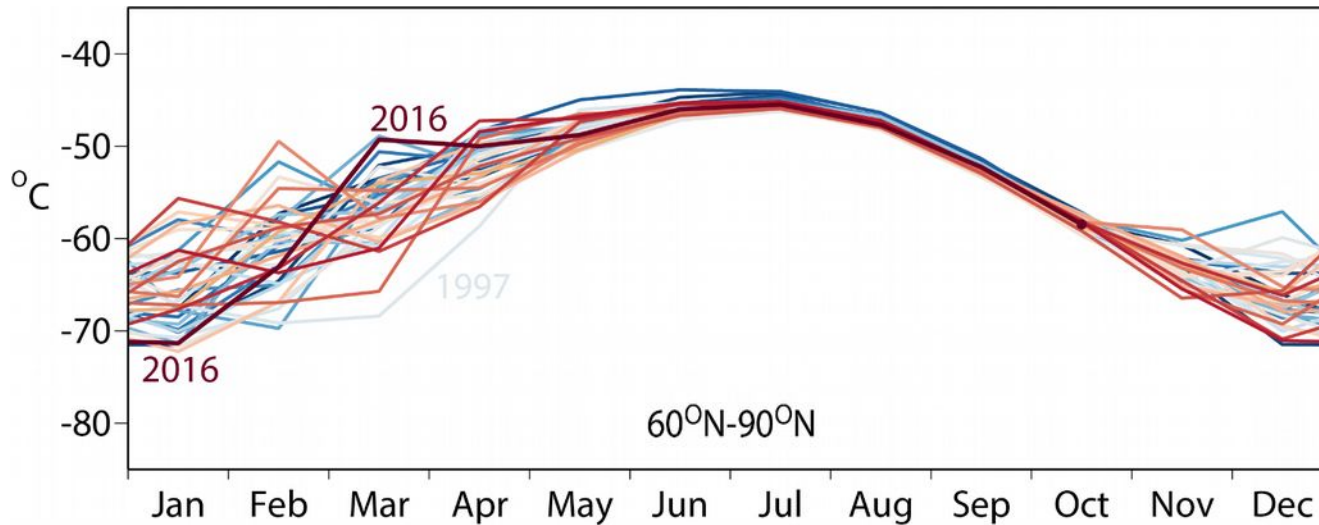
ERA5 increment



Increments (the differences between the analysis and the background) are generally smaller in ERA5

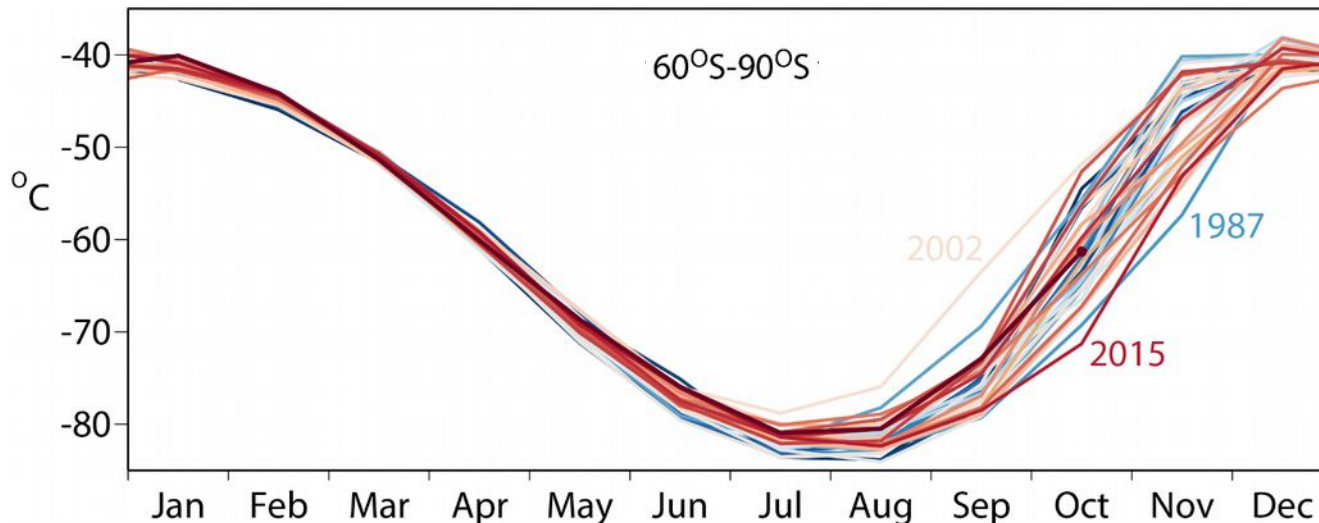
Monthly-mean 50hPa polar temperatures from 1979 to 2016

