



Climate Change

ERA5, the ECMWF C3S State-of-the-art Global Atmospheric Reanalysis

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Copernicus Service - brief introduction



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C O P E R N I C U S

The European Commission has **entrusted** ECMWF with the implementation of the **Copernicus Climate Change Service (C3S)** and the **Copernicus Atmosphere Monitoring Service (CAMS)**





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The Copernicus Climate Change Service (C3S) Vision

To support European adaptation and mitigation policies:

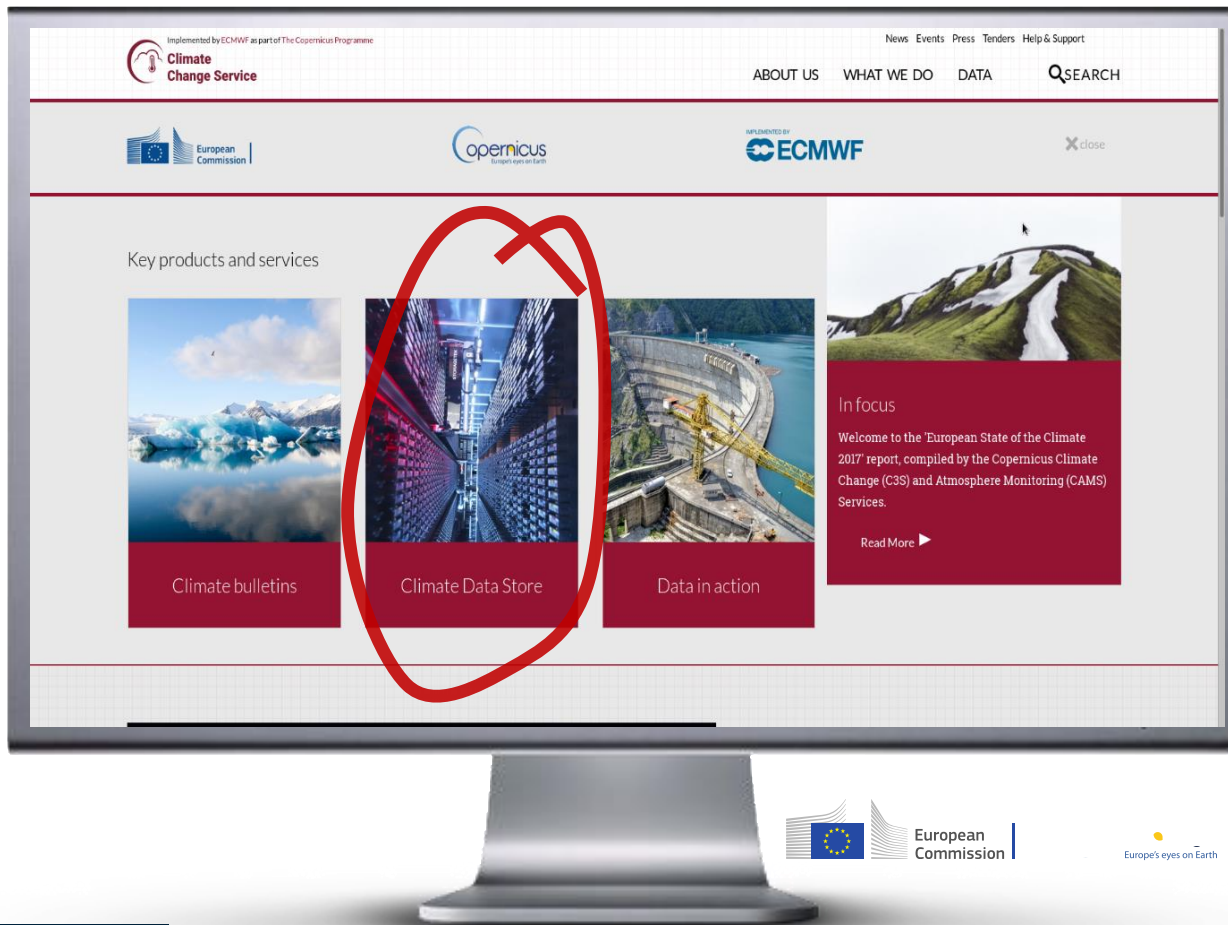
- Build upon massive European investments in science and technology
- Be an authoritative source of climate information for Europe
- Enable the market for climate services





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<https://climate.copernicus.eu>





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Climate Data Store

<https://cds.climate.copernicus.eu>

>10,000
users



The CDS contains **observations**, global and regional **climate reanalyses**, global and regional **climate projections** and **seasonal forecasts**. It also contains generic and **sectoral climate indicators**.

The CDS is designed as a **distributed system**, providing improved access to **existing datasets** through a **unified web interface**.



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CDS inventory



Scientific basis:

- Essential Climate Variables as defined by GCOS
- GCOS Status Report and Implementation Plan
- IPCC, CMIP

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
reanalyses for
Europe and Arctic

