# An overview of ERA5

Climate Change

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European Centre for Medium-Range Weather Forecasts
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# Overview

- Overview of Reanalysis products at ECMWF
- ERA5, the follow up of ERA-Interim, configuration and status
- ERA5 performance
- Concluding remarks

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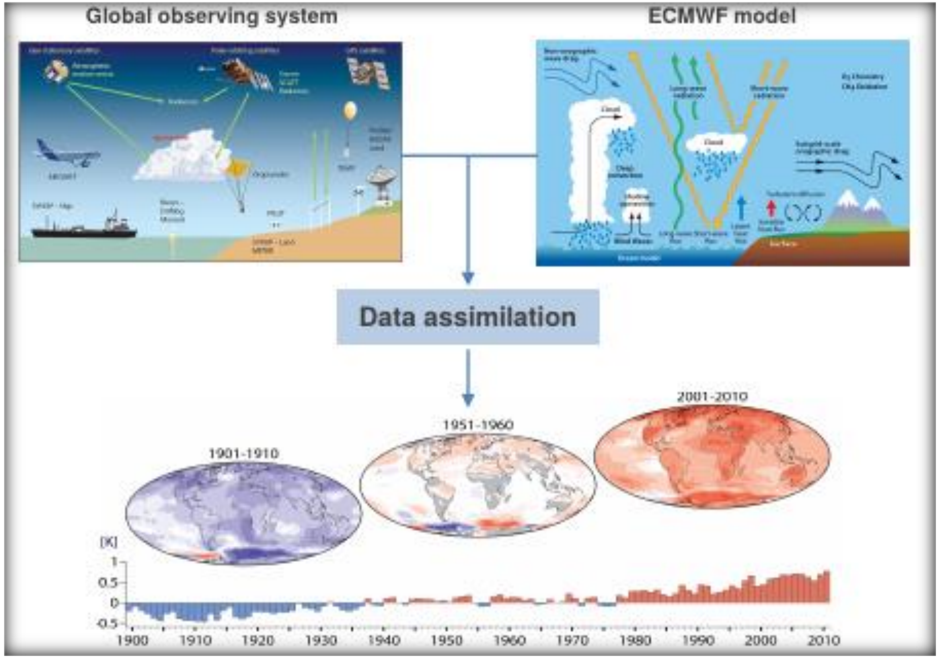
# Why Reanalysis?

## 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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# Reanalyses Produced at ECMWF

*Atmosphere/land* *including ocean waves*

| 1) 1979 - 1981 FGGE | 2) 1994 - 1996 ERA-15 | 3) 2001 - 2003 ERA-40 | 4) 2006 - … ERA-Interim | 5) 2016 - … ERA5 |
|---|---|---|---|---|

*Ocean* *including sea ice*

| 2006 ORAS3 | 2010 - … ORAS4 | 2016 - … ORAS5 |
|---|---|---|

*Centennial* *Coupled*

| 2013 - 2015 ERA-20CM/20C | 2016 CERA-20C | 2017 CERA-SAT |
|---|---|---|

*Enhanced land*

| 2012 ERA-Int/Land | 2014 ERA-20C/Land | … ERA5L |
|---|---|---|

*Atmospheric composition*

| 2008 - 2009 GEMS | 2010 - 2011 MACC | 2017 - … CAMS |
|---|---|---|

**Towards a coupled earth system**

| | | |
|---|---|---|
| LAND | ATMOSPHERE | COMPOSITION |
| OCEAN | WAVE | ICE |

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# ERA-Interim users world wide

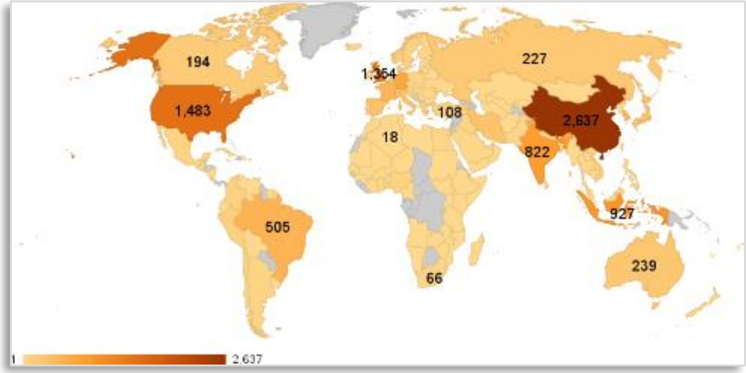
ERA-Interim had more than 20,000 unique users in 2015-2016 alone.