— 1979 — 1983 — 1987 — 1991 — 1995
— 1999 — 2003 — 2007 — 2011 — 2015



From ERA-Interim

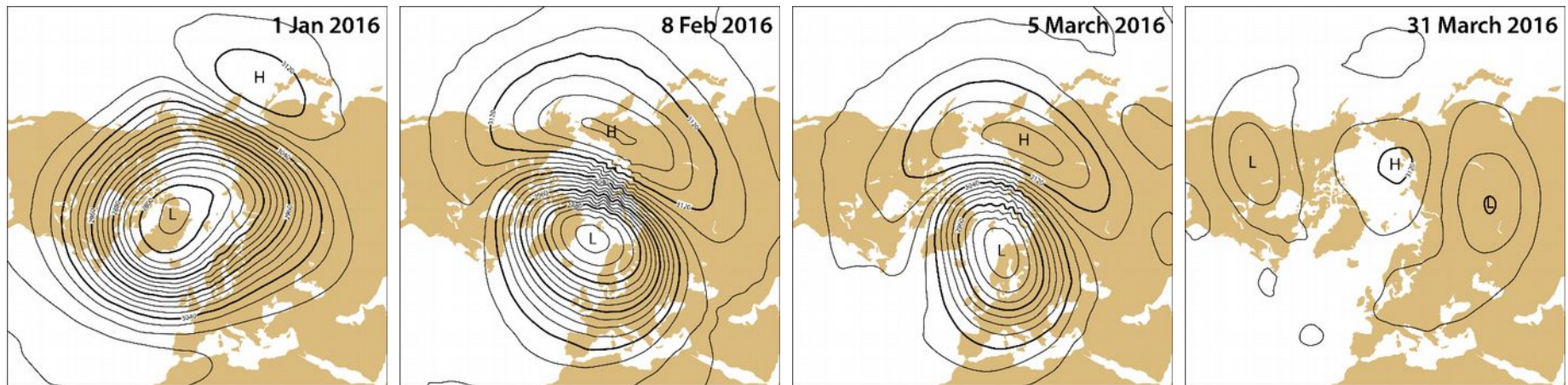
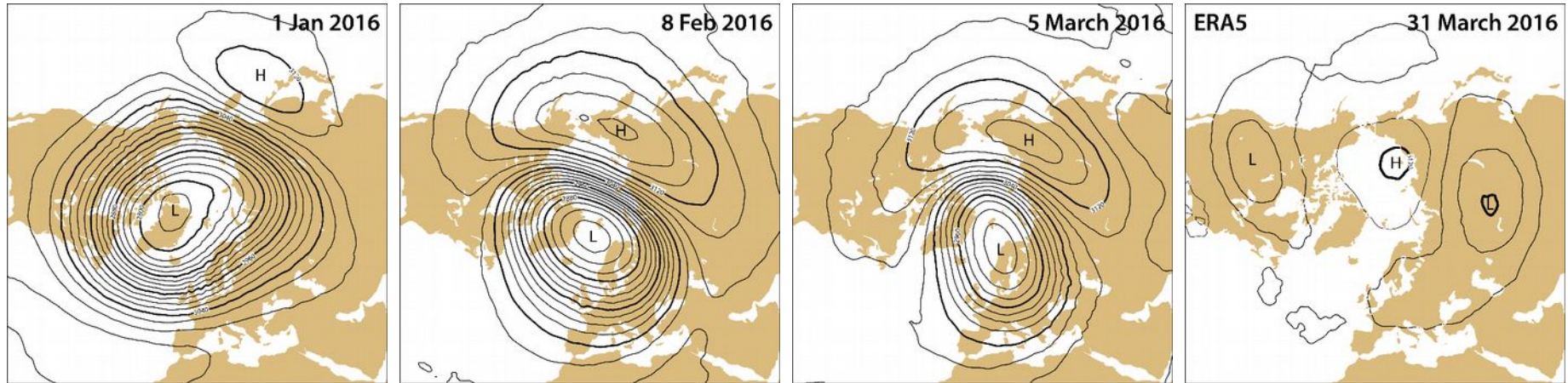
For the Arctic, 2016 is marked by the extent of the shift from a relatively cold January to a relatively warm March



