Climate Change

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.

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2019 theme: “The strength of ensembles”

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.*

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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

SHAEF Chief Meteorological Offcer

Group Captain J M Stagg

SHAEF Deputy Chief Meteorological Officer

Col D N Yates

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The 3-member “ensemble forecast system” for D-Day in June 1944

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

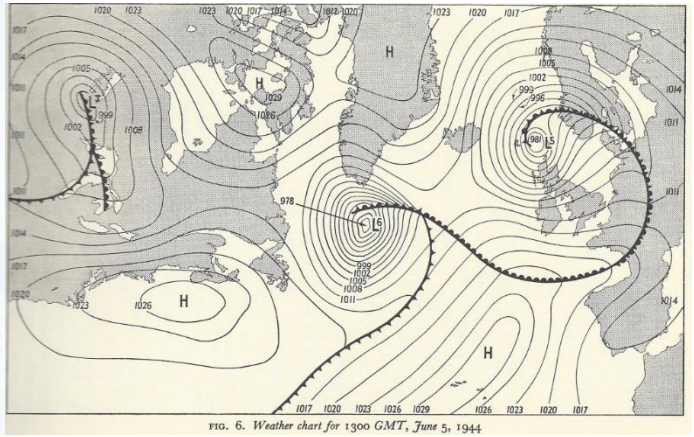

FIG. 6. *Weather chart for* 1300 *GMT, June* 5, 1944

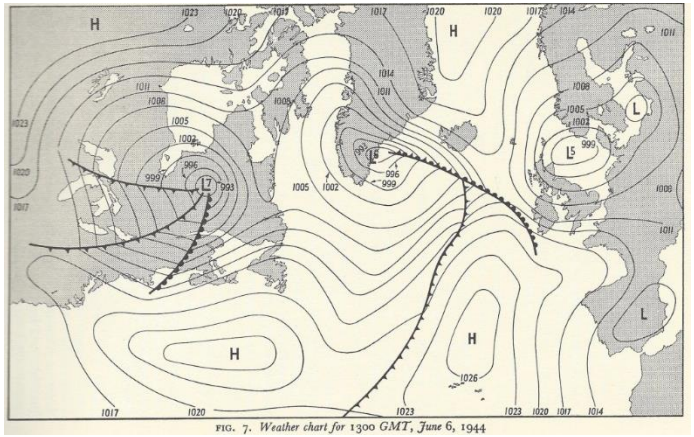

FIG. 7. *Weather chart for* 1300 *GMT, June* 6, 1944

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

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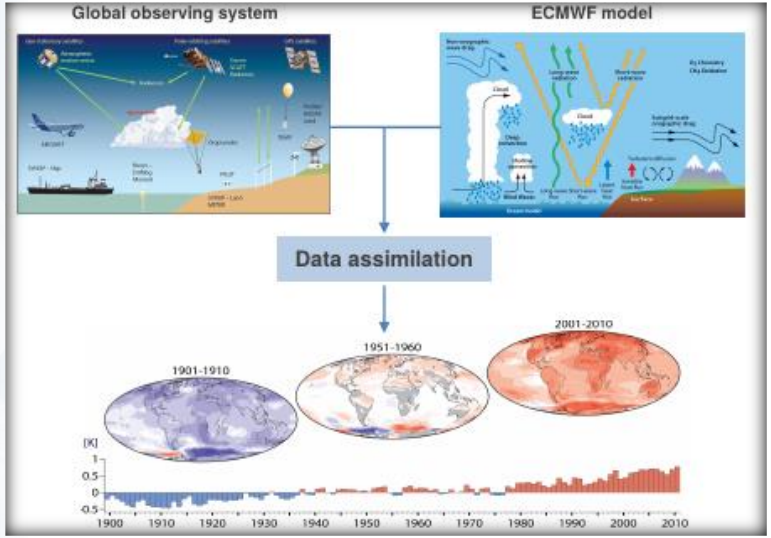
The need for ensembles in reanalysis

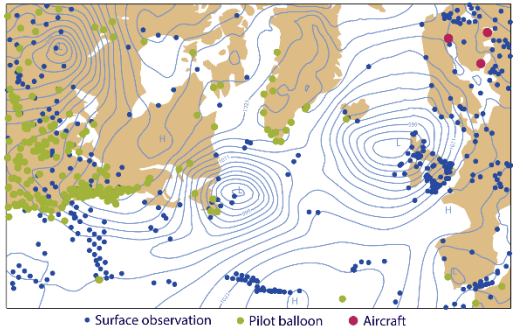
Reanalysis is very popular (e.g., ERA-Interim had over 40,000 users from 2015 alone)