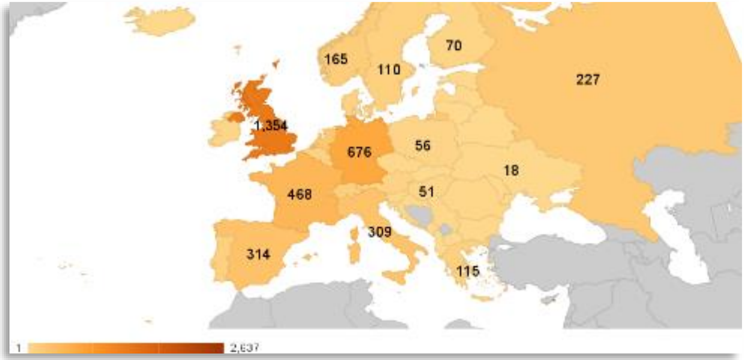
Users and stakeholders:

- Climate monitoring & provision of climatologies
- ECMWF member states
- Research and education, over 7,000 citations
- Public sector
- Space agencies
- Commercial applications

However, ERA-Interim is 10 years old and needs replacement

Unique registered users in 2016

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# What is new in ERA5?

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| | ERA-Interim | ERA5 |
|---|---|---|
| Period | 1979 – present | Initially 1979 – present, later addition 1950-1978 |
| Streams | 1979-1989, 1989-present | Parallel streams, one/two per decade |
| Assimilation system | 2006, 4D-Var | 2016 ECMWF model cycle (41r2), 4D-Var |
| ***Model input*** (radiation and surface) | As in operations, *(inconsistent sea surface temperature)* | ***Appropriate for climate***, e.g., evolution greenhouse gases, volcanic eruptions, sea surface temperature and sea ice |
| ***Spatial resolution*** | 79 km globally<br>60 levels to 10 Pa | ***31 km globally***<br>137 levels to 1 Pa |
| ***Uncertainty estimate*** | | Based on a 10-member ***4D-Var ensemble*** at 62 km |
| ***Land Component*** | 79km | ERA5L, 9km (separate, forced by ERA5) |
| ***Output frequency*** | 6-hourly Analysis fields | ***Hourly*** (three-hourly for the ensemble),<br>***Extended list of parameters***<br>***~ 9 Peta Byte (1950 - timely updates)*** |
| ***Extra Observations*** | Mostly ERA-40, GTS | Various ***reprocessed CDRs***, ***latest instruments*** |
| Variational Bias correction | Satellite radiances, radiosondes predetermined | Also ozone, aircraft, surface pressure, newly predetermined for radiosondes. |

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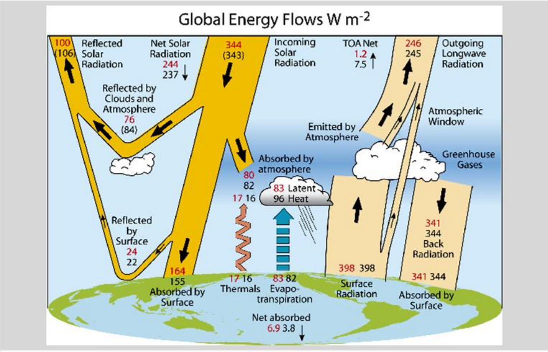
# Forcing and boundary conditions

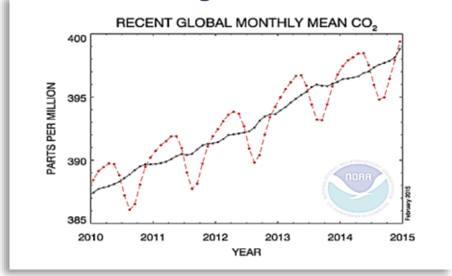
*that reflect the 20th century evolution*

## Solar forcing

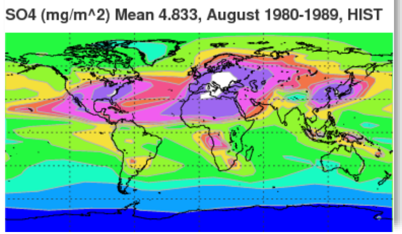



Energy flow in ERA-Interim (red) and ERA-40 (black), Berrisford et. al. 2011; figure adapted from Trenberth et.al., 2009

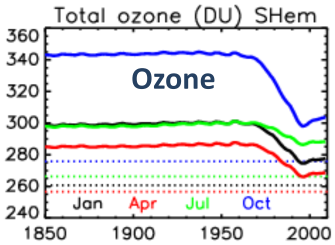
## Greenhouse gases




## Aerosols

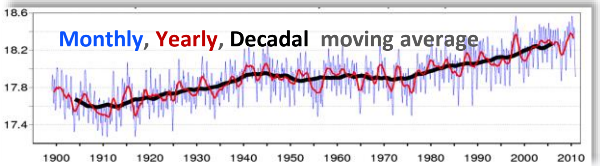



## Volcanic eruptions




AC&C SPARC ozone

## SST and sea ice

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# Status of production ERA5

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**Parallel production Streams:**

