The ERA5 Global Reanalysis: achieving a detailed record of the climate and weather for the past 70 years.

Hans Hersbach, Bill Bell, Paul Berrisford, Per Dahlgren, András Horányi, Joaquín Muñoz-Sabater, Julien Nicolas, Raluca Radu, Dinand Schepers, Adrian Simmons, and Cornel Soci.

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- **Introduction, overview of ERA5 products**

- ERA5 configuration (1979 onwards) and some diagnostics

- ERA5.1 (2000-2006); the importance of the weight of the background

- Preliminary results on the ERA5 back-extension (1950-1978)

- Final remarks and outlook

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ECMWF operates the Copernicus Climate Change Service (C3S) and the Copernicus Atmospheric Monitoring Service (CAMS) on behalf of the European Commission.

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A full-observing-system global reanalysis for the atmosphere, land and ocean waves.
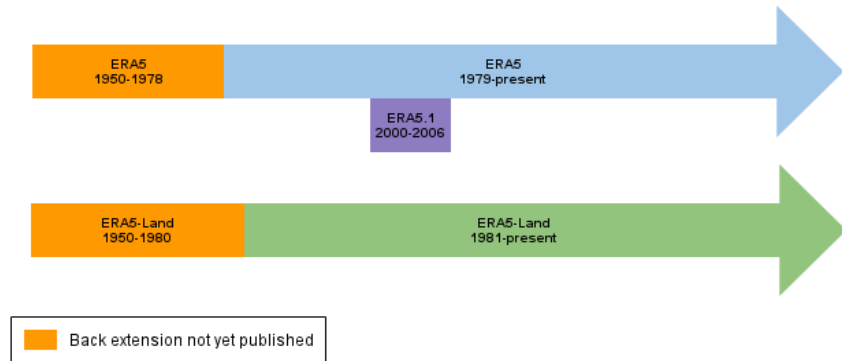
ERA5 replaced ERA-Interim (end date 31 August 2019)

To date ERA5 is publicly available from 1979 onwards, with daily updates 5 days behind real time.

ERA5-Land (9km downscaled) is available from 1981 (2 months behind real time)

Improvements compared to ERA-Interim:

- Benefit from 10 more years model development
- Much higher resolution; **31km** versus 79km
- More and better input data
- Hourly output
- Uncertainty estimate (at 63km)

ERA5 Family Timeline

ERA5 1950-1978

ERA5 1979-present

ERA5.1 2000-2006

ERA5-Land 1950-1980

ERA5-Land 1981-present

☐ Back extension not yet published

Updates in 2020:

- **New:** ERA5.1 (2000-2006) now available
- **soon:** ERA5 back extension (1950-1978)
- **Q3:** updates 5 days behind real time for ERA5-Land and 'ERA5-complete'
- **Q4:** ERA5-Land back extension (1950-1980)

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EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

Copernicus Europe's eyes on Earth

European Commission

ECMWF

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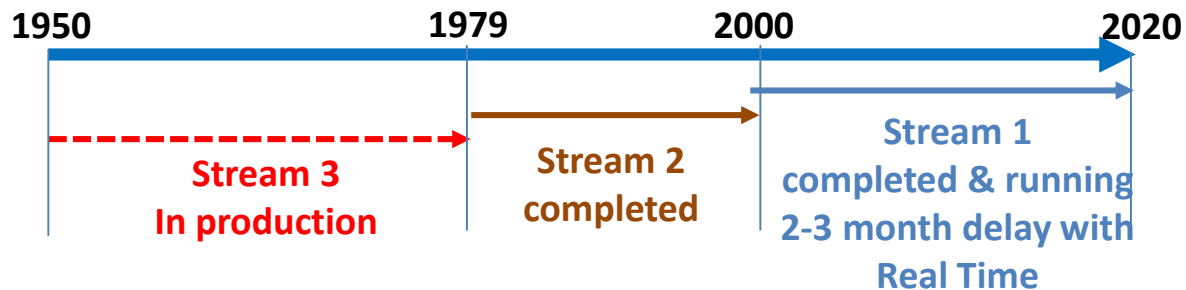
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What is new in ERA5?

|	ERA-Interim	ERA5
Period	1979 – present	**1950 – present**, produced in 2 phases
Availability behind real time	2-3 months	2-3 months (final product) **5 days** (ERA5T)
Assimilation system	2006 (31r2), 4D-Var	**2016** (41r2), **4D-Var, hybrid EDA providing B**
Model input (radiation and surface)	As in operations, *(inconsistent SST and sea ice)*	**Appropriate for climate**, e.g., evolution greenhouse gases, volcanic eruptions, sea surface temperature and sea ice
Spatial resolution	79 km globally 60 levels to 10 Pa	**31 km globally** 137 levels to 1 Pa
Uncertainty estimate		**from** 10-member **EDA at 63 km**
Output frequency	6-hourly Analysis fields	**Hourly** (three-hourly for the ensemble), Extended list of parameters ~ 9 Peta Byte (1950 - timely updates)
Extra Observations	Mostly ERA-40, GTS	Various **reprocessed CDRs**, **latest instruments**
Variational Bias control Radiosondes	Satellite radiances, RAOBCORE	Also ozone, aircraft, surface pressure, RISE
Land downscaling product	ERA-Interim land, 79km	ERA5L, **9km** (forced by ERA5)

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1950   1979   2000   2020

**Stream 3
In production**

**Stream 2
completed**

**Stream 1
completed & running
2-3 month delay with
Real Time**

➢ **Global**, spatial res. **9 km**, temporal res.