For the Antarctic, October 2015 is the coldest October in this data record

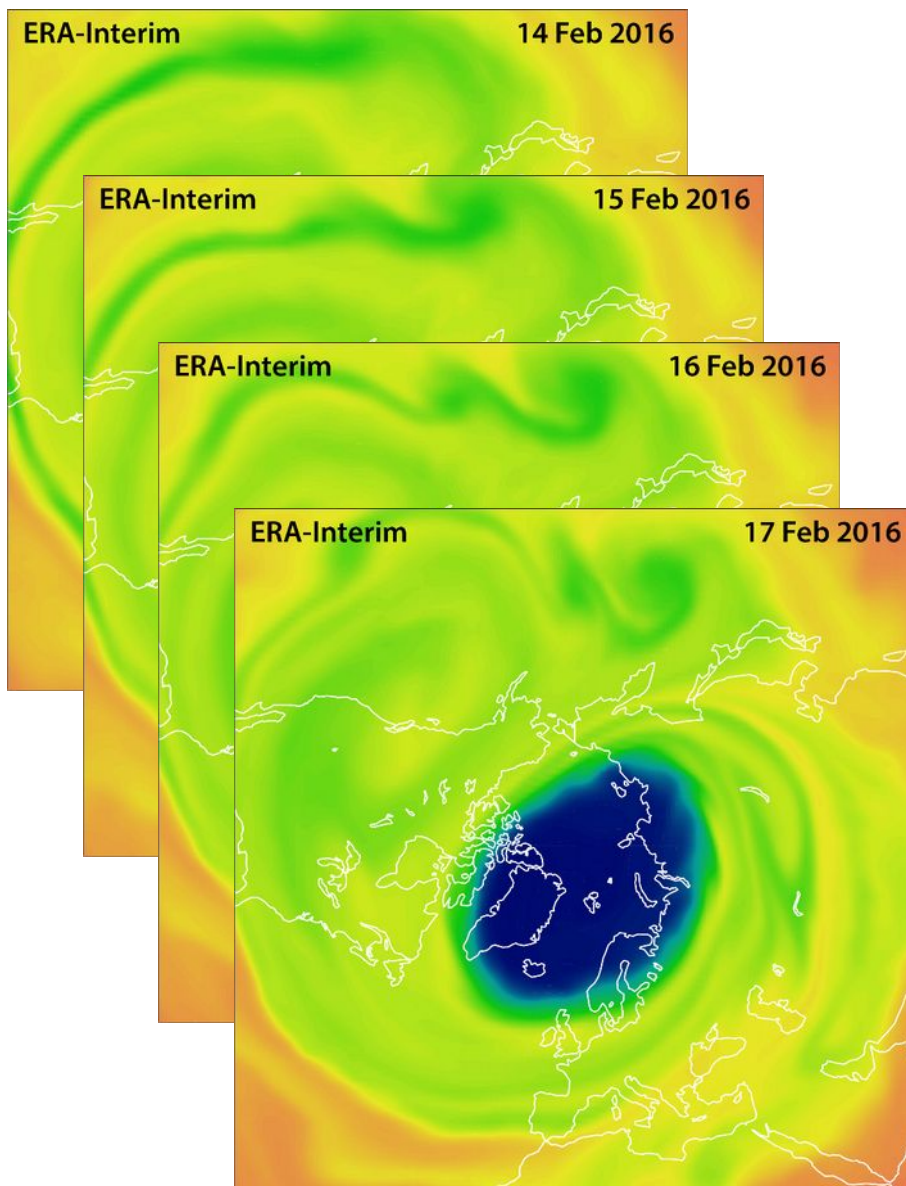
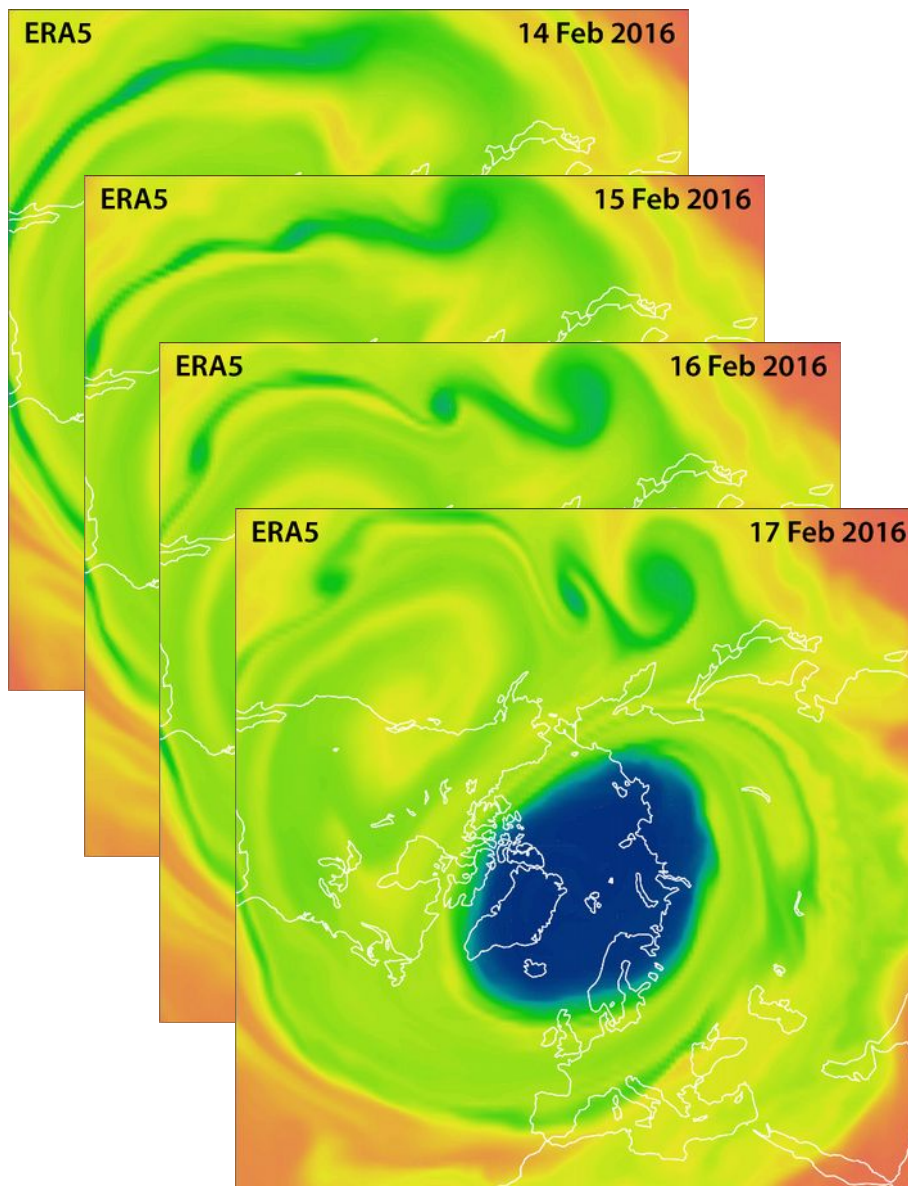
10hPa geopotential height analyses