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



Europe's eyes on Earth



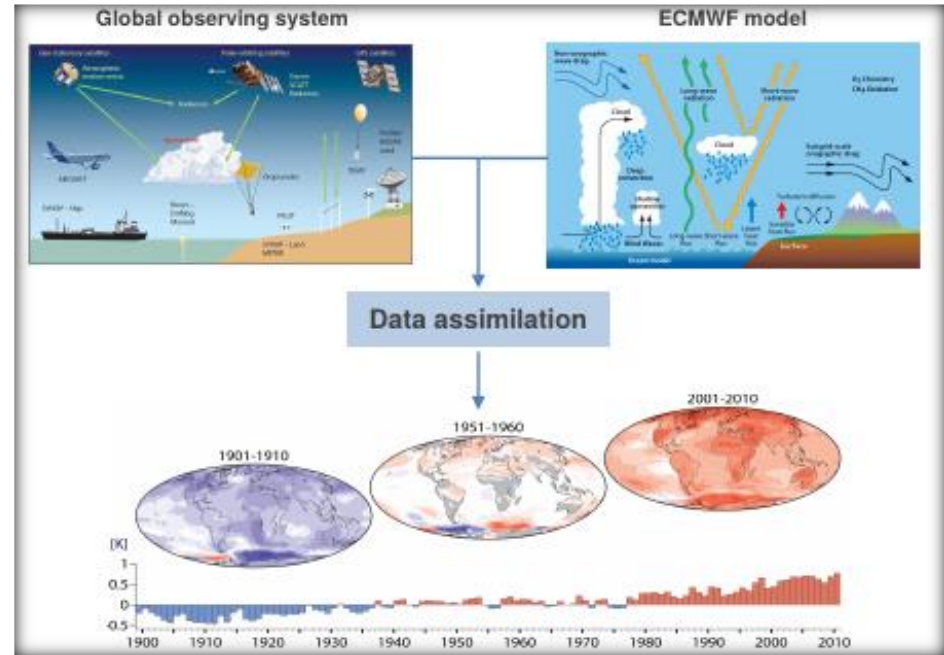


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Why Reanalysis?

Reanalysis offers a detailed overview of the past atmosphere (and other components)

- **Complete:** combining vast amounts of observations into (global) fields
- **Consistent:** use the same physical model and DA system throughout
- **State-of-the-art:** use the best available observations and model at highest feasible resolution
- *Reanalysis allows for a close monitoring of the Earth's climate system also where direct observations are sparse.*





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ERA5 Configuration and Performance



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ECMWF has a long experience with reanalysis

Atmosphere/land

1) 1979 - 1981
FGGE

2) 1994 - 1996
ERA-15

3) 2001 - 2003
ERA-40

4) 2006 - ...
ERA-Interim

5) 2016 - ...
ERA5

including ocean waves



Ocean

2006
ORAS3

2010 - ...
ORAS4

2016 - ...
ORAS5

including sea ice

Centennial

2013 - 2015
ERA-20CM/20C

2016
CERA-20C

2017
CERA-SAT

Coupled

Enhanced land

2012
ERA-Int/Land

2014
ERA-20C/Land

2018 - ...
ERA5L



Atmospheric composition

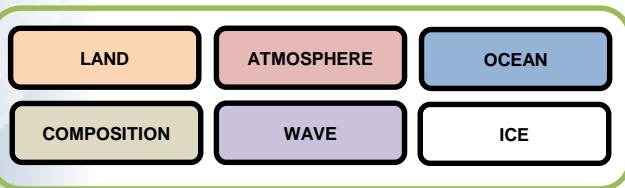
2008 - 2009
GEMS

2010 - 2011
MACC

2017 - ...
CAMS



ECMWF





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C3S Global Reanalysis

ERA5 is in production at ECMWF

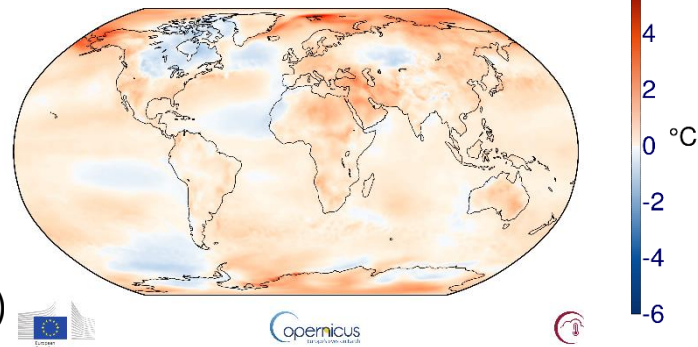
ERA5 is replacing ERA-Interim

In 2015-2018 ERA-Interim had about **40,000 users**

To date ERA5 is publicly available from **1979 to Feb 2019 (40 years!)**

Improvements compared to ERA-Interim:

- Benefit from 10 years model development
- Much higher resolution: **31km** versus 80km
- More and better input data
- Hourly output
- Uncertainty estimate (at 62km)



T2m, Feb 2018 - Jan 2019
relative to 1981-2010

CDS Public Release plan for 2019:

- **Currently:** updates 2-months behind real time
- **soon:** updates 2-5 days behind real time: **ERA5T**
- **Next:** access to ERA5 observations
- **Q1 2020:** **1950-1978.**



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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, (<i>inconsistent SST and sea ice</i>)	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)



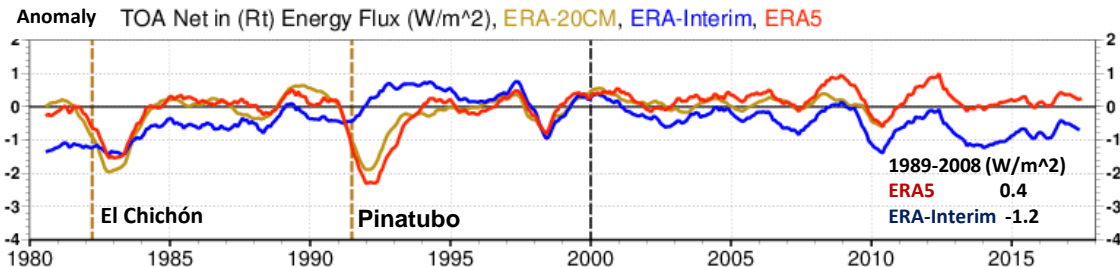
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ERA5 forcing appropriate for climate