hourly

➢ **Availability** in the CDS: **Jan-1981 to Feb-**

2020

➢ 1950-1980 in production

➢ **NRT** capacity (5 days behind RT) **by Q3-**

2020

➢ Preliminary validation against in-situ data &

comparison with ECMWF reanalysis
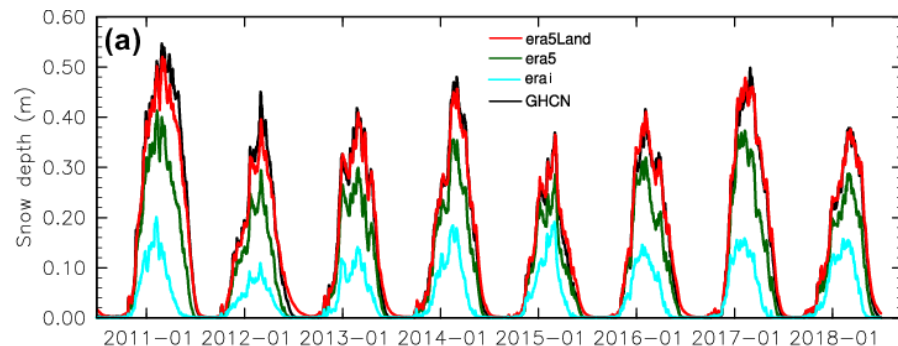
*Comparison of North-America snow depth observations from the Global
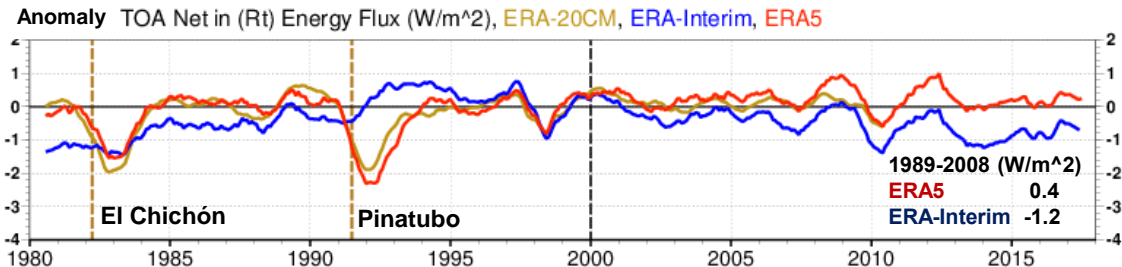Historical Climatological Network for different ECMWF reanalysis*
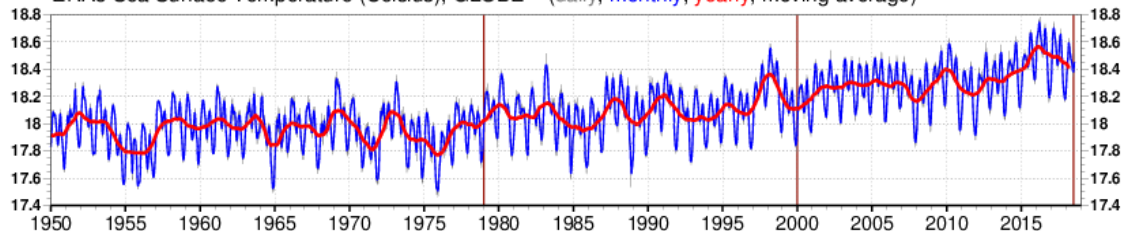
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CMIP5 recommended data sets

Total solar irradiance, greenhouse gases, ozone, aerosols (including volcanic)

(Prepared in the ERA-CLIM project, ERA-20CM, Hersbach et. al., 2015)

Anomaly TOA Net in (Rt) Energy Flux (W/m^2), ERA-20CM, ERA-Interim, ERA5

El Chichón   Pinatubo

1989-2008 (W/m^2)
ERA5   0.4
ERA-Interim   -1.2

ERA5 Sea Surface Temperature (Celsius), GLOBE   (daily, monthly, yearly, moving average)
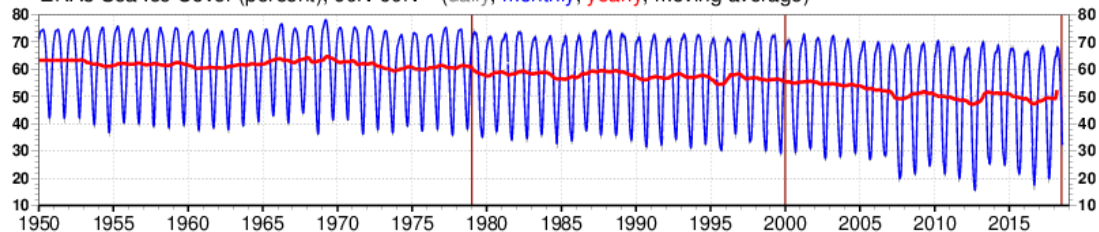
SST and sea ice cover

Carefully selected from OSTIA, OSI-SAF and HadISST2 (Hadley Centre, *ERA-CLIM*)

(Hirahara et. al., 2016)

ERA5 Sea Ice Cover (percent), 60N-90N   (daily, monthly, yearly, moving average)

The ERA5 observing system

Over 200 types of reports

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Reprocessed data sets

Radiances: SSM/I brightness temp from CM-SAF
MSG from EUMETSAT

Atmospheric motion vector winds: METEOSAT, GMS/GOES-9/MTSAT,
GOES-8 to 15, AVHRR METOP and NOAA

Scatterometers: ASCAT-A (EUMETSAT),
                ERS 1/2 soil moisture (ESA)

Radio Occultation: COSMIC, CHAMP, GRACE, SAC-C, TERRASAR-x (UCAR)