**Speed: 7-9 days/day per stream**

**'NRT':** running 2-3 days behind real time

- *so far, released 2-3 months later*
- *Soon: released 1 week behind real time*

**2008-2017: released**

**2000-2007: completed,**

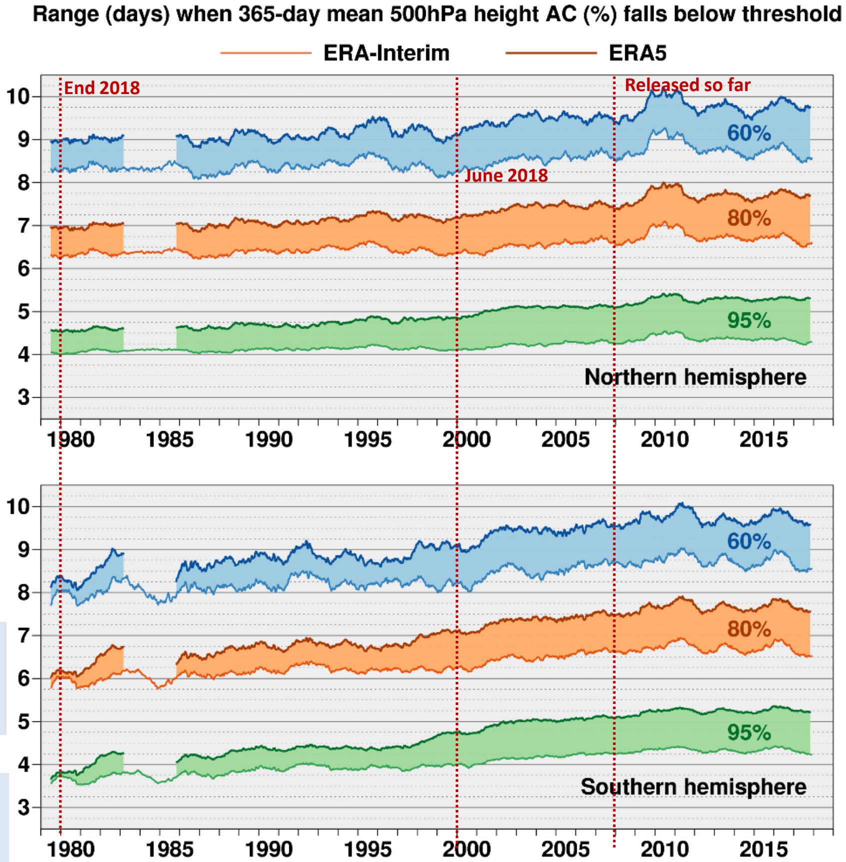
- *to be released end of June*

**1990->1995->1999 streams: to be completed end Sept**

**1979->1985->1989 streams: to be completed end Sept**

**Back-extension from 1950: in preparation**

**Integration ERA5 land has just started**

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# Newly 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

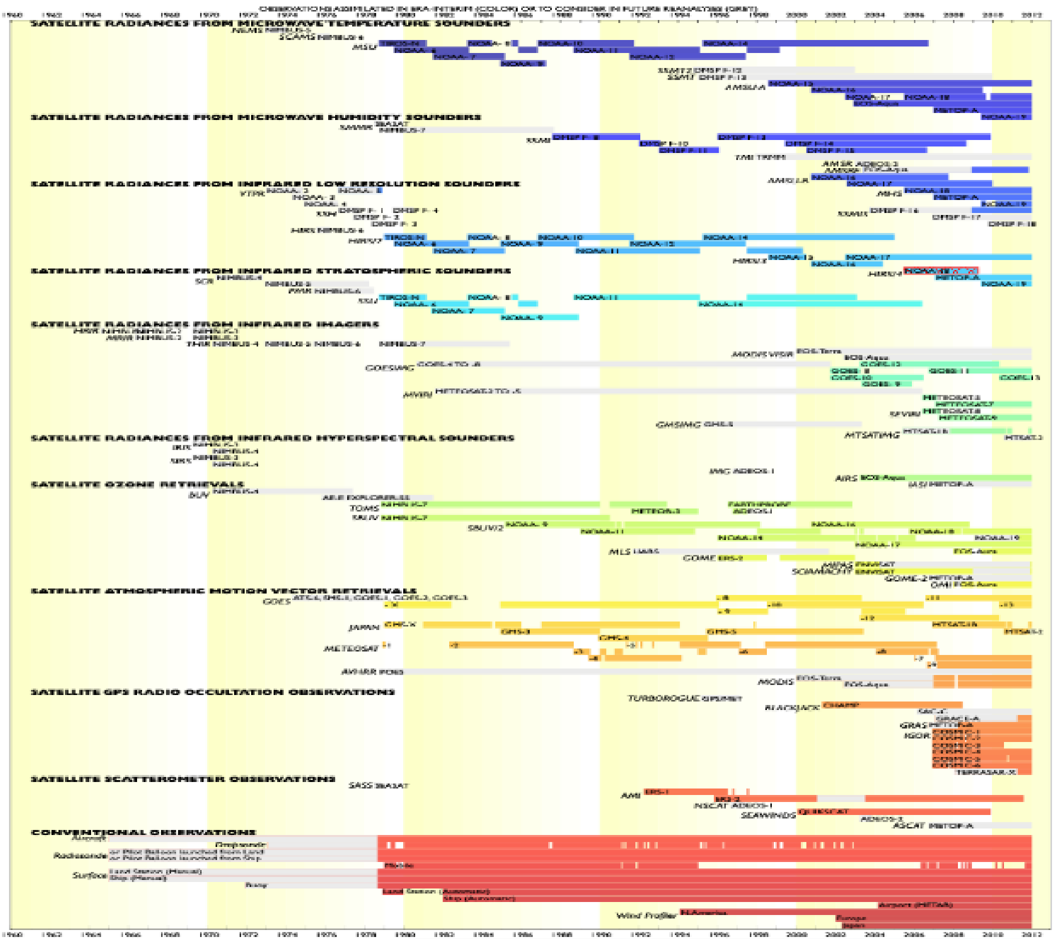
## plus data that were not used by ERA-Interim