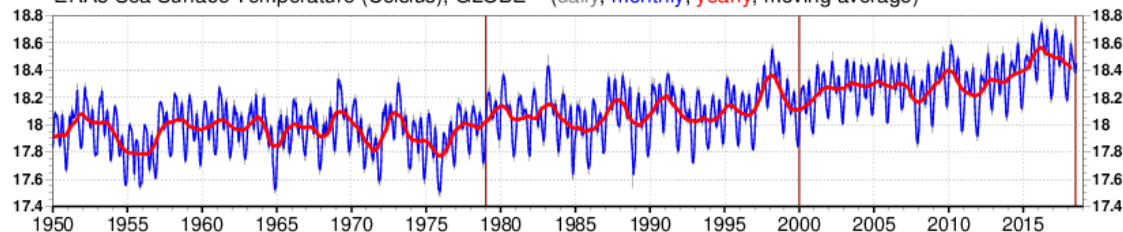
CMIP5 recommended data sets

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

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



ERA5 Sea Surface Temperature (Celsius), GLOBE (daily, monthly, yearly, moving average)

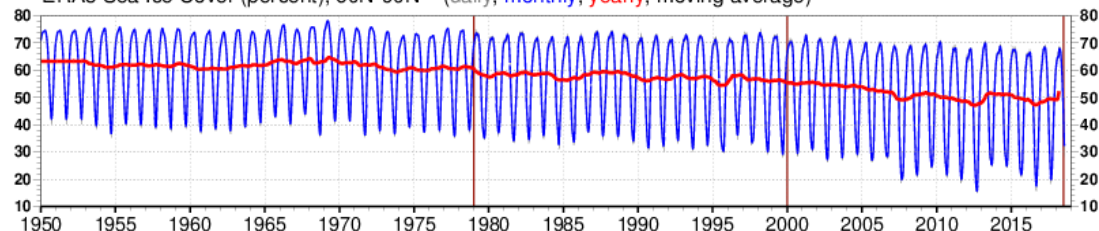


SST and sea ice cover

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)



ropean
mission

Europe's eyes on Earth

ECMWF



The ERA5 observing system

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Over 200 report types

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

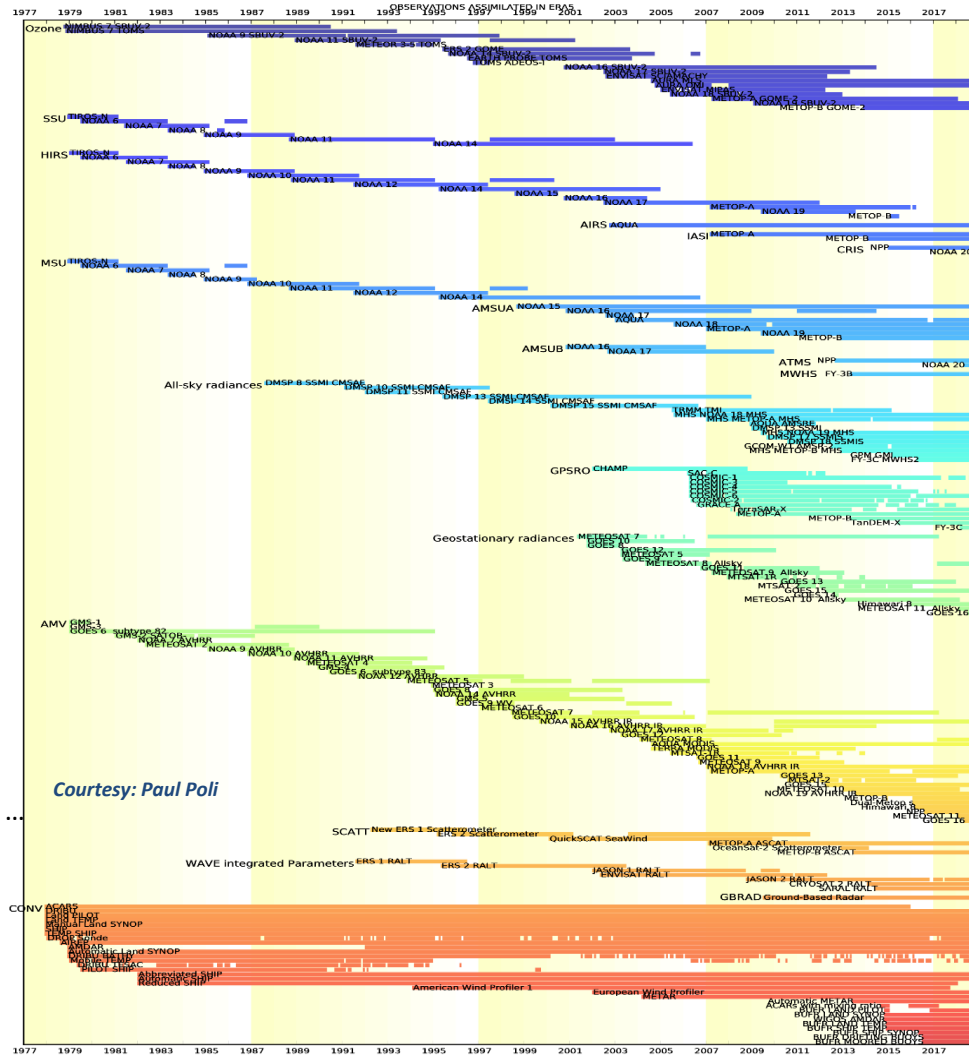
IASI, CrIS, ASCAT, ATMS, MWHS, ...

