Goodbye ERA-Interim, hello ERA5
“The strength of ensembles”

Hans Hersbach,
Bill Bell, Paul Berrisford, Gionata Biavati, Dick Dee, Rossana Dragani, Anabelle Guillore, Andras Horanyi, Julien Nicolas, Carole Peubey, Raluca Radu, Iryna Rozum, Patricia de Rosnay, Joaquin Munoz Sabater, Dinand Schepers, Adrian Simmons, Cornel Soci and Freja Vamborg.
Twenty-five years ago ECMWF was one of the first forecasting centres to start issuing operational ensemble forecasts. The implementation of these ensembles induced a paradigm shift in numerical weather prediction (NWP).

Today, exactly 75 years ago, the method of ensembles was used for the weather forecast for D-Day.
The 3-member “ensemble forecast system” for D-Day in June 1944

Widewing forecasters (USAAF)
- Lt-Col. I P Krick
- Lt-Col. B G Holzman

Dunstable Forecasters
- C K M Douglas
- S Petterssen

Admiralty Forecasters (RN)
- Inst Lt G L Hogben
- Inst Lt-Cmdr G M Wolfe

SHAER Chief Meteorological Officer
Group Captain J M Stagg

SHAER Deputy Chief Meteorological Officer
Col D N Yates
Forecasts for conditions on 5 June made on the evening of 3 June and confirmed early in the morning of 4 June
• on which the forecasting teams initially split two-to-one in favour of conditions that led to postponement

Forecasts for conditions on 6 June made on the evening of 4 June and confirmed early in the morning of 5 June
• on which the forecasting teams initially split two-to-one in favour of conditions that led to a decision to proceed
The need for ensembles in reanalysis

Reanalysis is very popular (e.g., ERA-Interim had over 40,000 users from 2015 alone)

- **Complete**: combining vast amounts of observations into (global) fields
- **Consistent**: use the same physical model and DA system throughout
- **Convenient**: “maps without gaps”, always available in the same way

- **However**: The observing system has evolved considerably and so the quality of the reanalysis products that rely on this!

  ➢ ERA5 is based on a 10-member Ensemble 4D-Var data assimilation system
Ensemble spread as a measure for the *synoptic* ERA5 uncertainty

1971 CERA-20C: Surface pressure, marine wind, only

1971 ERA5: Upper-air data

1980 ERA5: Early-satellite era

2018 ERA5: Current observing system
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)

SST and sea ice cover
Carefully selected from OSTIA, OSI-SAF and HadISST2 (Hadley Centre, ERA-CLIM)
Different ensemble members use different SST realizations

(Hirahara et. al., 2016)
Full-observing-system global reanalysis for atmosphere, land and ocean waves.

ERA5 is replacing ERA-Interim: end date ERA-I **31 August 2019**

To date ERA5 is publicly available from **Jan 1979 - March 2019** (40 years + 3 months)

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

**CDS Public Release plan for 2019/2020:**
- **Currently:** updates 2-months behind real time
- **Soon:** ERA5-Land from 2001 (9km)
- **soon:** updates 2-5 days behind real time: **ERA5T**
- **Next:** access to ERA5 observations
- **Early 2020:** **1950-1978**.
The ERA5 observing system

0.75 (1979) – 24 Million (2019) obs per day
Over 200 types of reports

**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**
Skill from re-forecasts as a measure for the accuracy of reanalysis products

The (forecast) model is an integral part of the assimilation system

**Also:** better analyses produce better forecasts

Re-forecasts from ERA5 have higher skill than those from ERA-Interim
Better model, more and better observations, higher resolution, hourly output.
Maximum of daily ERA5 precipitation in 2018 relative to the 1981-2010 climatology

Courtesy of Adrian Simmons, Freja Vamborg; to appear in BAMS SOC 2019
Global mean temperature compared to 1981-2010

El Chichón  Pinatubo  Change in B
Welcome to the Climate Data Store

Dive into this wealth of information about the Earth’s past, present and future climate.

It is freely available and functions as a one-stop shop to explore climate data. Register for free to obtain access to the CDS and its Toolbox.

We are constantly improving the services and adding new datasets. For more information, please consult the catalogue, our FAQ or the CDS forum.
The Climate Data Store

One of the pillars of C3S
• One-stop shop for climate data
• Free access
• User support
• Includes CDS Tool Box
• Quality assurance (in steps)

Observations
- Global estimates of ECVs from satellite and in-situ observations
- Reprocessed CDRs, reference observations
- Support for data rescue, climate data collections

Climate reanalysis
- Global atmosphere, ocean, land
- Regional reanalysis for Europe
- Coupled climate reanalysis for 100 years

Model output
- Multi-model seasonal forecast products
- Access to CMIP data and products (global and regional)
- Reference set of climate projections for Europe

Climate Indicators
How to access ERA5 data?

**Online data sets:** [Copernicus Climate Data Store](https://www.copernicus.eu/eoc-ea-research-environmental-data-store) | [Copernicus Climate Data Store](https://www.copernicus.eu/eoc-ea-research-environmental-data-store)
- Regridded to regular lat-lon (0.25 degrees)
- Pressure levels and single levels
- Hourly and monthly averages
- Simplified structure (best estimate)

**Data on tape:** ERA5 complete: via CDS_API

**Copernicus knowledge base:**
- How to download data: [How to download ERA5](https://www.eumetsat.int/en/news-events/news-releases/how-to-download-era5) - [Copernicus Knowledge Base](https://www.copernicus.eu/eoc-ea-research-environmental-data-store) - ECMWF Confluence Wiki
- C3S forum: [forum](https://confluence.ecmwf.int/display/C3S) - [Copernicus User Support Forum](https://confluence.ecmwf.int/display/C3S) - ECMWF Confluence Wiki

**ERA5 reference:**
- ECMWF Newsletter (Spring 2019): [Global reanalysis: goodbye ERA-Interim, hello ERA5](https://www.ecmwf.int/en/newsletters/newsletters) | ECMWF
- ERA report: [Operational global reanalysis: progress, future directions and synergies with NWP](https://www.ecmwf.int/en/newsletters/newsletters) | ECMWF

**Copernicus user support:** copernicus-support@ecmwf.int
Final remarks and outlook

**ERA5 is available from 1979 and is replacing ERA-Interim.**
- Much higher resolution, better model, better and more observations
- The ensemble provides information on the evolving confidence of its products

**Reanalysis provides a physically complete view of the recent climate.**
- Reanalysis is now fully integrated into international assessments of climate change as delivered by, for example, the WMO, and the European State of the Climate.

**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 outsourced providers:
  - satellite reprocessing (EUMETSAT), data rescue, consolidation of historical datasets
  - the production of two high-resolution regional reanalyses, for Europe and the Arctic

**The ERA5 data product portfolio is growing:**
- Next: ERA5-Land, timely updates 2 days behind real time, access to observation feedback, back extension to 1950
- Evolution of the CDS, increasing versatility of the toolbox, implementation of quality assurance stamps (EQC)
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ERA5-Land, a high-resolution downscaling of the land-surface component

Discharge time series correlation difference ERA5-Land vs. ERA5

Blue = improvement
Red = Deterioration

ERA5-Land is currently in production.
2001 onwards to become available via the C3S Climate Data Store soon

Joaquin Munoz-Sabater