ERA5

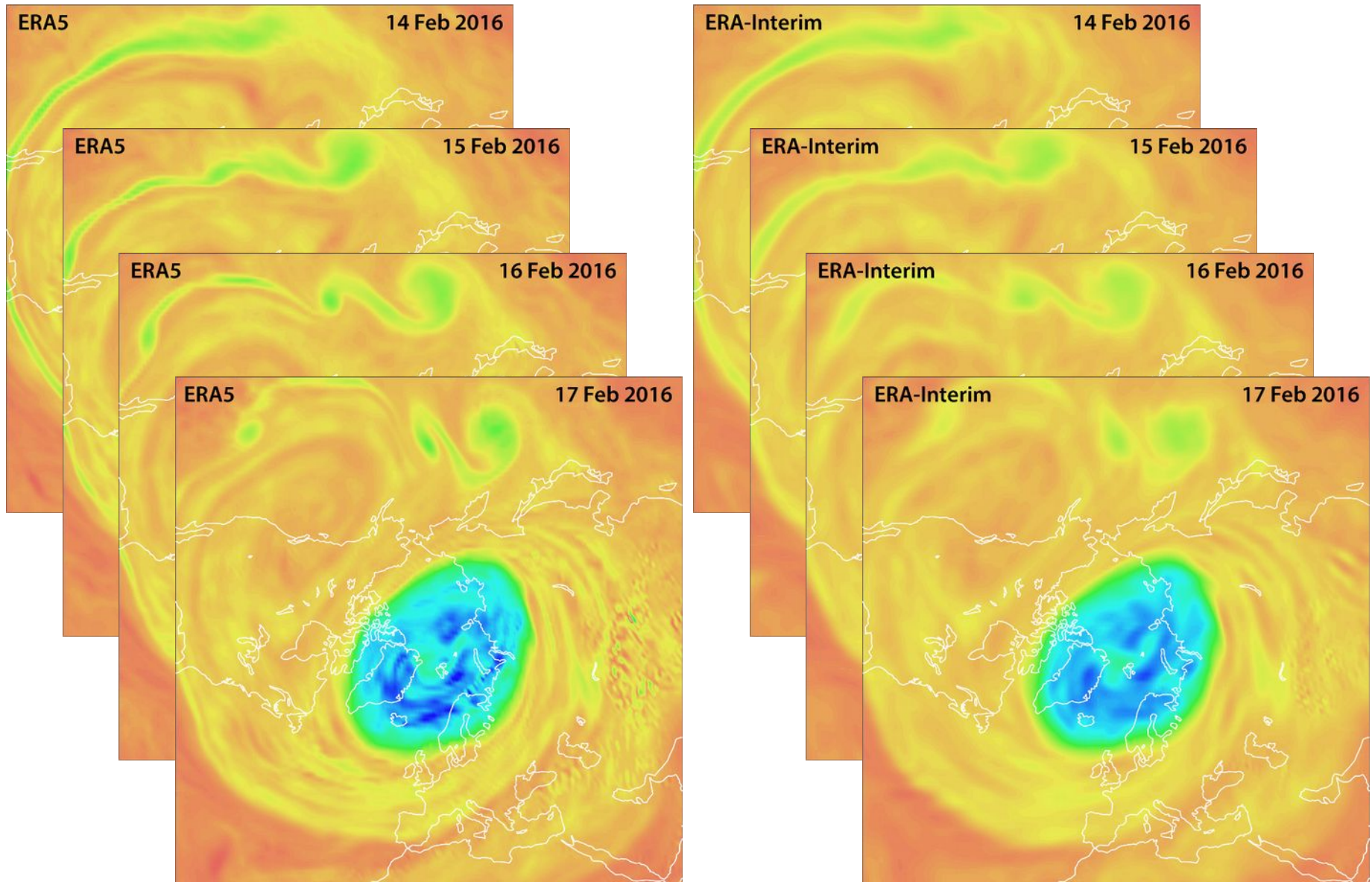


ERA-Interim