Latest Satellites

MET-11, Himawari, NOAA-20, GOES-16

Improved data usage

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





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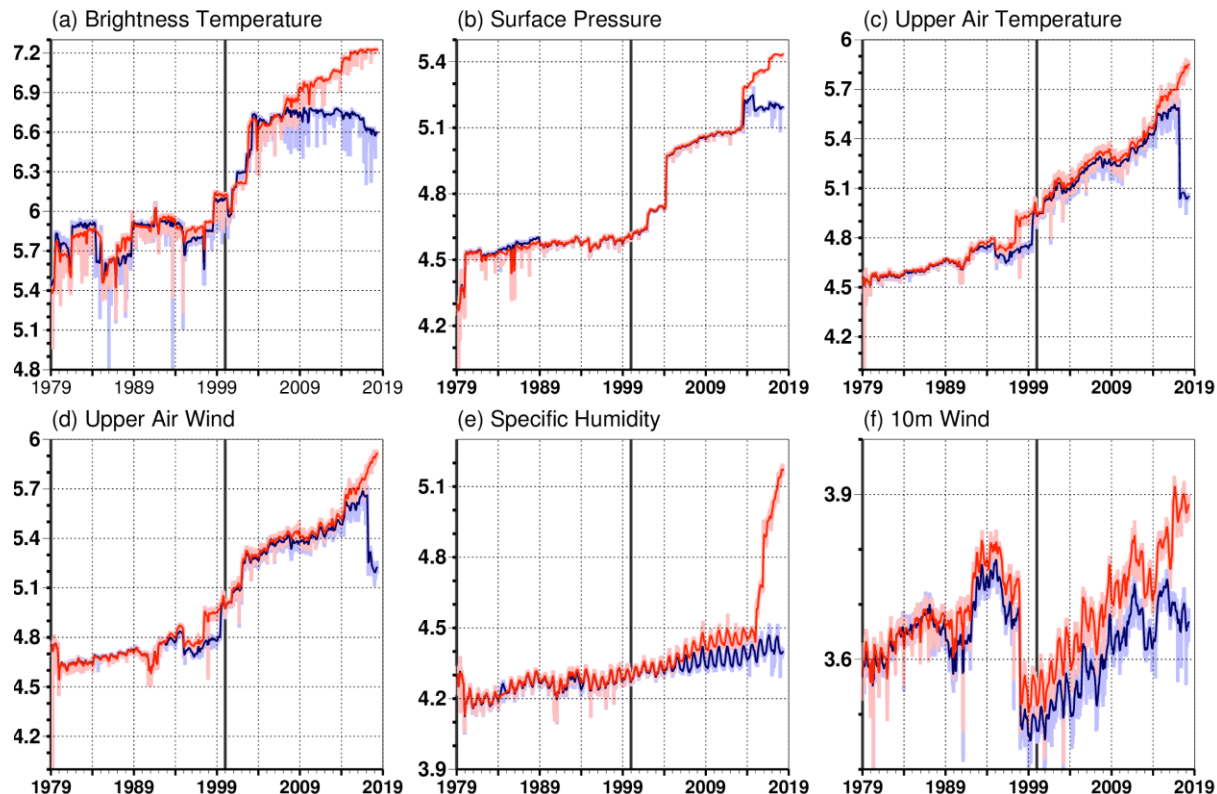
ERA5 data usage compare to ERA-Interim

ERA5 data usage has increased from 0.75 million/day (1979) to 21 million/day (2018)

ERA-Interim is progressively getting outdated. It is not able to:

- use the latest instruments
- respond to changes in data format (like the ongoing transition to BUFR format for conventional data)

*Number of used observations per day (10log scale) for **ERA5** and **ERA-Interim***





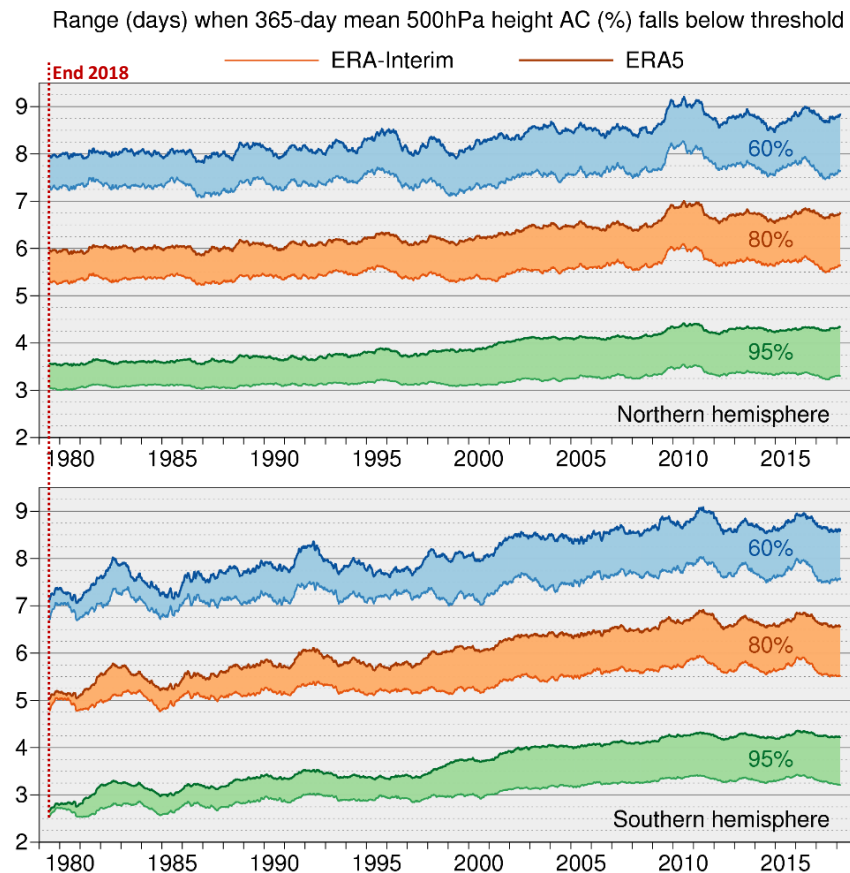
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ERA5 Performance and Status

Improvement of forecast skill: up to one day gain with respect to ERA-Interim

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

- It provides the 'glue' between observations which are scattered across space, time and geophysical variables
- Also: better analyses produce better forecasts