IASI, ASCAT, ATMS, Cris, Himawari, …

*Typically the latest instruments:*
*ERA5 is more future proof!*

## and improved data usage

all-sky vs clear-sky assimilation,
latest radiative transfer function …

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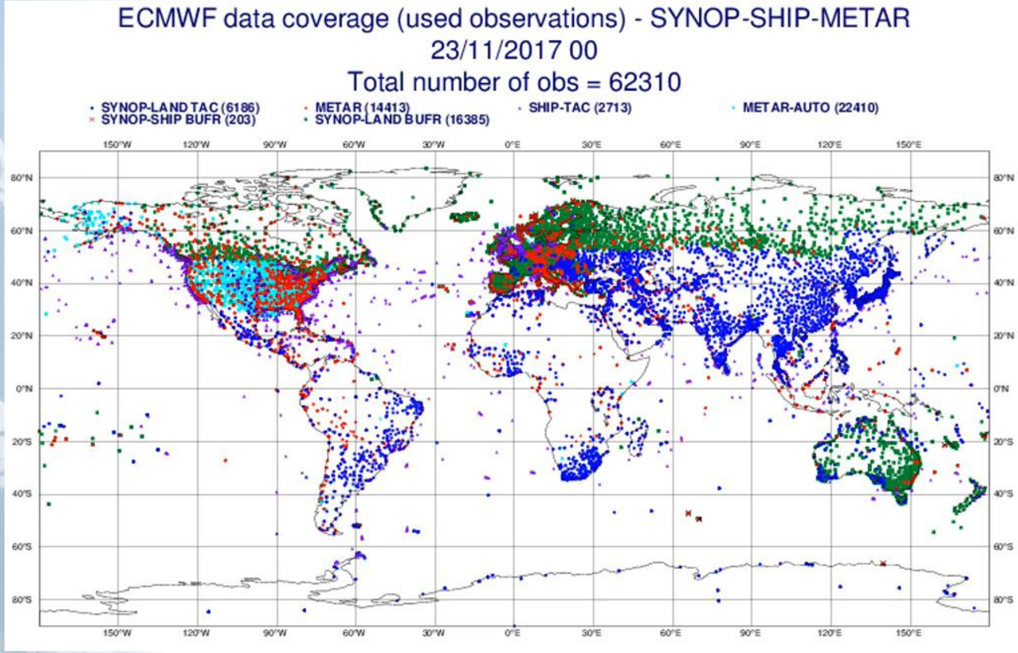
# Data usage in ERA5




***Data sources:***

*In situ, conventional, satellite*

*Global and as resilient as possible*

*Pressure, wind, temperature, humidity, wind, ozone, ..*

*brightness temperature, bending angles, …*

***Multivariate assimilation method:***

*e.g., most variables also provide information on wind*

*(like pressure and brightness temperature)*

***Observation counts in ERA5:***

*Increasing over time*

*Currently ingest about 650 Million observations a day*

*Use about 50 Million of them*

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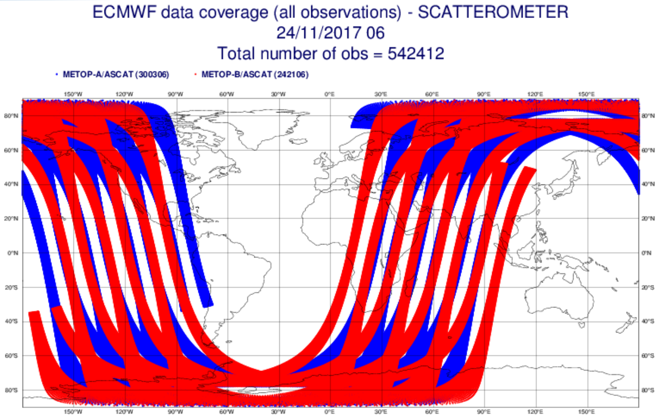
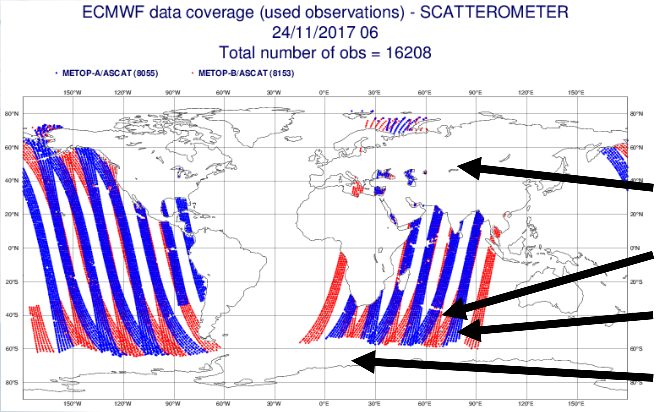
# Quality control