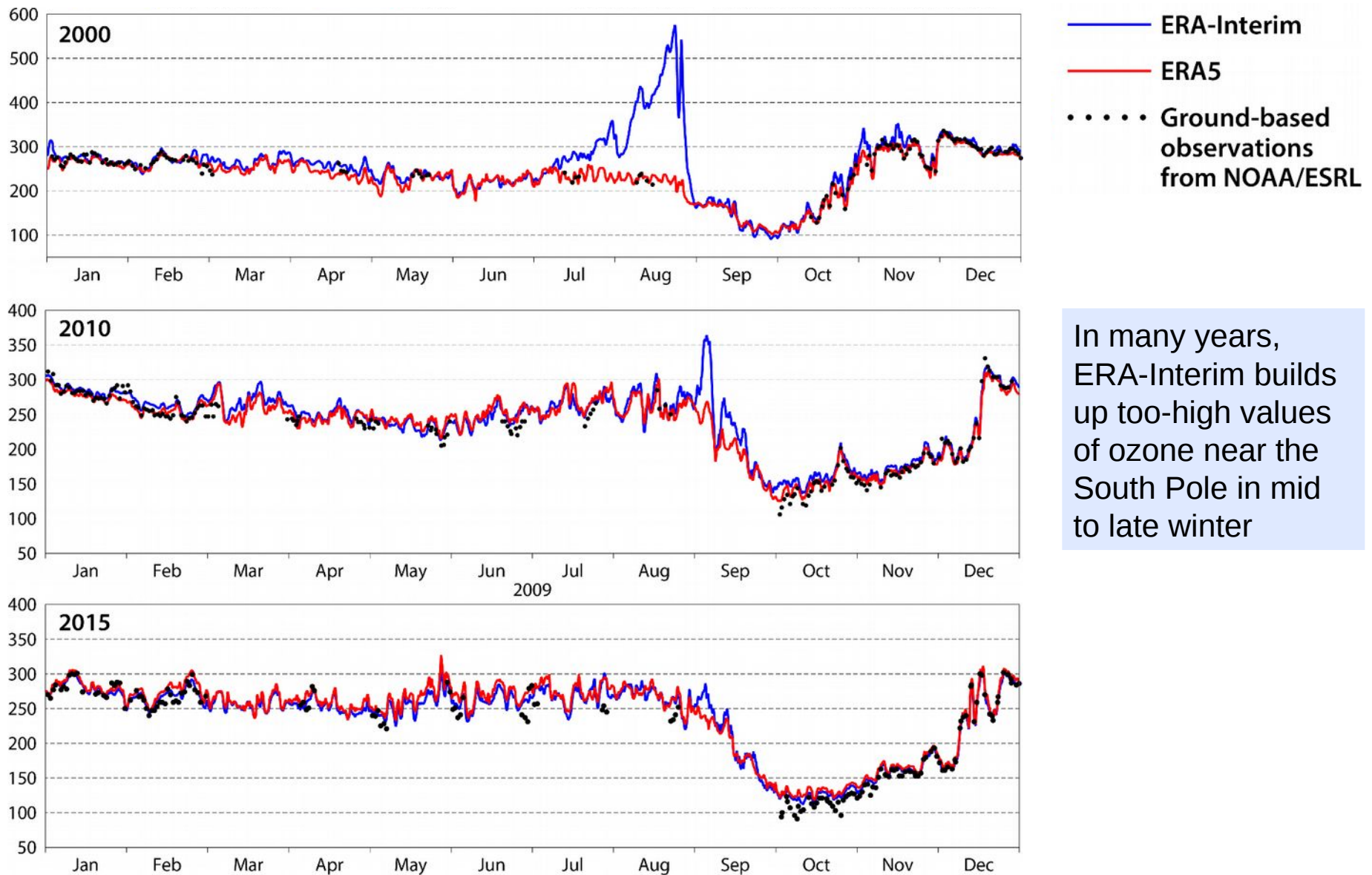
Specific humidity (mg/kg) on 700K isentropic surface