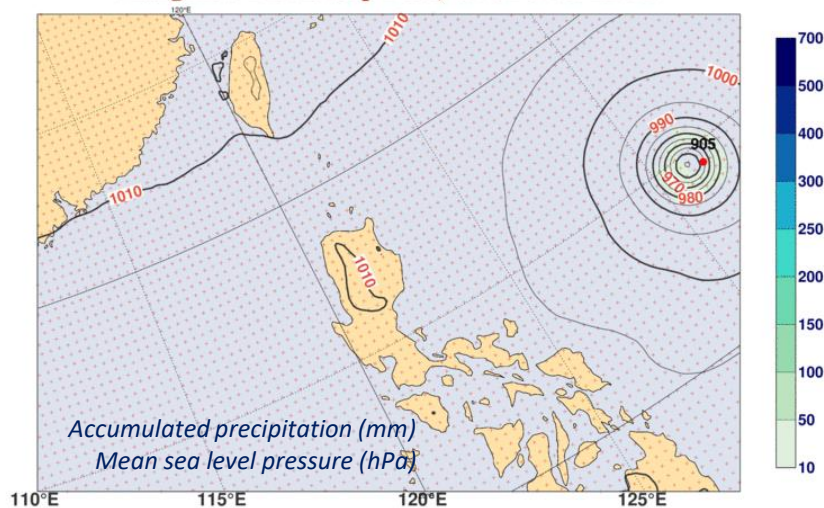
Re-forecasts from ERA5 have higher skill than those from ERA-Interim



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

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Mangkhut Thu 13 Sep 2018, 01 UTC for ERA5

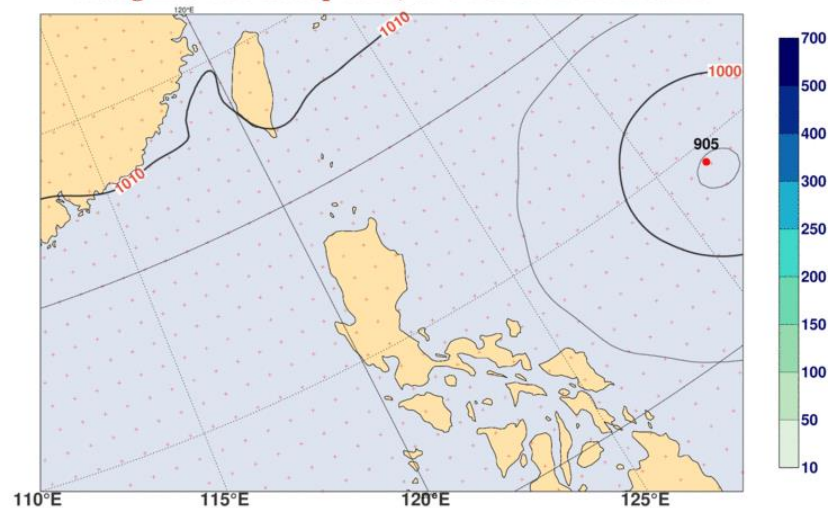


ERA5



Freja Vamborg, Hans Hersbach

Mangkhut Thu 13 Sep 2018, 01 UTC for ERA-Interim



ERA-Interim

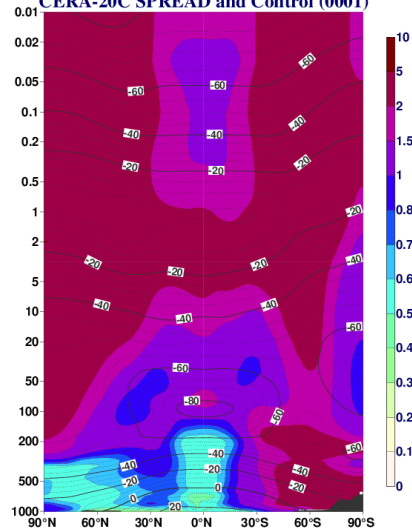




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Ensemble spread as a measure for the *synoptic* ERA5 uncertainty

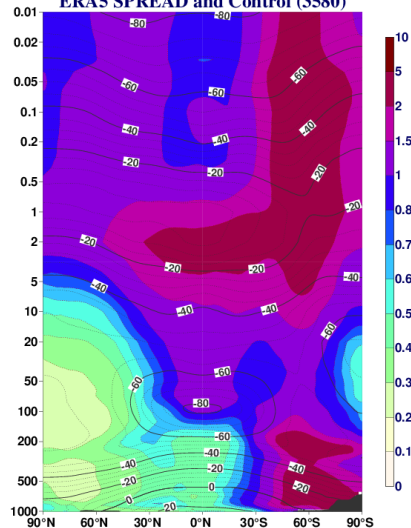
Temperature (Celsius) in MAM 1971
CERA-20C SPREAD and Control (0001)



1971 CERA-20C:

Surface pressure, marine
wind, only

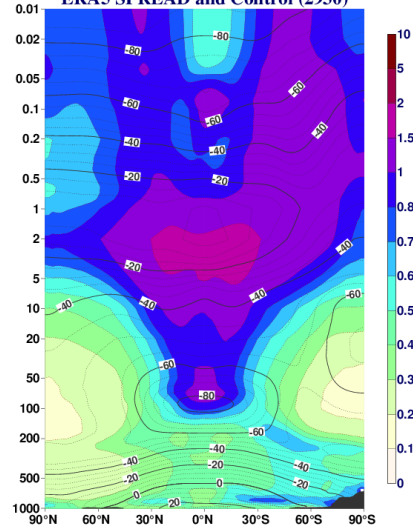
Temperature (Celsius) in MAM 1971
ERA5 SPREAD and Control (3580)



1971 ERA5:

Upper-air data

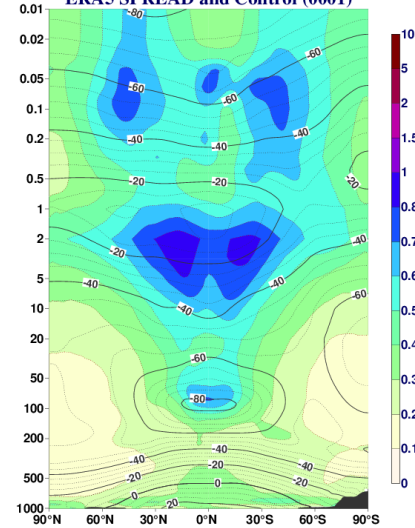
Temperature (Celsius) in MAM 1980
ERA5 SPREAD and Control (2930)