- 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

Observations and ERA-PreSAT reanalysis for June 4 1944

Mean-sea-level pressure analysis for 1200 UTC 4 June 1944
Observations from 0901 UTC 4 June 1944 to 0900 UTC 5 June 1944



- 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

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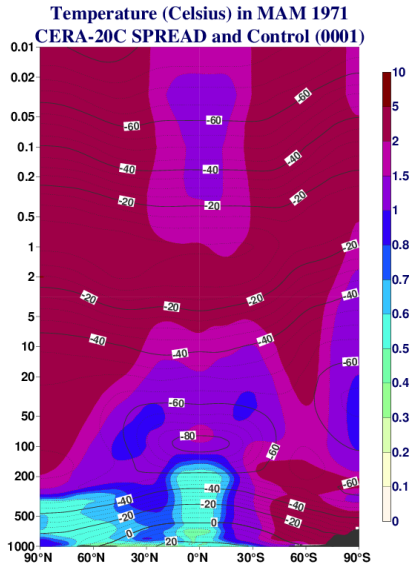
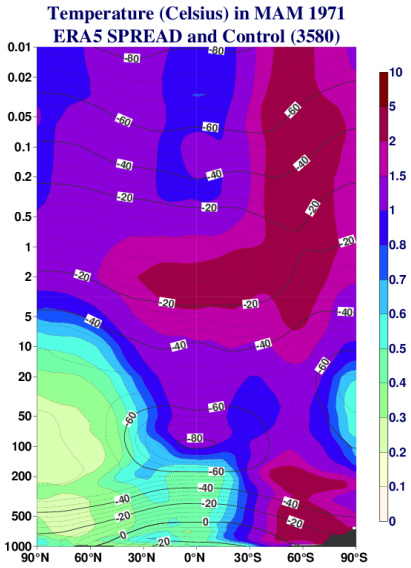
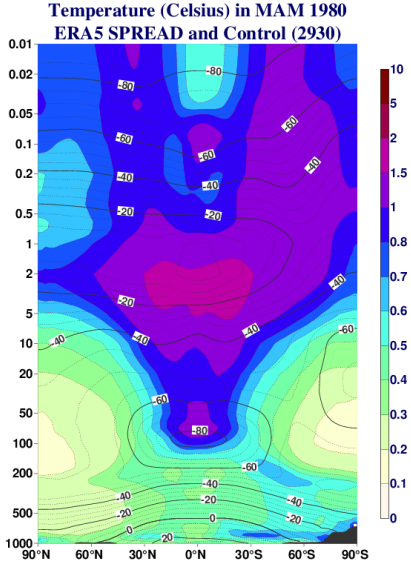
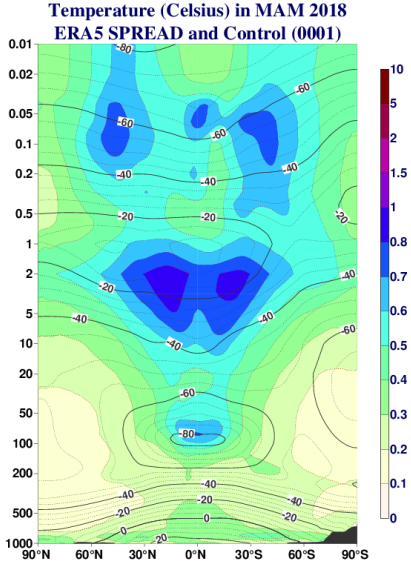
Ensemble spread as a measure for the *synoptic* ERA5 uncertainty