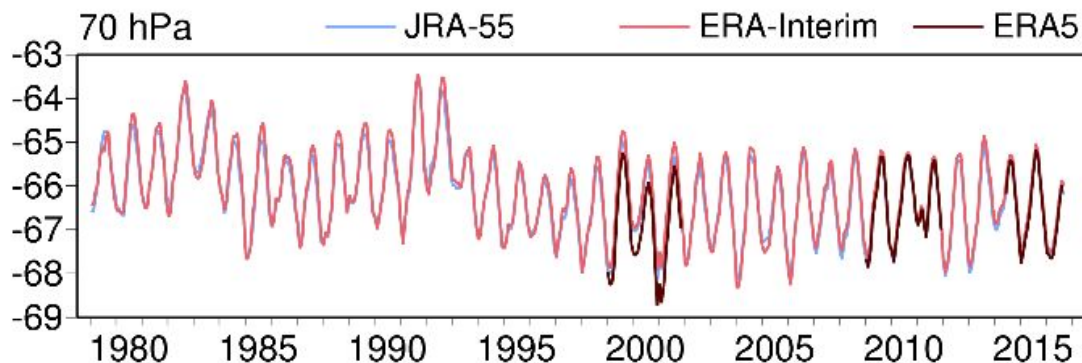
Potential vorticity (PVU) on 700K isentropic surface



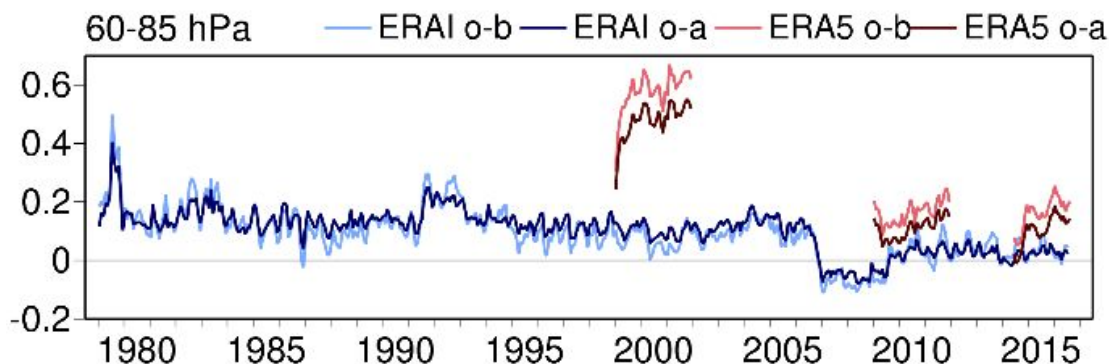
Total column ozone (Dobson units) at the South Pole



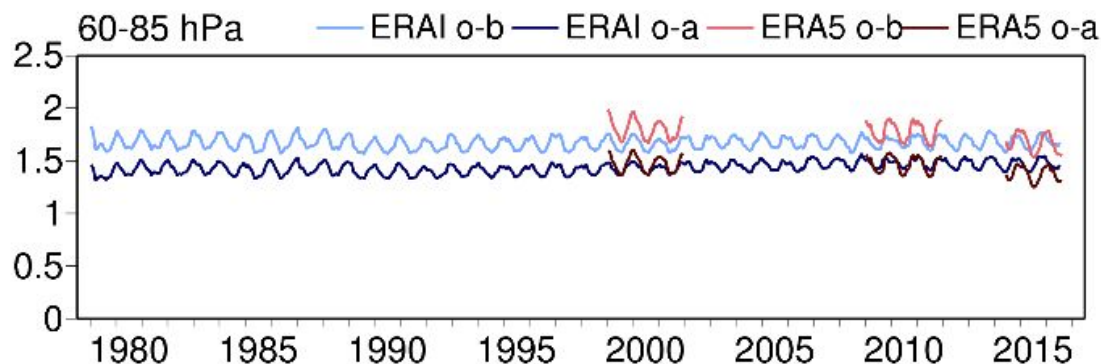
Global-mean temperature (°C)