1980 ERA5:

Early-satellite era

Temperature (Celsius) in MAM 2018
ERA5 SPREAD and Control (0001)



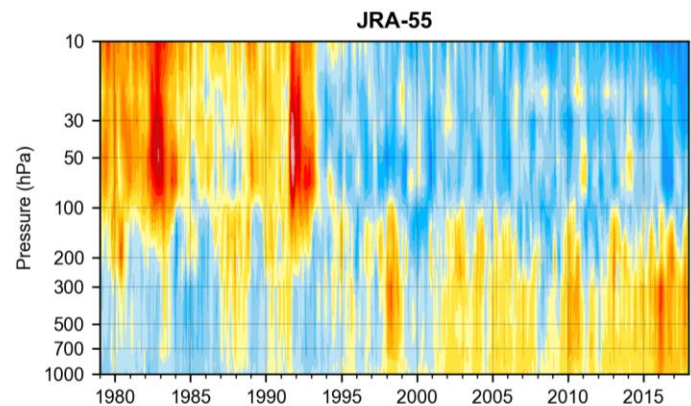
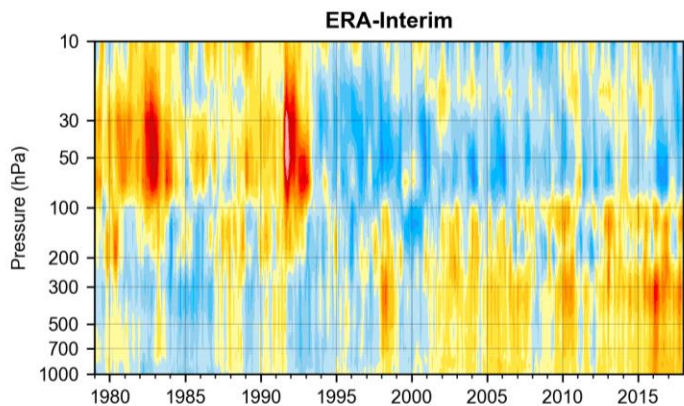
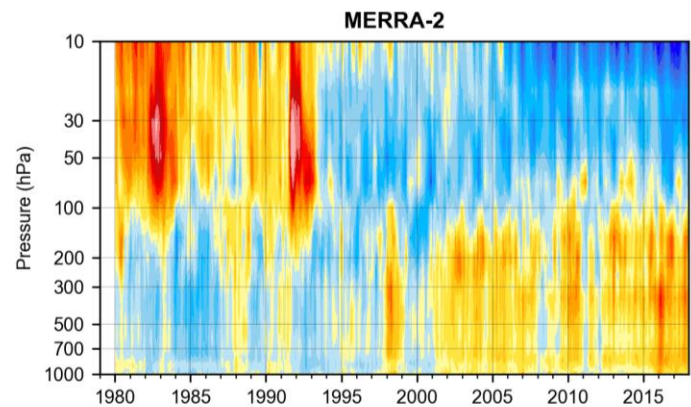
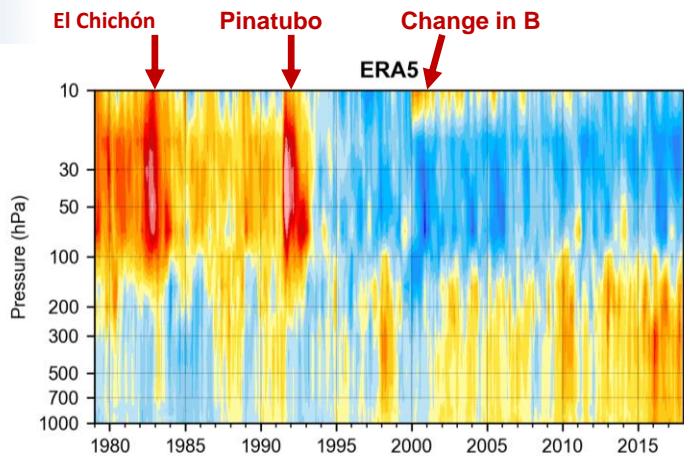
2018 ERA5:

Current observing system



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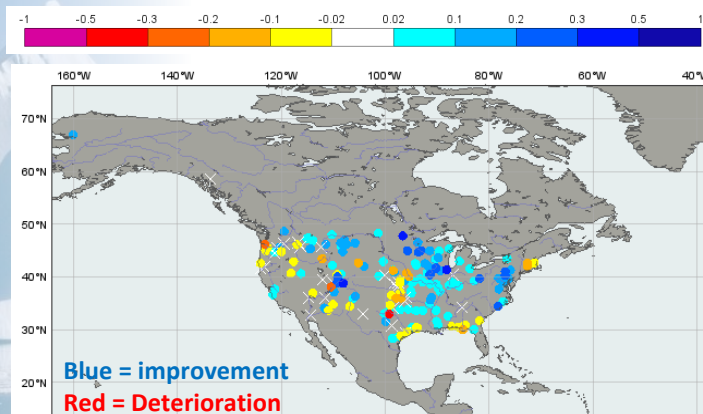
Global mean temperature compared to 1981-2010





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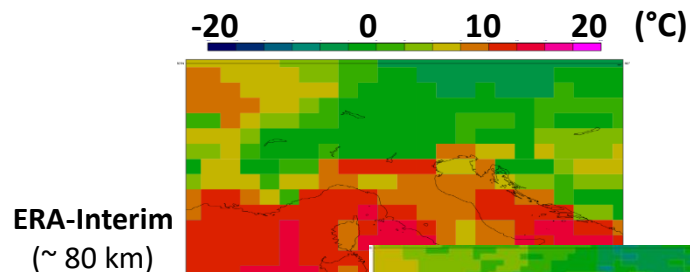
ERA5-Land, a high-resolution downscaling of the land-surface component



Discharge time series correlation difference ERA5-Land vs. ERA5

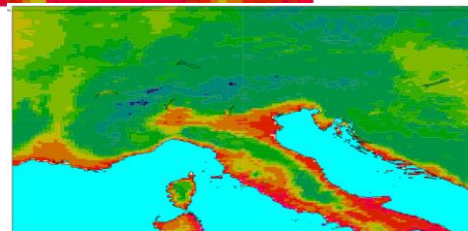
ERA5-Land is currently in production.