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

1971 ERA5:
Upper-air data

1980 ERA5:
Early-satellite era

2018 ERA5:
Current observing system

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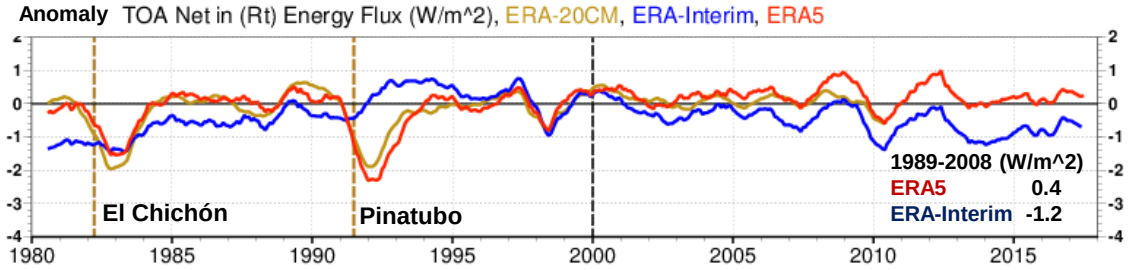
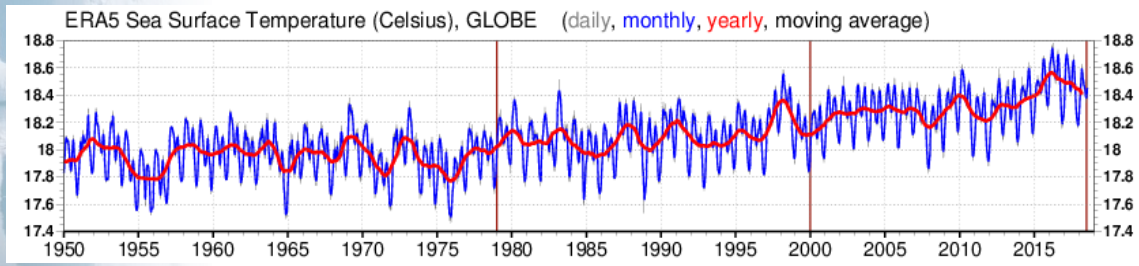
ERA5 forcing appropriate for climate

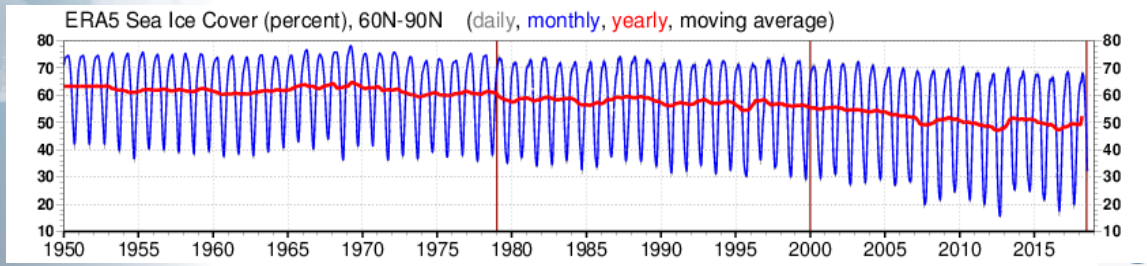
CMIP5 recommended data sets

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)

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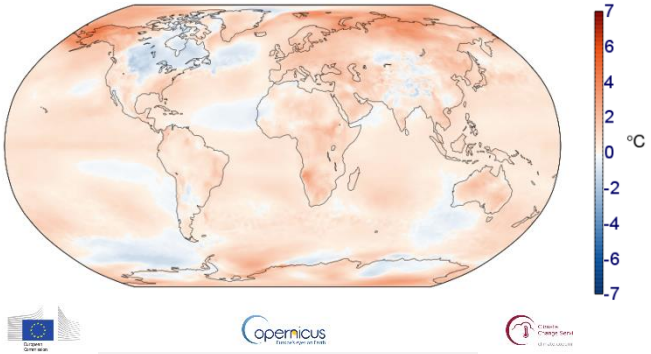
Status of ERA5

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**)



T2m, **June 2018 - May 2019** relative to 1981-2010

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

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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