Global-mean temperature at 70hPa

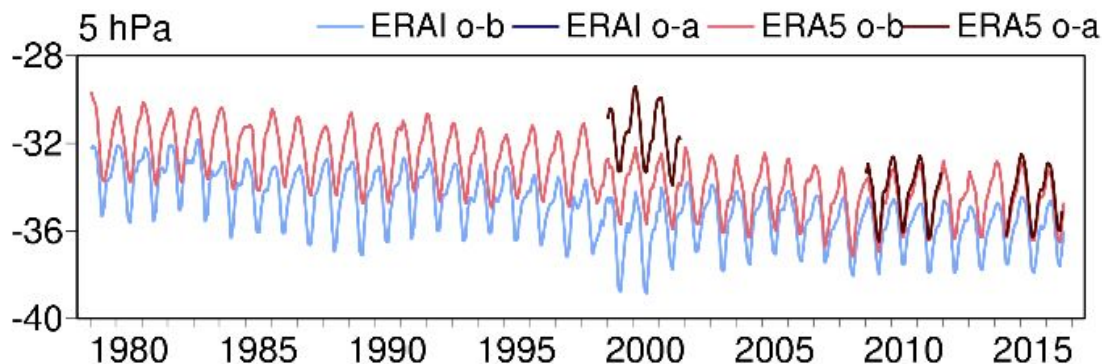


Mean analysis and background differences from bias-adjusted radiosonde data in layer around 70hPa

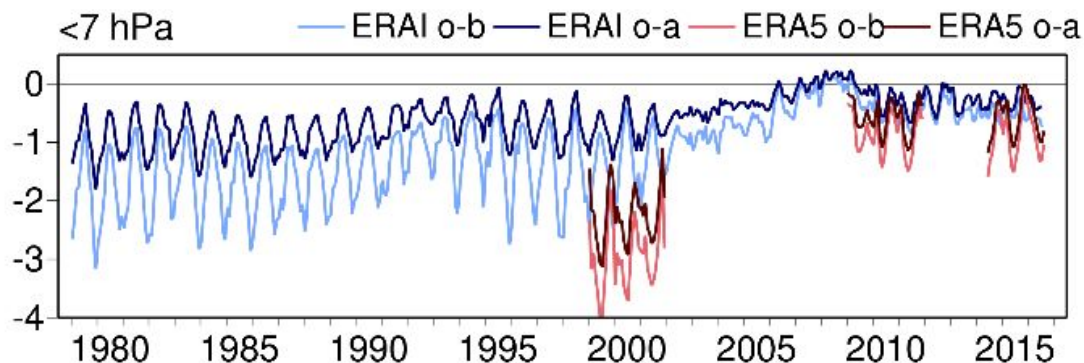


Standard deviation of analysis and background differences from bias-adjusted radiosonde data in layer around 70hPa

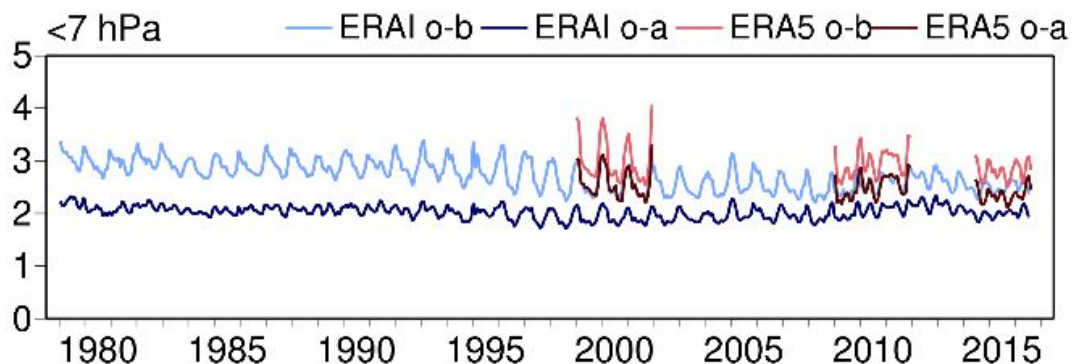
Global-mean temperature (°C)