To become available via the **C3S Climate Data Store** in 2019



ERA5
(~ 31 km)

ERA5-Land
(~ 9 km)

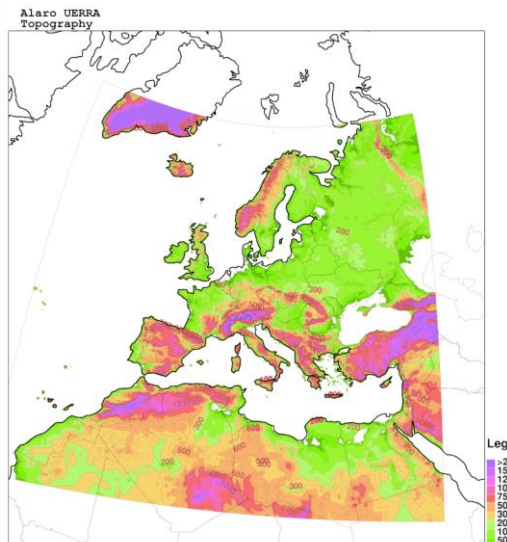




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Copernicus C3S High-resolution Regional Reanalysis

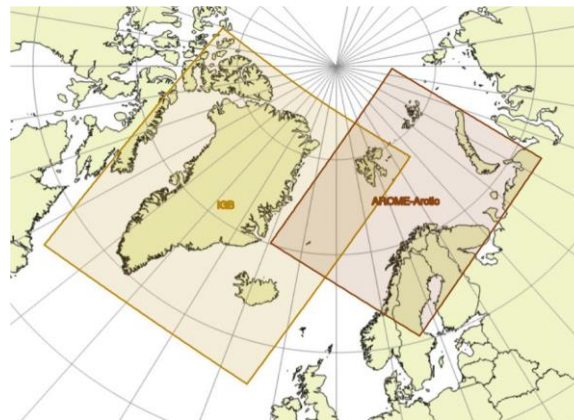
European area



5.5 km, 106 levels, Harmonie/Aladin, hydrostatic
Surface analysis at 5.5 km – no downscaling
Plus 10 ensemble members at 11km
Will start from the early 1980s

SMHI, Météo-France - MET Norway

Arctic area



2.5 km, 65 levels, Harmonie/Arome non-hydrostatic
Reanalysis period July 1997 – June 2021 (24 years)

Special emphasis on handling of “cold surfaces”: snow,
sea ice, glaciers

Met Norway , the Nordic countries and Météo-France.



Europe's eyes on Earth





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Concluding Remarks and Outlook



Concluding Remarks and Outlook

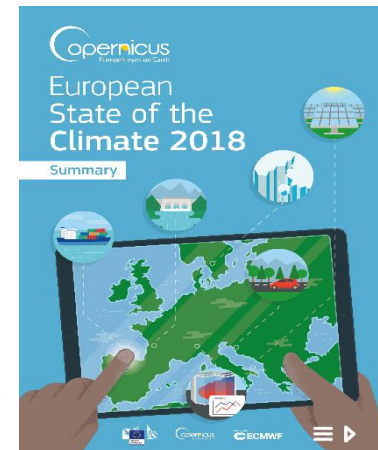
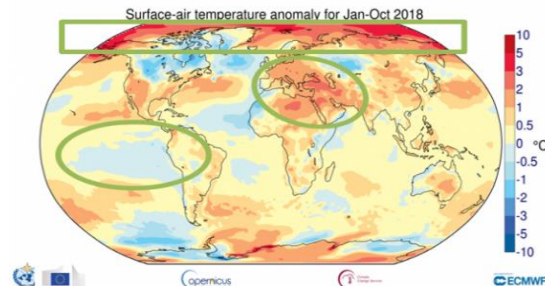
ERA5 is available through the C3S CDS from 1979 and is replacing ERA-Interim.

- Much higher resolution, better model, better and more observations;
- To include timely updates (**ERA5T**) with a latency of 2-5 days;
- the production of ERA5 spanning 1950-1978 is well underway;
- C3S User service Desk, Knowledge Base, FAQ's, user support;
- Article on ERA5 in preparation – to appear in QJRMS by end of 2019.

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.

WMO climate statement: past 4 years warmest on record





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Concluding Remarks and Outlook

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

- A **centennial global reanalysis** going back to 1851 (to start around 2021)
- A full-observing-system coupled reanalysis **ERA6** (to start around 2023)
- A joint **CAMS/C3S** reanalysis with coupled chemistry, from 1979, with timely updates
- Future **regional reanalysis** by third parties. Possibly centennial.