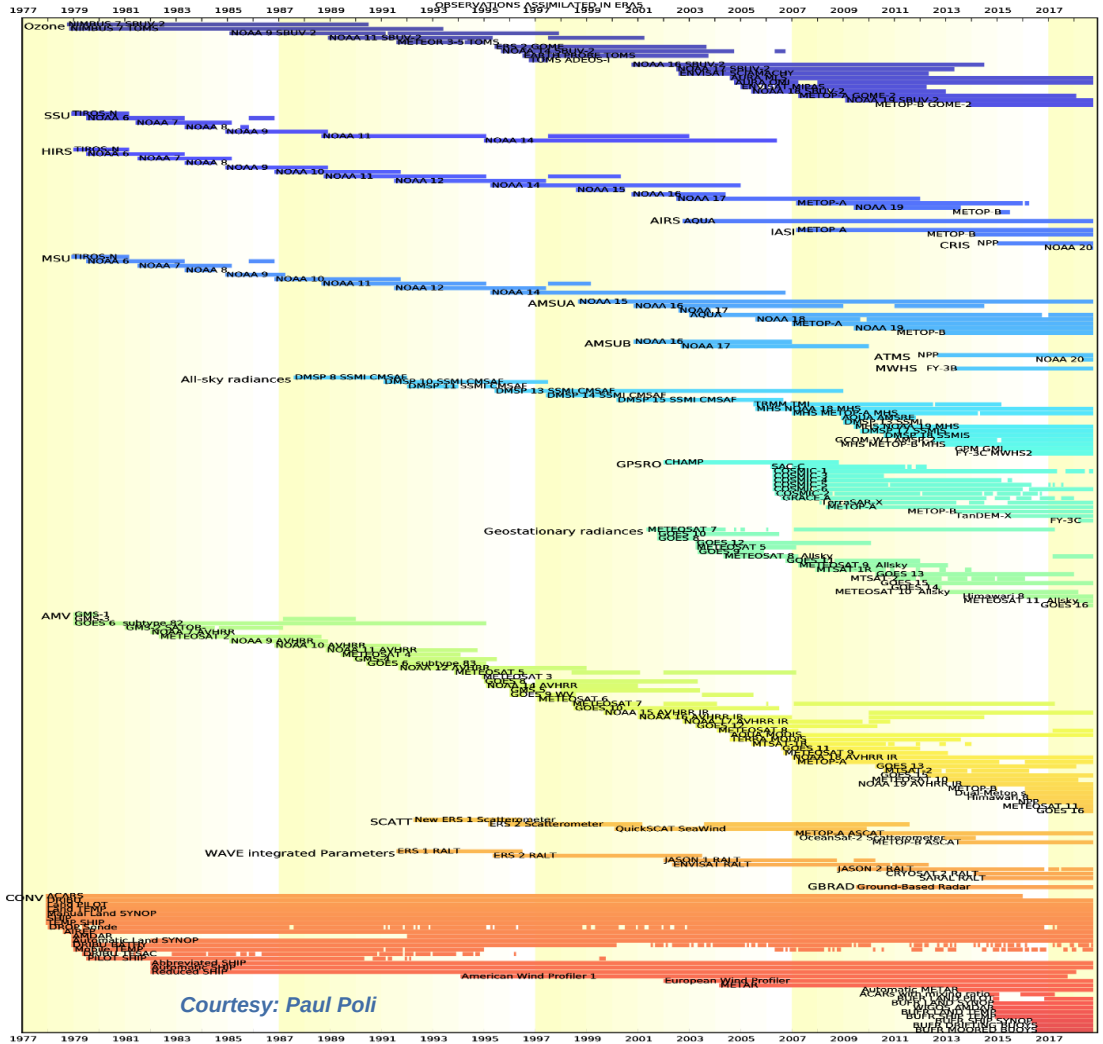
Wave Height: ERS-1,ERS-2, Envisat, Jason

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



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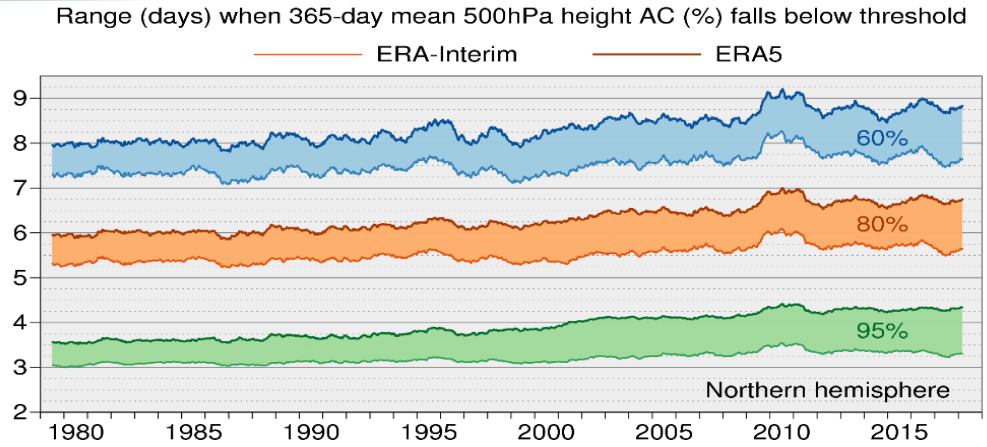
Skill from re-forecasts as a measure for the accuracy of reanalysis products