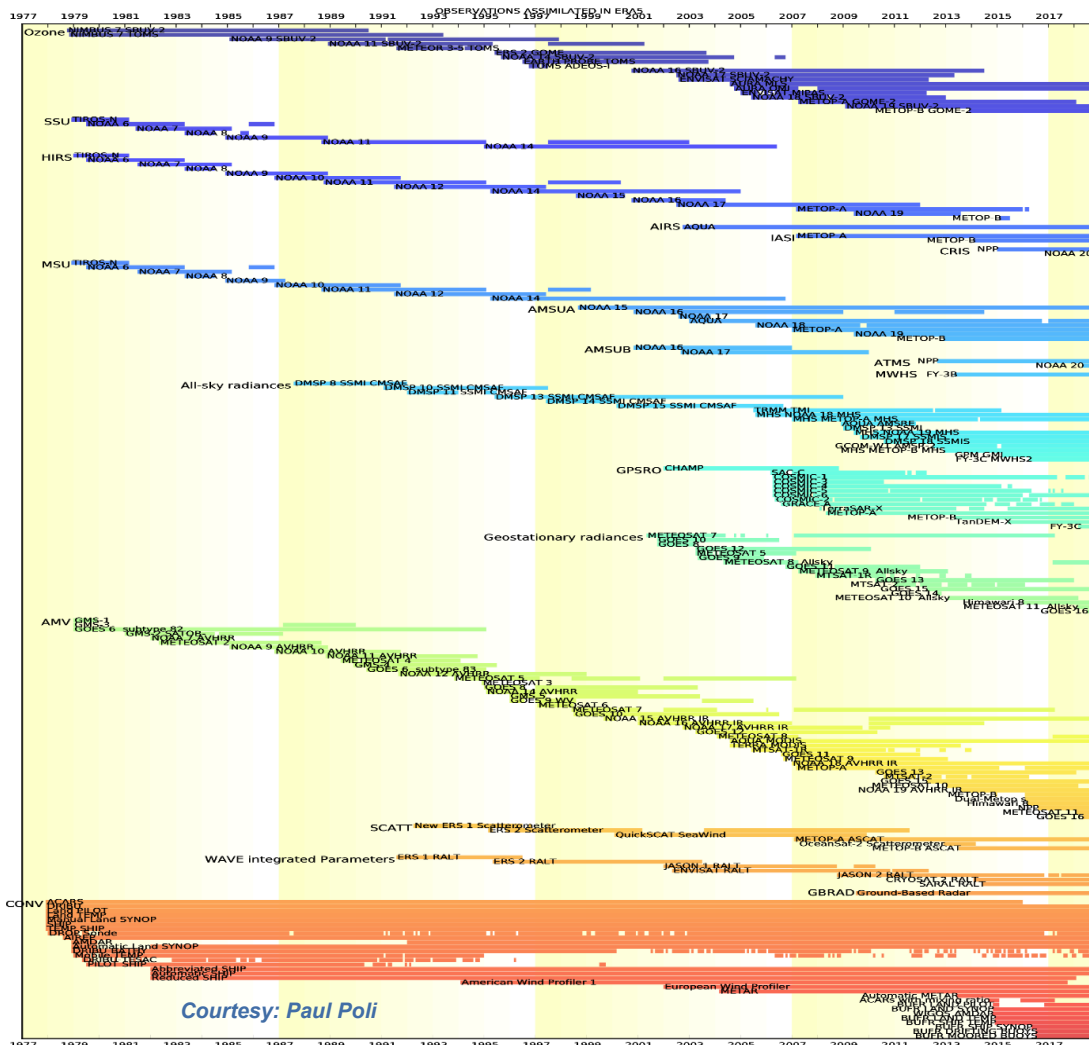Ozone: NIMBUS-7, EP TOMS, ERS-2 GOME, ENVISAT SCIAMACHY, Aura
MLS, OMI, MIPAS, SBUV

Wave Height: ERS-1,ERS-2, Envisat, Jason

Latest instruments

IASI, ASCAT, ATMS, CrIS, MWHS, Himawari, …

Improved data usage

all-sky vs clear-sky assimilation,
latest radiative transfer function, corrections,
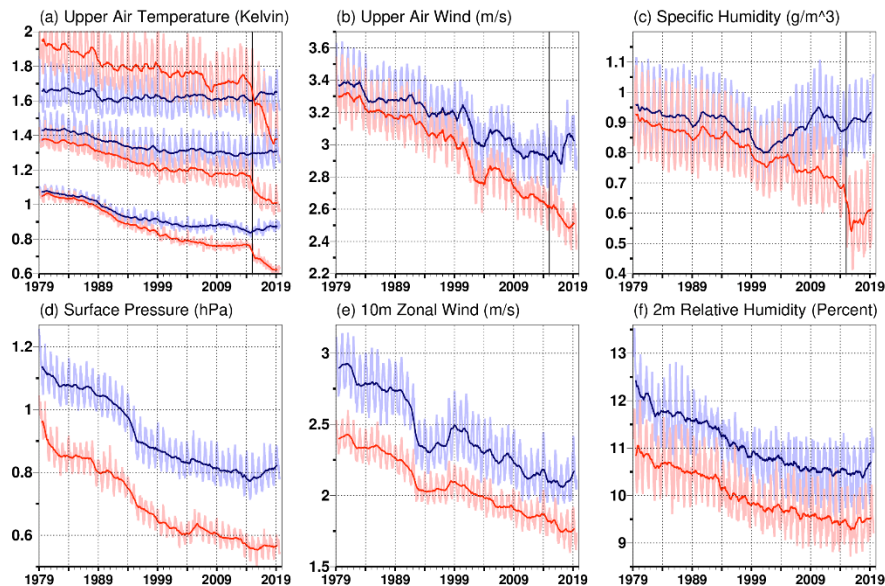extended variational bias control

Courtesy: Paul Poli

Standard deviation of **ERA5** *and* **ERA-Interim** *first-guess departures*

In the troposphere ERA5 has a much
Improved fit to observations.
However, in the stratosphere the fit is
worse for temperature due to a larger
model bias.

(a) upper-air temperature from radiosondes (from top to bottom in the panel) within ±25 hPa of 50 hPa, 850 hPa and 400 hPa, (b) upper-air zonal wind from radiosondes, dropsondes and PILOTs, (c) upper-air humidity from radiosondes and dropsondes, (d) surface pressure from SYNOP, buoys, ships and METAR, (e) 10m zonal wind from buoys, ships, radiosondes, PILOT and SYNOP, (f) 2m relative humidity from SYNOP. The vertical black line marks the start date of the usage of BUFR TEMP data in ERA5 from 1 January 2015.