land

Incomplete

thinning

Ice

***Quality Control:***

*Thinning and duplicate checks*

*Blacklisting of known suspect data*

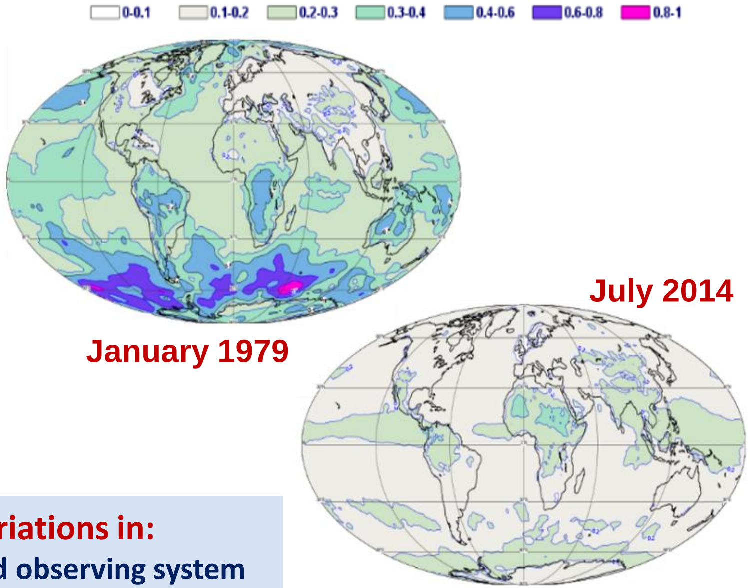
*Sanity checks, such as too far from the model*

*Bias corrections*

# Uncertainty in ERA5

## Uncertainty estimate

Spread in Surface Pressure (hPa)




- 10 member ensemble (EDA)
- $J_b$ in ERA5: 85% static, 15% from EDA
- Ensemble spread and mean
- Spread indicates the relative uncertainty
  - in space and time
  - only accounts for random error (except SST)

$J_b$ is the background error covariance matrix

**Reflects variations in:**

- **ingested observing system**
- **flow-dependent sensitivity**

# Horizontal resolution and depiction of tropical cyclones

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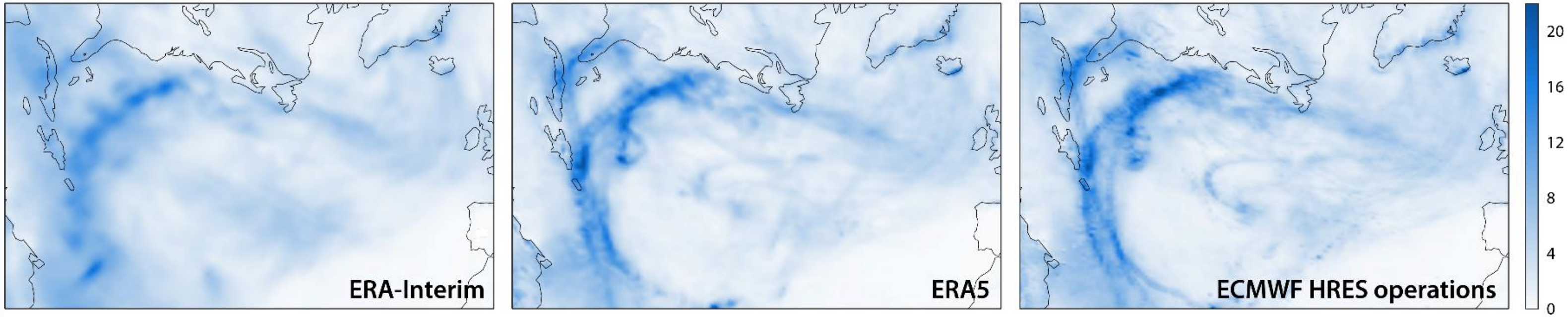
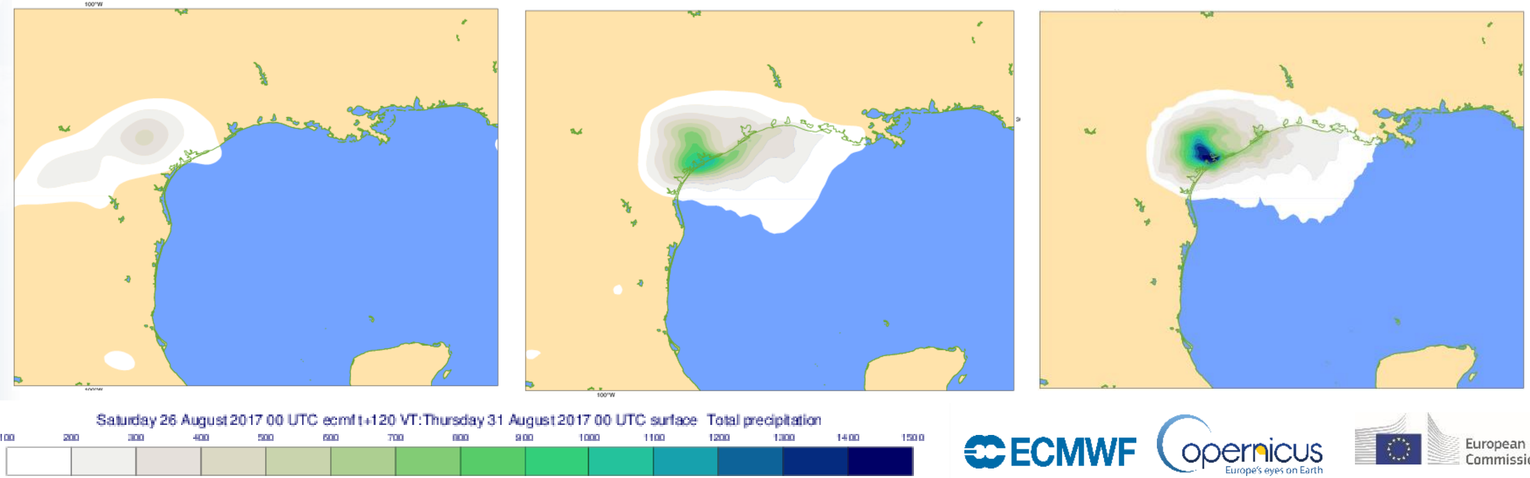
Mean precipitation rate (mm/day) for September 2017