Re-forecasts from ERA5 have higher skill than those from ERA-Interim

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

Also: better analyses produce better forecasts

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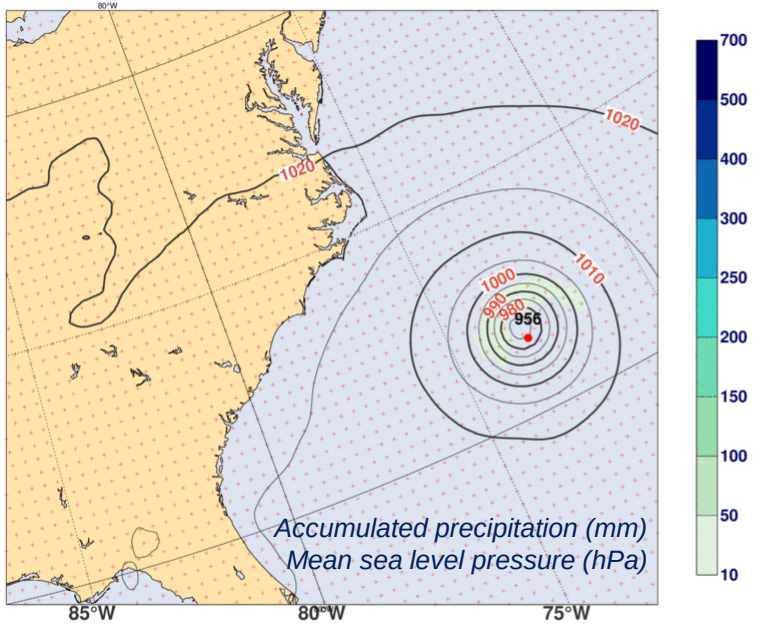
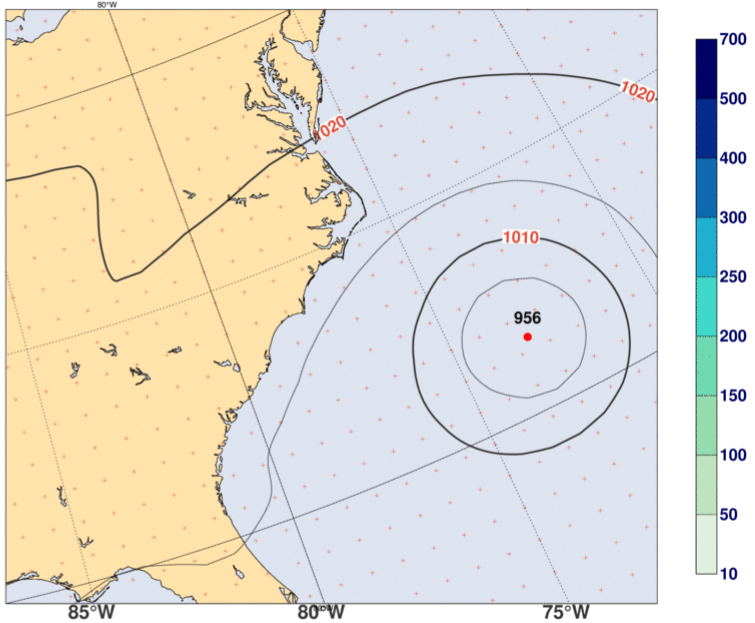
Better model, more and better observations, higher resolution, hourly output



ERA5



ERA-Interim

Freja Vamborg, Hans H

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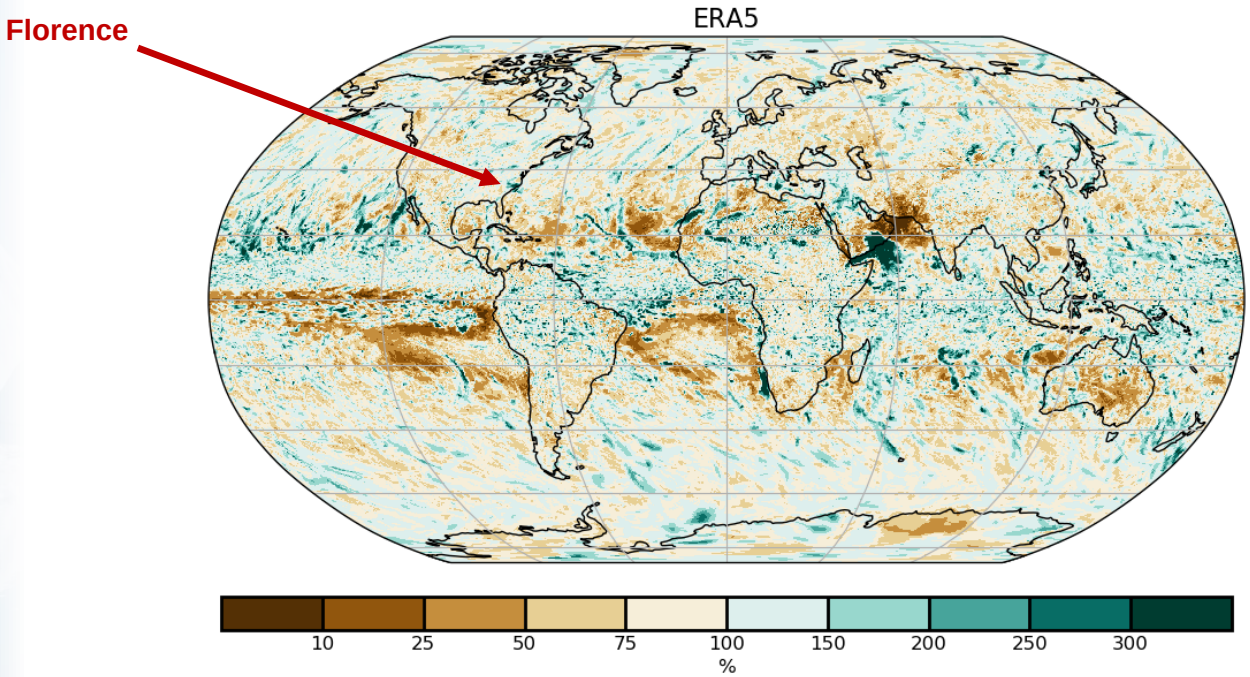
Maximum of daily ERA5 precipitation in 2018 relative to the 1981-2010 climatology