Hersbach, H. et al., 2020 (in press), doi:10.1002/qj.3803

# Inter-comparison of global mean temperature relative to 1981-2010

Julien Nicolas
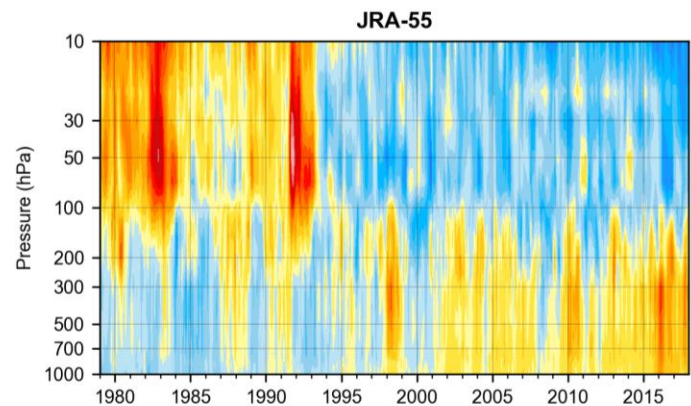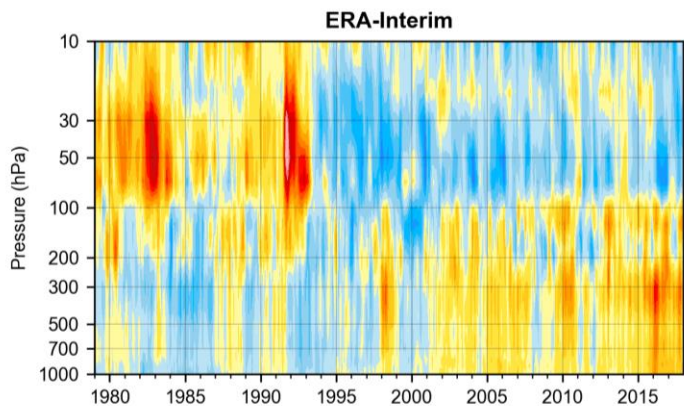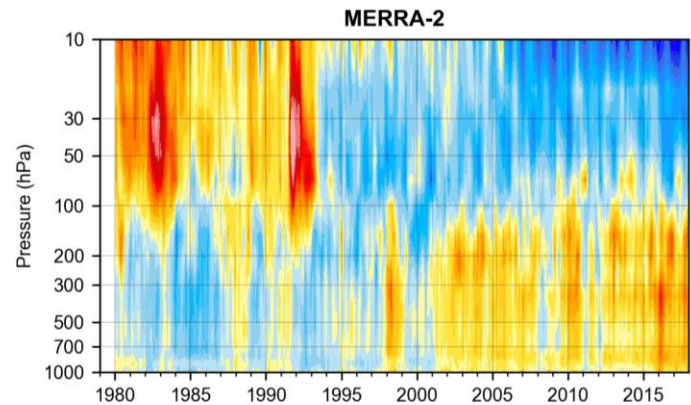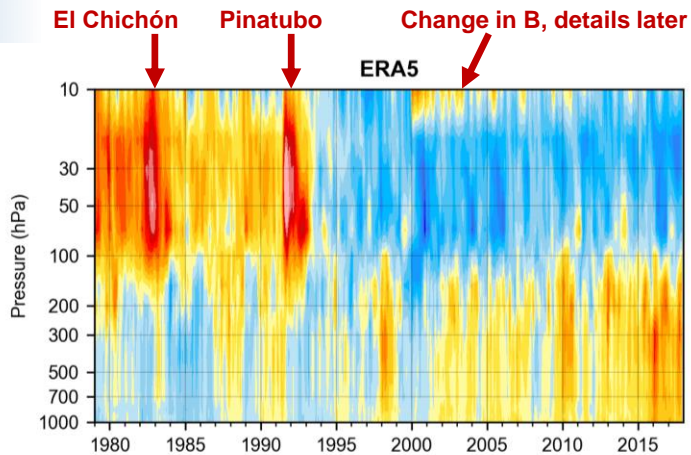
The advantage of hourly output (soon from 1950 onwards) for December storm Lothar

The ERA5 hourly resolution presents a detailed view of this rapidly evolving storm.

Although at 9 UTC the ERA5 minimum pressure is about 5 hPa higher (ensemble spread 2.1 hPa) than the reported minimum (Hewson and Neu 2015) (which also has an associated uncertainty) and also somewhat misplaced, the match is within one hPa at 10 and 11 UTC (spread 0.5 hPa at 12 UTC), and the analysed position is highly accurate at 11 UTC.

ERA5 provides a detailed view of wind gust with maximum values up to 42 m/s in the Black Forest and French Alpine area. Maximum observed gusts in the Black Forest area were 59 m/s (DWD 2000).
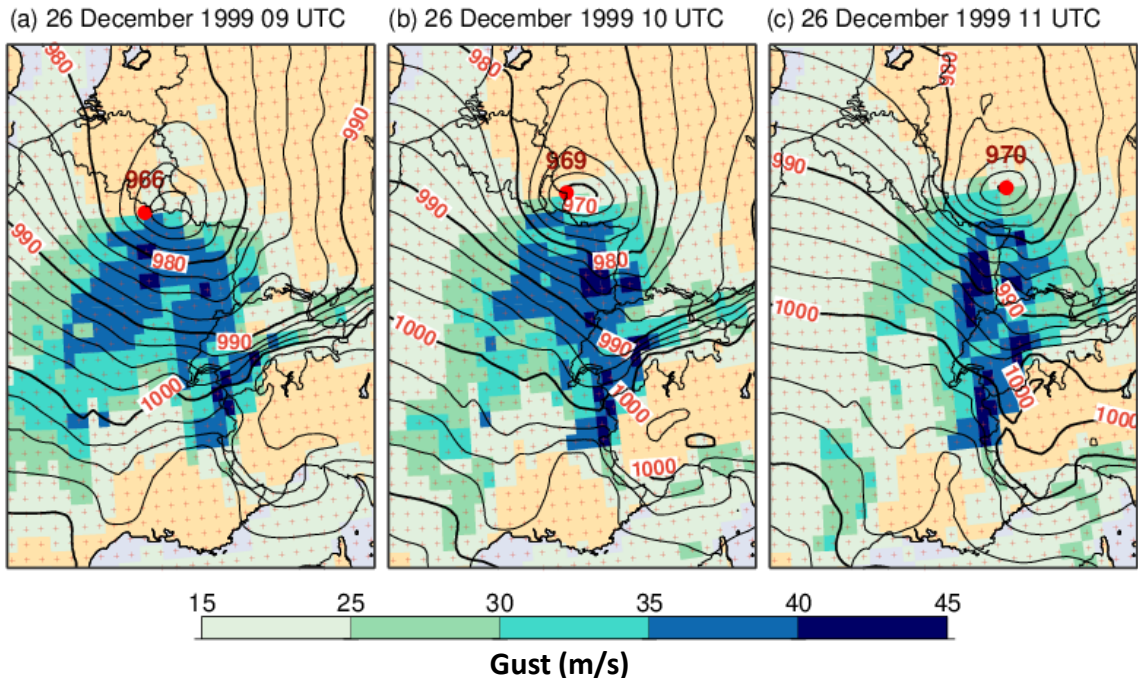
ERA5 analysis of mean sea level pressure and wind gust within the preceding hour for Lothar on 26 December 1999 at (a) 09, (b) 10, and (c) 11 UTC. Red dots and values mark the position and pressure (hPa) of the reported low. Red plusses indicate the ERA5 native grid.