**Horizontal resolutions:** ~80km ~30km ~10km

## 5-day precipitation for Harvey

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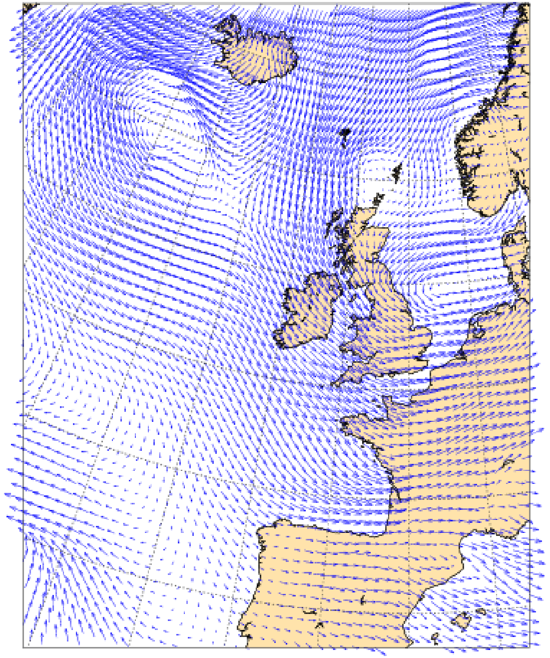
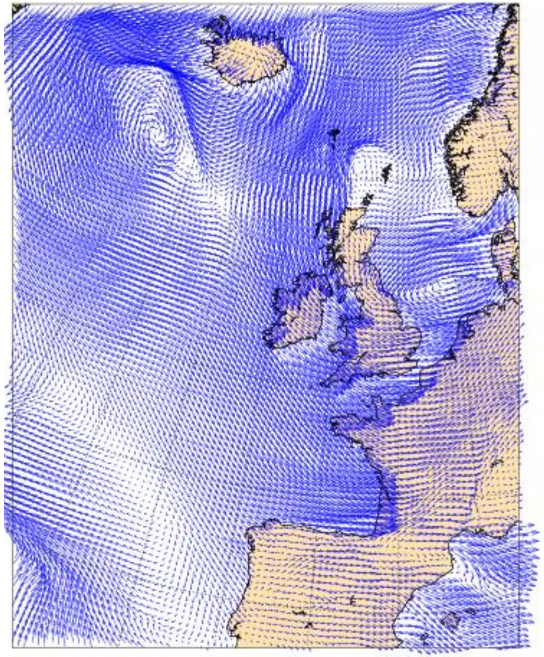
# Comparison with Merra-2

| | Merra-2 | ERA5 |
|---|---|---|
| *Spatial resolution* | *0.5 x 0.625 degrees*<br>*72 levels to 1 Pa* | *0.28125 x 0.28125 degrees*<br>*137 levels to 1 Pa* |
| *Assimilation system* | *3D-Var FGAT, 6-hour window* | *4D-Var, 12-hour window* |
| *Output frequency* | *Hourly* | *Hourly* |