Courtesy of Adrian Simmons, Freja Vamborg; to appear in BAMS SOC 2019

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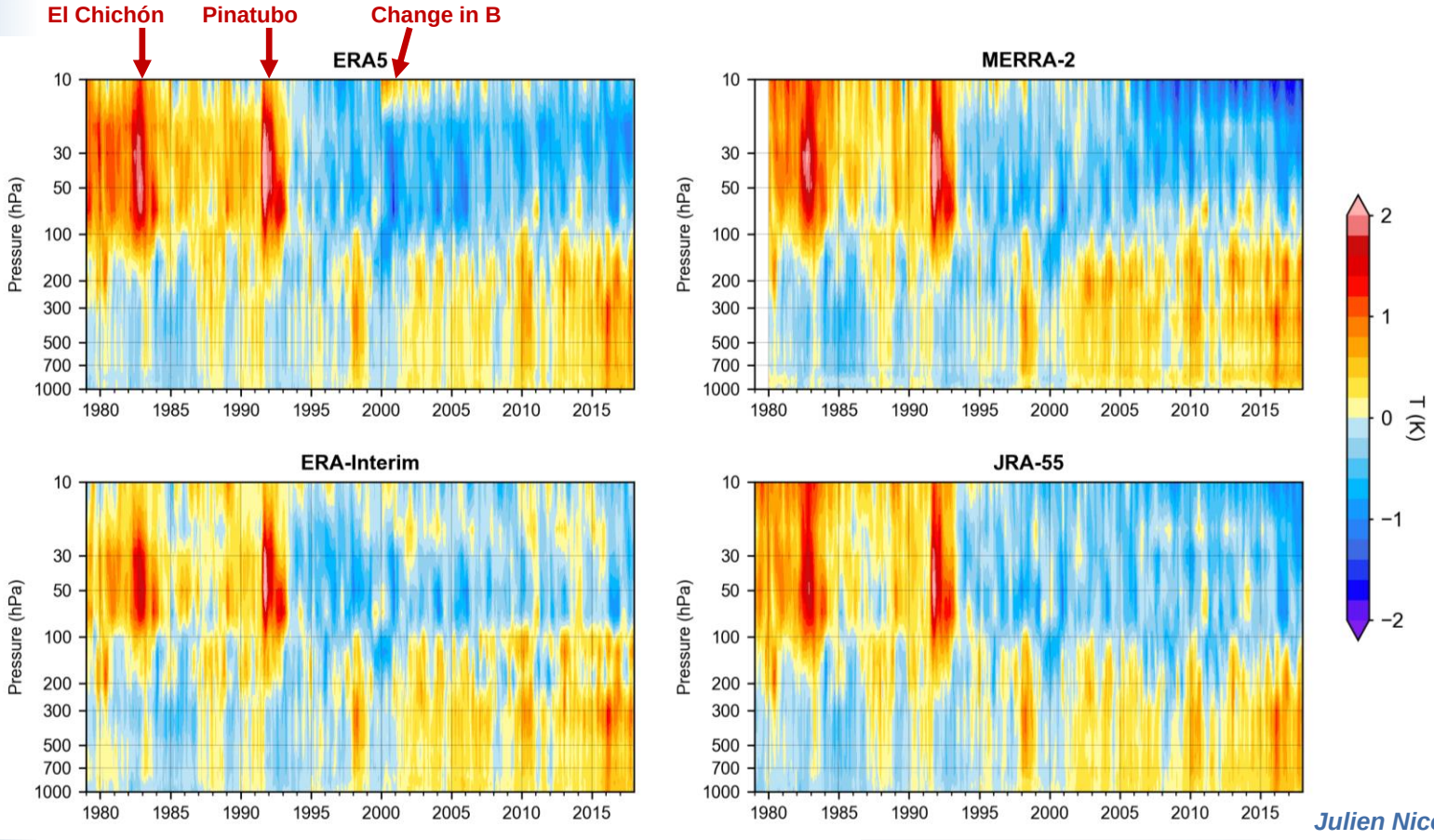
Global mean temperature compared to 1981-2010