Hersbach, H. et al., 2020 (in press), doi:10.1002/qj.3803

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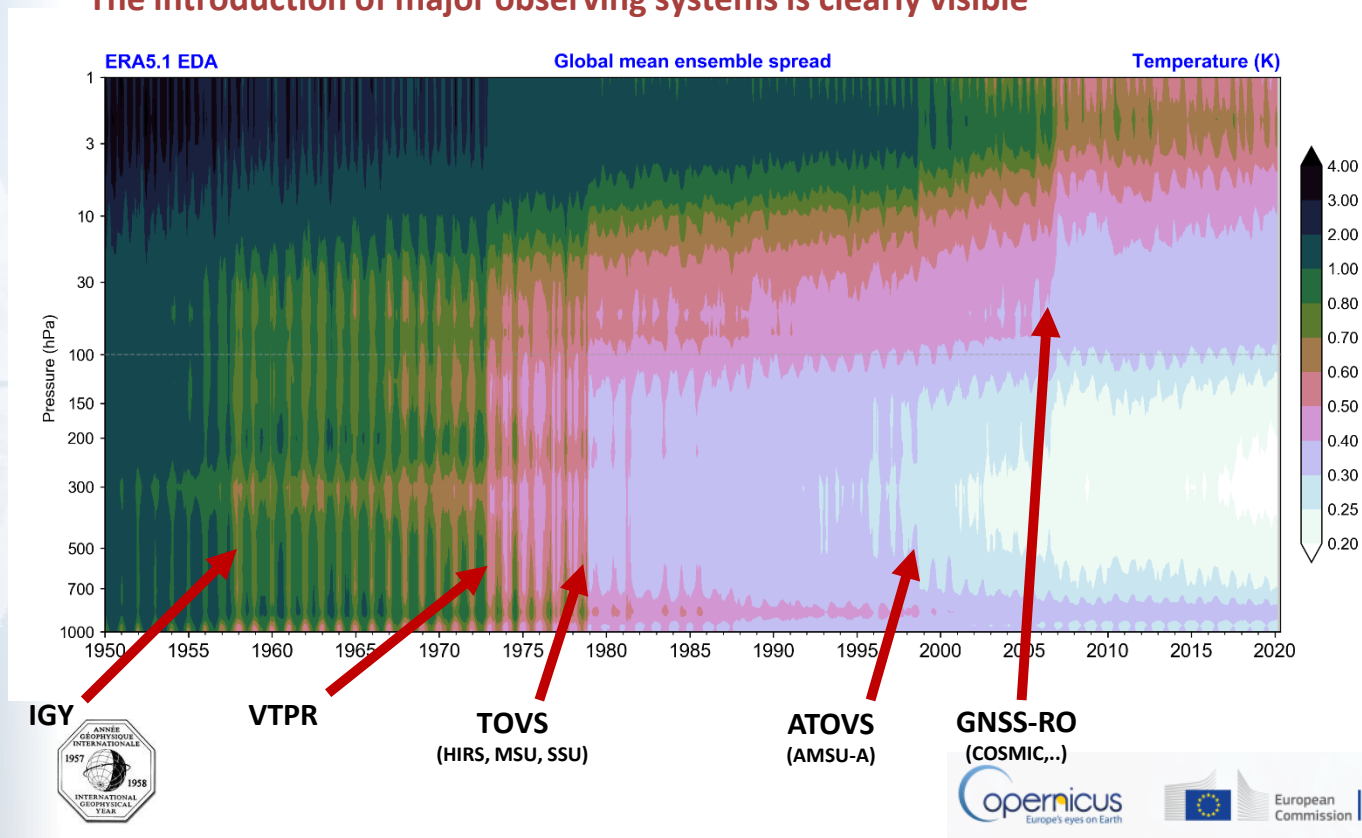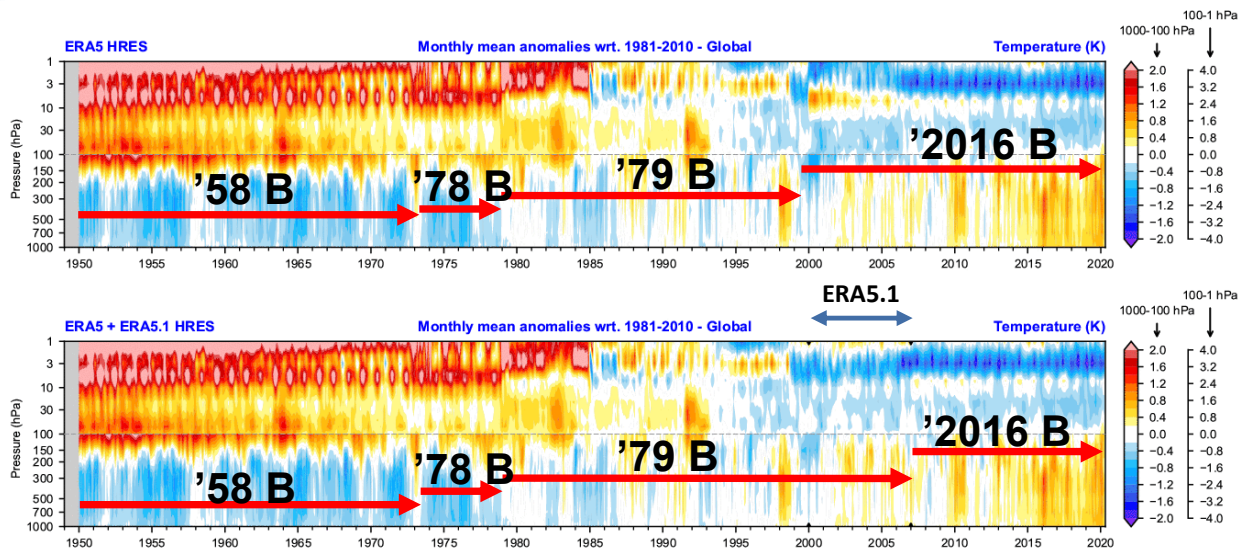**Spread decreases over time when more and more observations become available**
The introduction of major observing systems is clearly visible