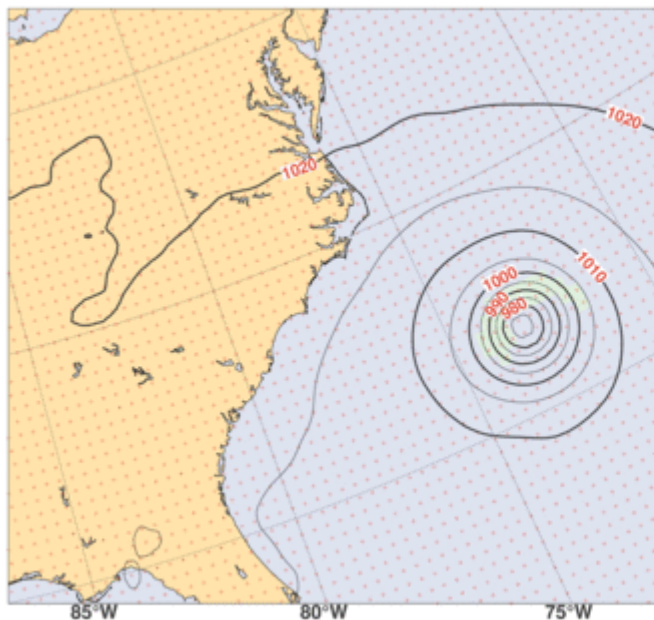
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Horizontal resolution and depiction of tropical cyclones

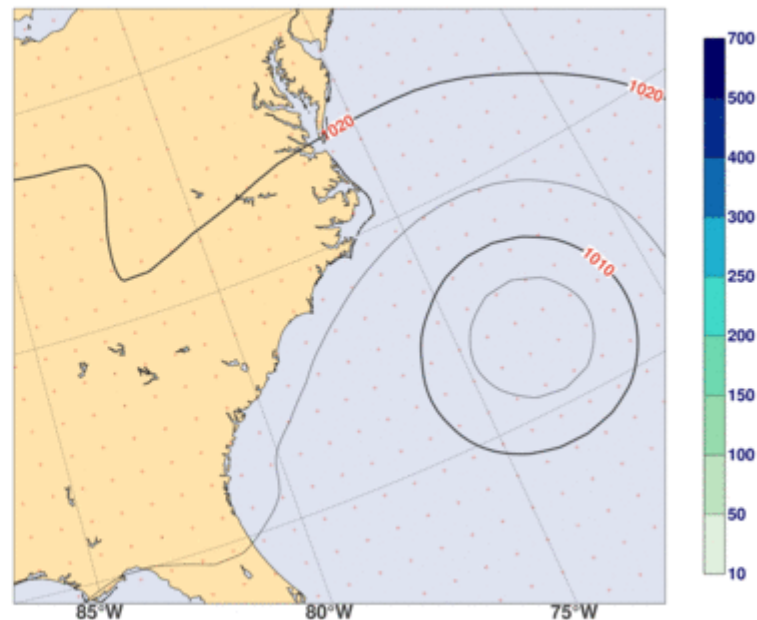
Better model, better and more observations, higher resolution

New: hourly output

Florence Thu 13 Sep 2018, 01 UTC for ERA5



Florence Thu 13 Sep 2018, 01 UTC for ERA-Interim





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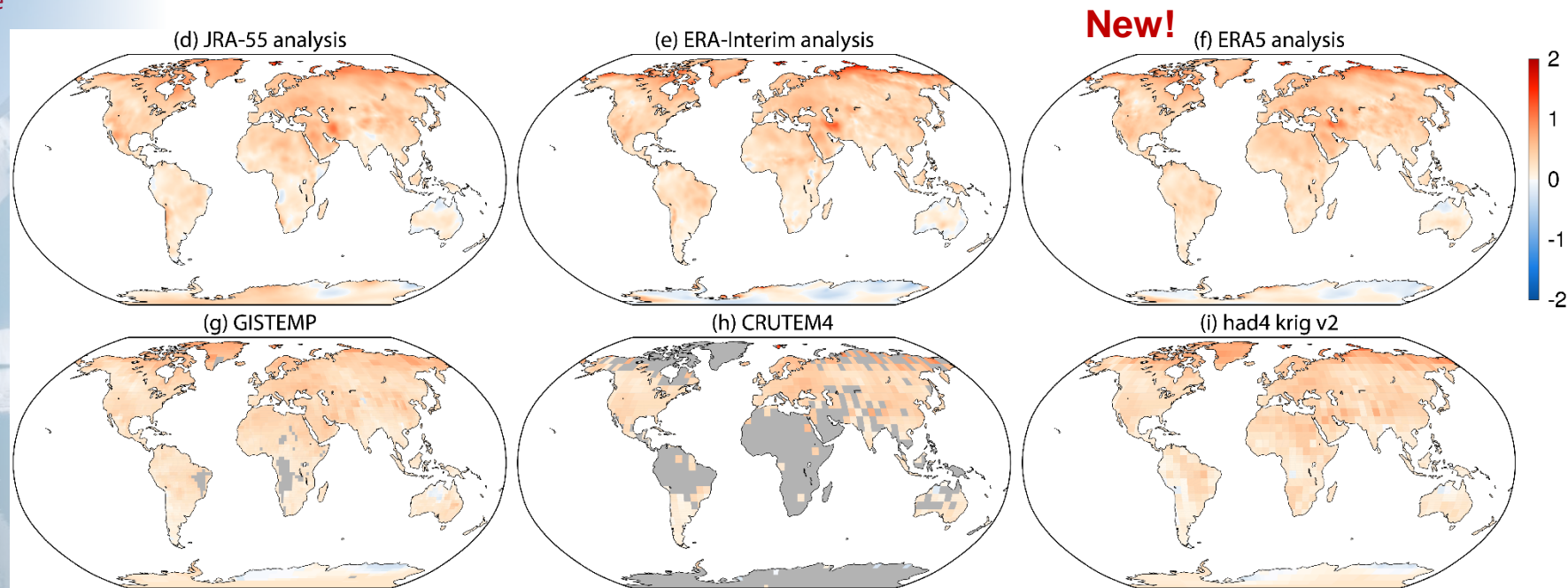
Extra Slides



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Linear trend in surface air temperature over land

Kelvin/Decade for 1979-2017 (~0.18 globally)



Adrian Simmons

There is a good general consensus between various products (including ERA5), although there are differences in the details.