Julien Nicolas

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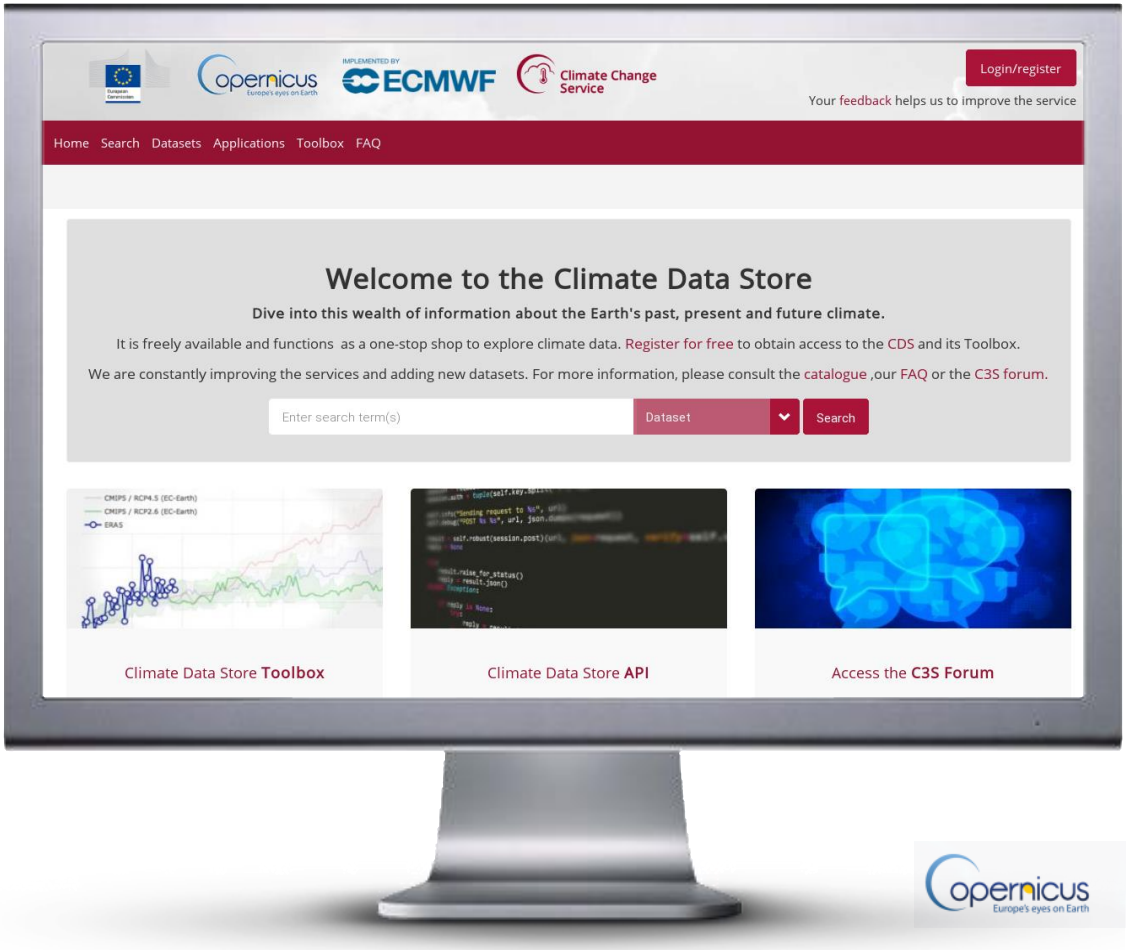
ERA5 in the Climate Data Store



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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 Indicators
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	

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How to access ERA5 data?