IGY

VTPR

TOVS
(HIRS, MSU, SSU)

ATOVS
(AMSU-A)

GNSS-RO
(COSMIC,..)

The effect of the background error covariance marix on the mean state

In ERA5 the 10-member ensemble of data assimilation systems (EDA) also provides a flow-dependent background error covariance matrix **B**:

$$B(t) = (1-\alpha)B_{cli} + \alpha B_{EDA}(t)$$

It relies partly on a static component **Bcli**, which should evolve slowly with the observing system: In ERA5 **Bcli** was changed with the introduction of major changes in the observing system. However, too short correlations in **'2016 Bcli** could not counteract a model cold bias in the lower stratosphere. This was improved by a rerun for 2000-2006 (ERA5.1) using the longer correlations from **Bcli** tuned for 1979. From 2007 onwards such bias is resolved by GNSS-RO observations.
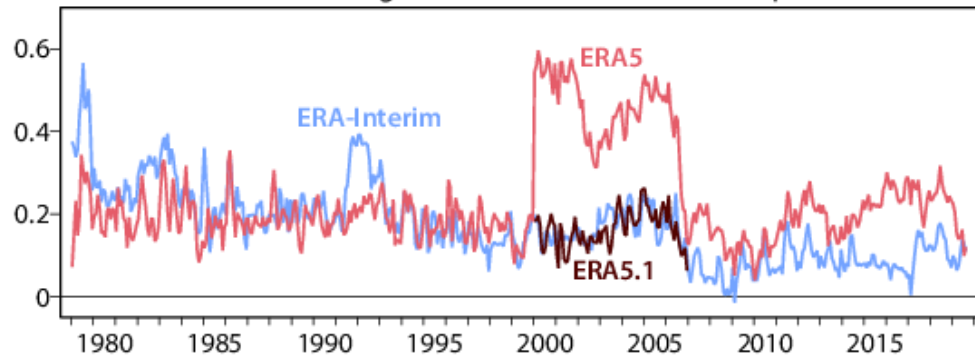
The improved mean state for stratospheric temperature in ERA5.1

ERA5.1 provides an improved mean state for stratospheric temperature.

In the troposphere the difference between ERA5 and ERA5.1 is very small.

In the CDS ERA5.1 is now available as: 'era5.1-complete'.

Global-mean ob-bg for 60-40hPa radiosonde temperatures (K)

Monthly average observation-background differences from 1979 onwards for all assimilated bias-adjusted radiosonde temperature data (K) between 40 and 60 hPa, for ERA-Interim, ERA5 (based on 1979-B cli before 2000 and 41r2-B cli afterwards) and ERA5.1 (using 1979-B cli from 2000-2006).

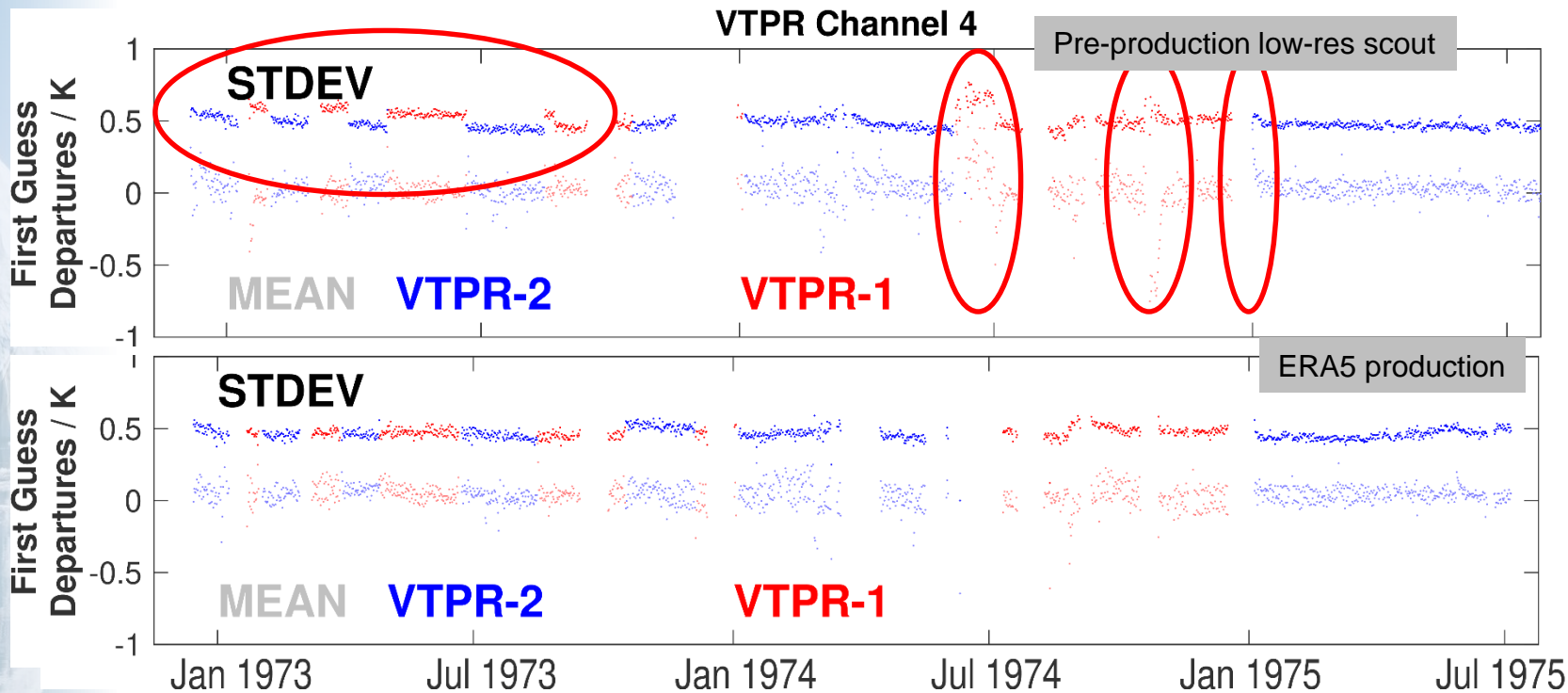Hersbach, H. et al., 2020 (in press), doi:10.1002/qj.3803