# Global mean surface temperature

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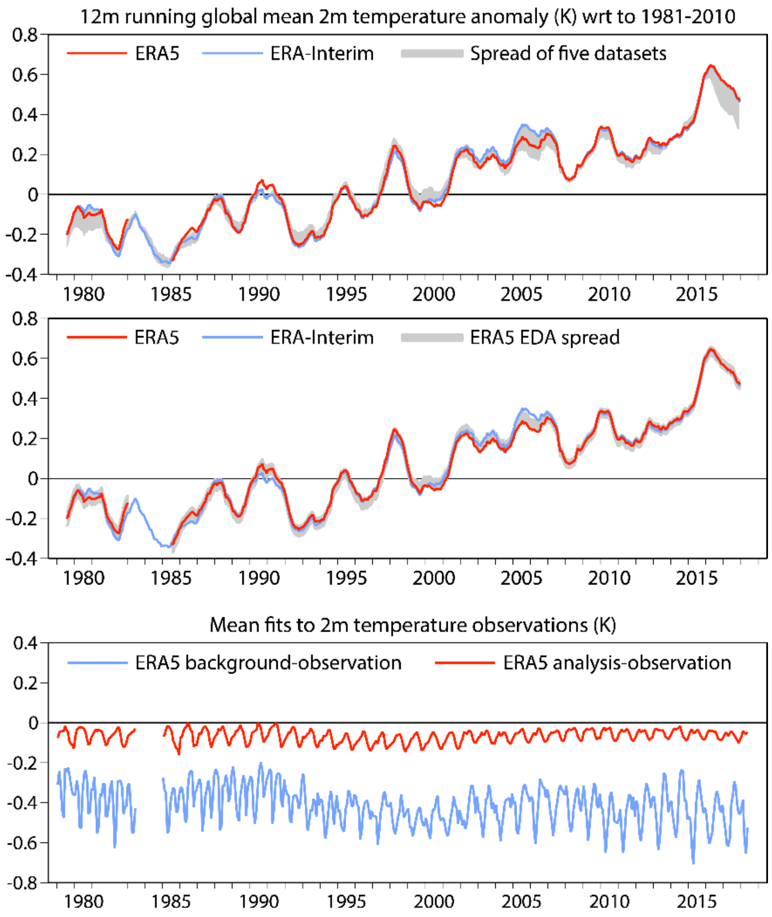


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# Ozone over the South Pole

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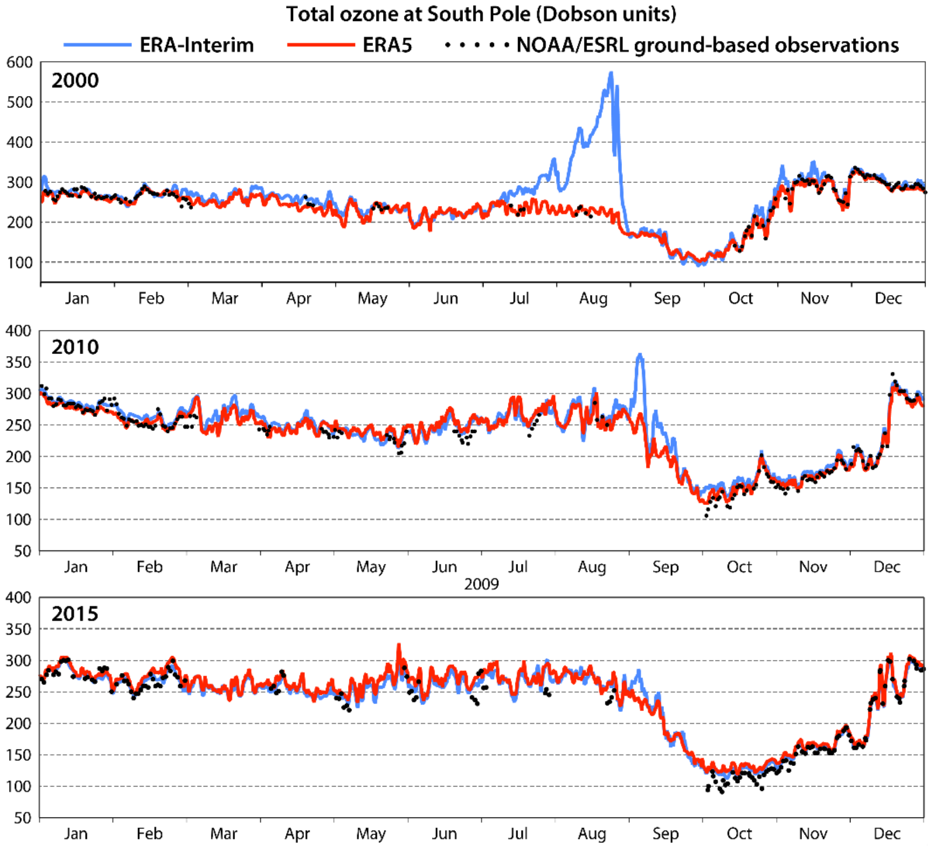


ERA-Interim assimilates no ozone data in the polar night, and structure functions can generate spurious values at the South Pole when there are increments near the edge of the polar vortex.