Online data sets: Copernicus Climate Data Store | Copernicus Climate 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:

- CKB portal:Copernicus Knowledge Base - Copernicus Knowledge Base - ECMWF Confluence Wiki
- How to download data: How to download ERA5 - Copernicus Knowledge Base - ECMWF Confluence Wiki
- ERA5 online documentation: ERA5 data documentation - Copernicus Knowledge Base - ECMWF Confluence Wiki
- C3S forum: forum - Copernicus User Support Forum - ECMWF Confluence Wiki

ERA5 reference:

- ECMWF Newsletter (Spring 2019): Global reanalysis: goodbye ERA-Interim, hello ERA5 | ECMWF
- ERA report: Operational global reanalysis: progress, future directions and synergies with NWP | ECMWF
- Peer-reviewed: in preparation (2019)

Copernicus user support: copernicus-support@ecmwf.int

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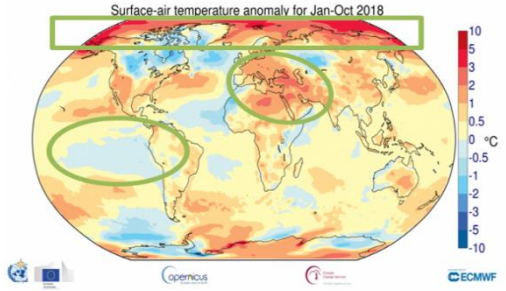
Final remarks and outlook

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

WMO climate statement: past 4 years warmest on record

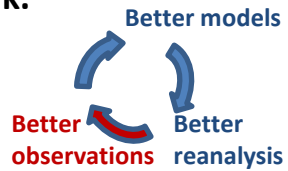


Reanalysis provides a physically complete view of the recent climate.

- 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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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) ***2-5 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 62 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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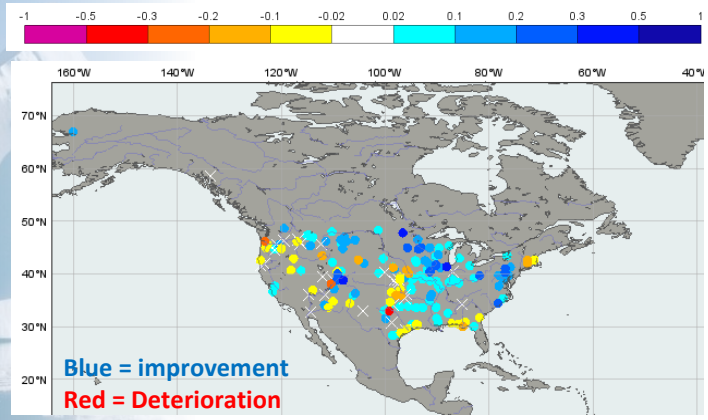
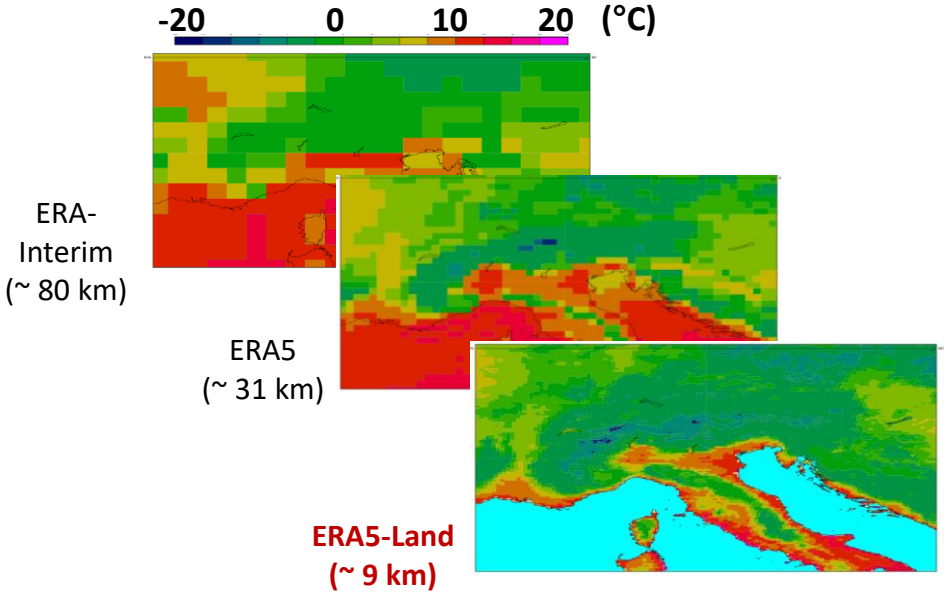
ERA5-Land, a high-resolution downscaling of the land-surface component



Discharge time series correlation difference ERA5-Land vs. ERA5



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

Joaquin Munoz-Sabater

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