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VTPR Channel 4

Pre-production low-res scout

STDEV

MEAN **VTPR-2** **VTPR-1**

ERA5 production

STDEV

MEAN **VTPR-2** **VTPR-1**

Jan 1973   Jul 1973   Jan 1974   Jul 1974   Jan 1975   Jul 1975

Relative to ERA-40

- New cloud detection scheme
- RT coefficient optimisation
- Blacklisting periods of degraded data quality
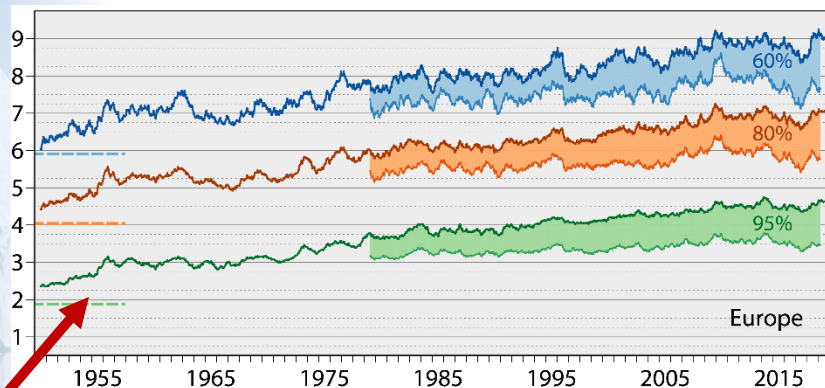- Observation error tuning (Desroziers, reduced obs errors)

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

——— ERA5   ——— ERA-Interim   - - - - - ECMWF operations 1981
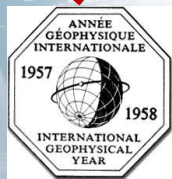

Europe

Australia/New Zealand

ERA5 1979 onwards:
Re-forecasts from ERA5 are up to 1 day more skilful than ERA-Interim

ERA5 back extension:
NHEM (especially Europe) skill is rather robust, but decline prior to the IGY in 1957-1958

Over SHEM there is a dramatic collapse prior to the satellite ERA

ANNÉE GÉOPHYSIQUE INTERNATIONALE
1957 1958
INTERNATIONAL GEOPHYSICAL YEAR

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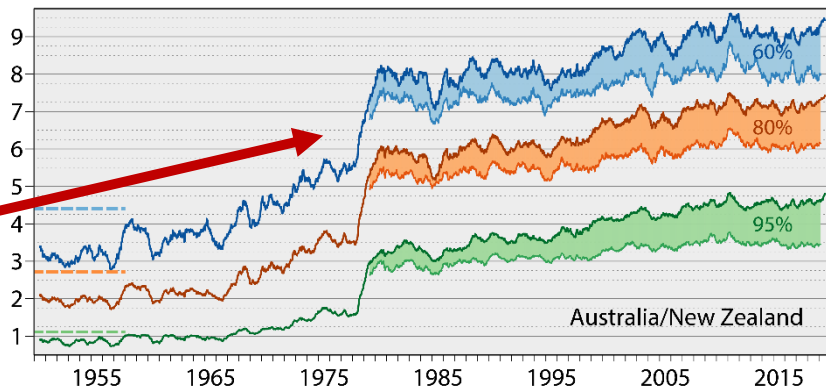
In general there is a good agreement between datasets.

However, note:
- Reanalysis is colder prior to 1970
- Reanalysis is warmer over the last few years

(a) 12 month running global mean 2m temperature anomaly (K)