Global-mean temperature at 5hPa

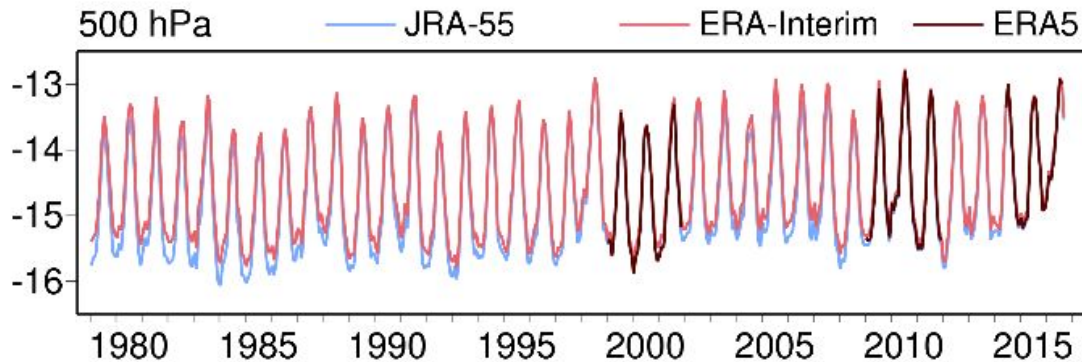


Mean analysis and background differences from bias-adjusted radiosonde data from heights above 7hPa

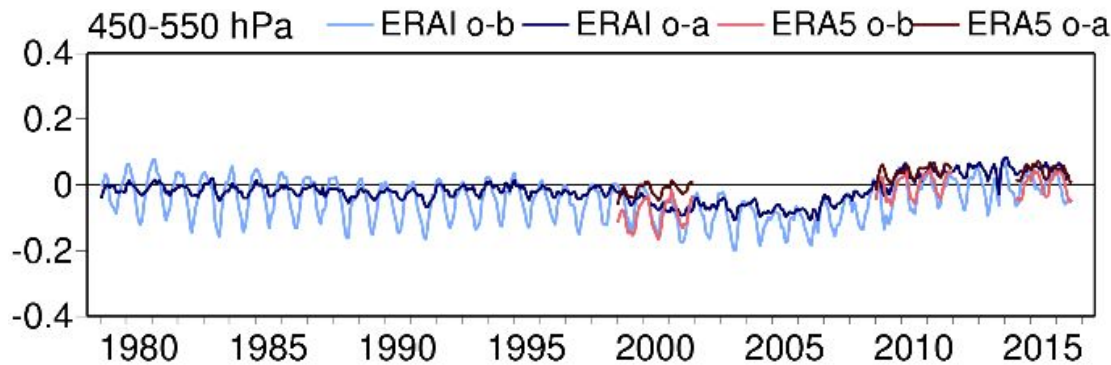


Standard deviation of analysis and background differences from bias-adjusted radiosonde data from heights above 7hPa

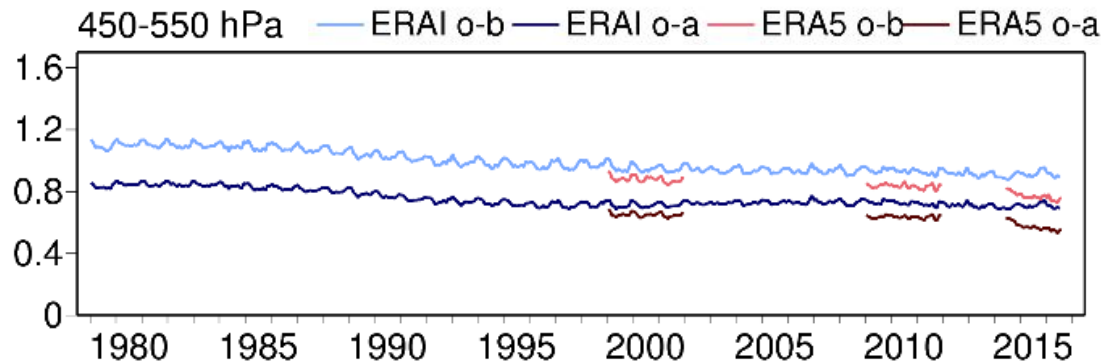
Global-mean temperature (°C)



Global-mean temperature at 500hPa



Mean analysis and background differences from bias-adjusted radiosonde data in layer around 500hPa



Standard deviation of analysis and background differences from bias-adjusted radiosonde data in layer around 500hPa; higher-resolution BUFR data introduce inhomogeneity at end of period for ERA5

In conclusion

ERA-Interim is, on the whole, standing the test of time reasonably well, but nevertheless is showing its age in several ways

Production of ERA5 is well underway for the current decade

ERA5 products to date mainly show either improvements on ERA-Interim, or similar behaviour of these two reanalyses

The issue of bias in the stratosphere in the 1999-2009 stream needs to be understood – the stream could be rerun

Other issues need resolving before the two earlier streams can be started