(b) 12 month running mean 2m temperature anomaly (K) over all land areas
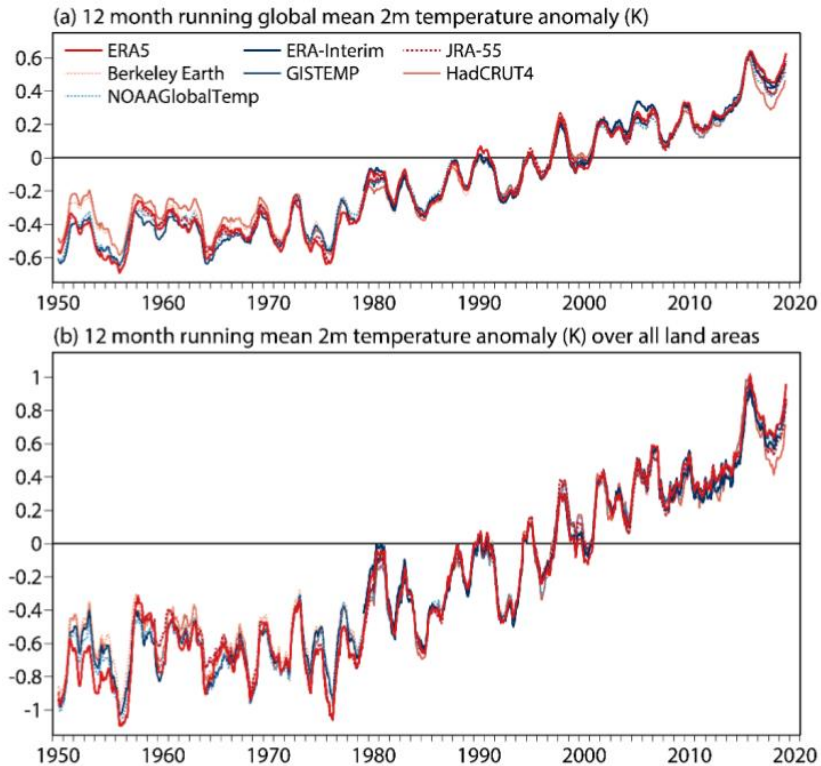
Inter-comparison of 2m temperature anomalies for sub areas
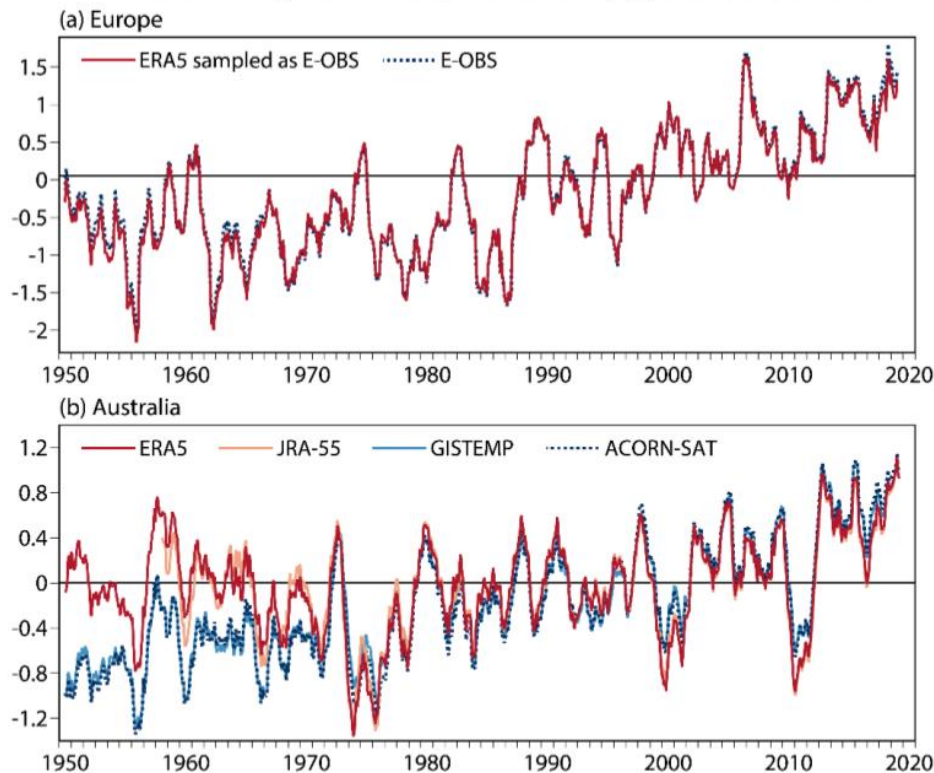
ERA5 agrees very well with the E-OBS gridded-observation data set.

However,
- Reanalysis is quite warmer over Australia before 1970 than more direct observational datasets.

12-month running mean 2m temperature anomaly (K) relative to 1981-2010

(a) Europe

ERA5 sampled as E-OBS ········ E-OBS

(b) Australia

ERA5   JRA-55   GISTEMP   ········ ACORN-SAT

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ERA5 data availability
– 1979-present available in the Climate Data Store (hourly data and monthly means)
– Preliminary version of ERA5 (ERA5T) available with 5-day delay behind real-time
– ERA5 has replaced ERA-Interim

Reference paper about ERA5
– Hersbach, H. *et al.*, 2020: The ERA5 Reanalysis. *Quart. J. Roy. Meteorol. Soc.*, doi:10.1002/qj.3803, accepted.

ERA5 back-extension (1950-1978)
– Production has completed, to be available soon.
– Later: possible extension of ERA5 to 1940 (low-hanging fruit but lower skill expected)

ERA5.1 (2000-2006)
– Rerun of ERA5 to improve stratospheric temperatures, now available
– Detailed description in Simmons, A., *et al.*, 2020: Global stratospheric temperature bias and other stratospheric aspects of ERA5 and ERA5.1. ECMWF Technical Memorandum number 859, 40 pp., doi:10.21957/rcxqfmg0.

ERA5-Land
– High-resolution (9km) land product forced by ERA5 (no data assimilation)
– 1981-present currently available in the Climate Data Store
– Production of back-extension (1950-1978) is ongoing

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The ongoing production of ERA5 is undertaken within the Copernicus C3S framework at ECMWF as part of the C3S operational service.

Many reanalysis-related tasks are being carried out by C3S providers:
– satellite reprocessing (EUMETSAT), data rescue, consolidation of historical datasets
– the production of two high-resolution regional reanalyses, for Europe and the Arctic

ECMWF's vision for C3S post-2020 continues to allocate a high priority to reanalysis:

High-resolution climate integrations back to 1850 or earlier
– Coupled with the ocean if possible, but constrained by SST and sea ice cover (nudging)
– Ensemble, CMIP6 forcings
– Test-bed for non-DA areas relevant for next reanalysis
– Production to start around 2021

Next full-observing-system coupled reanalysis (ERA6)
– State-of-the-art NWP system, coupled with the ocean
– Boundary conditions: similar concept to what was used for the climate integrations (see above)
– Production to start around 2023