ERA5 assimilates infrared and microwave data on ozone, and has different structure functions.

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# ERA5 performance over time compared to ERA-Interim

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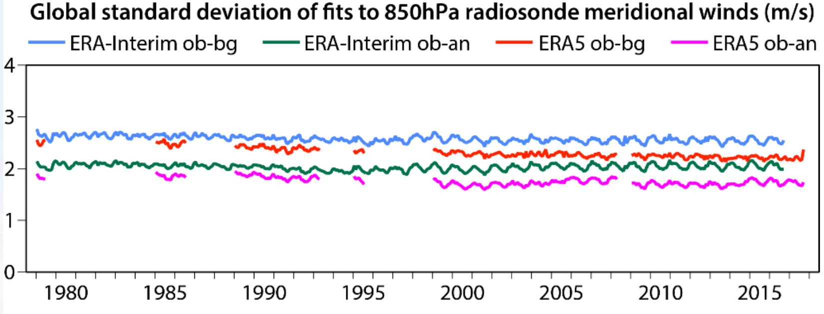
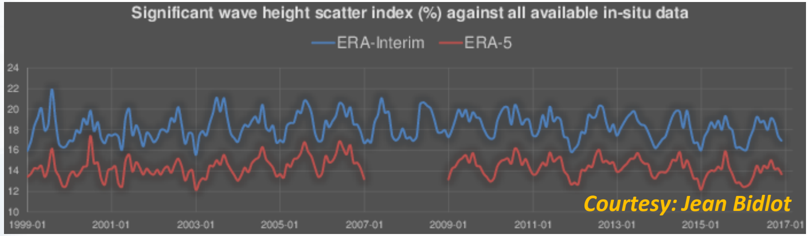



**Troposphere**
Standard deviations of (observation-background) and (observation-analysis) are generally smaller for ERA5 particularly at 850hPa




**Ocean Waves**
Buoy-comparison improved for ERA5

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# Tropical stratospheric humidity

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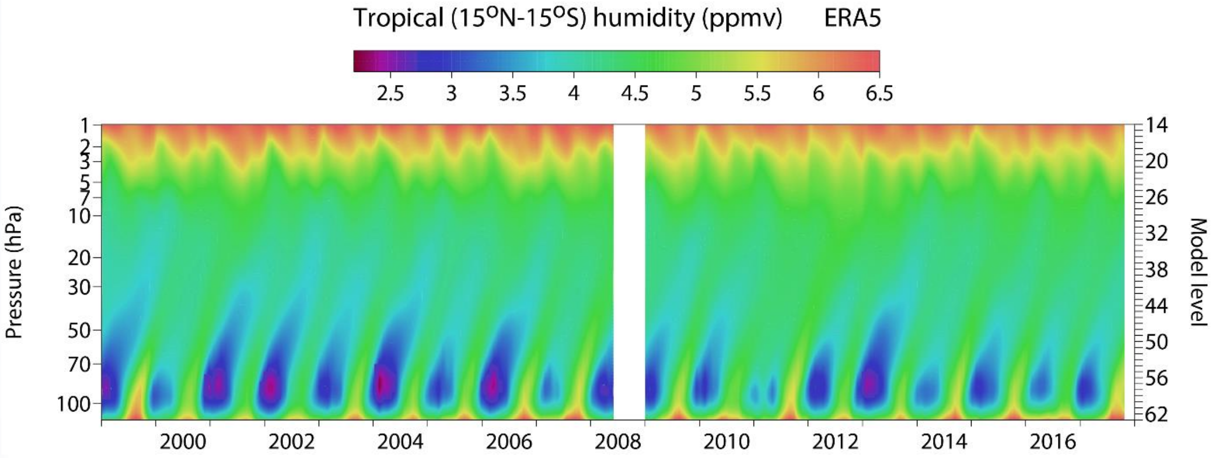


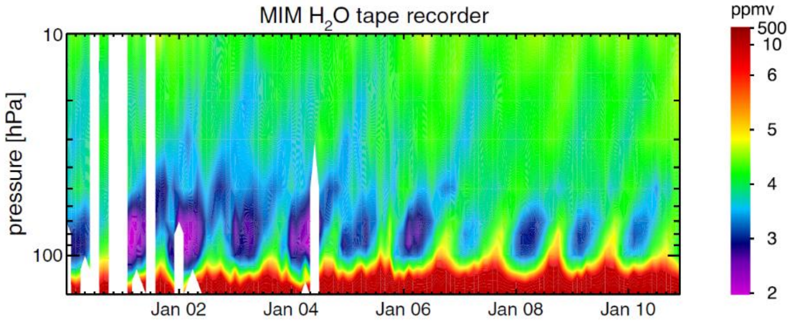


Multi-instrument mean from Hegglin *et al*. (2013) SPARC data initiative: Comparison of water vapour climatologies

Interannual variations in the dryness of the tropical lower stratosphere are realistic.

Upward movement of the annual variation in humidity in ERA5 is not as slow as observed ...

... but is slower than in ERA-Interim.

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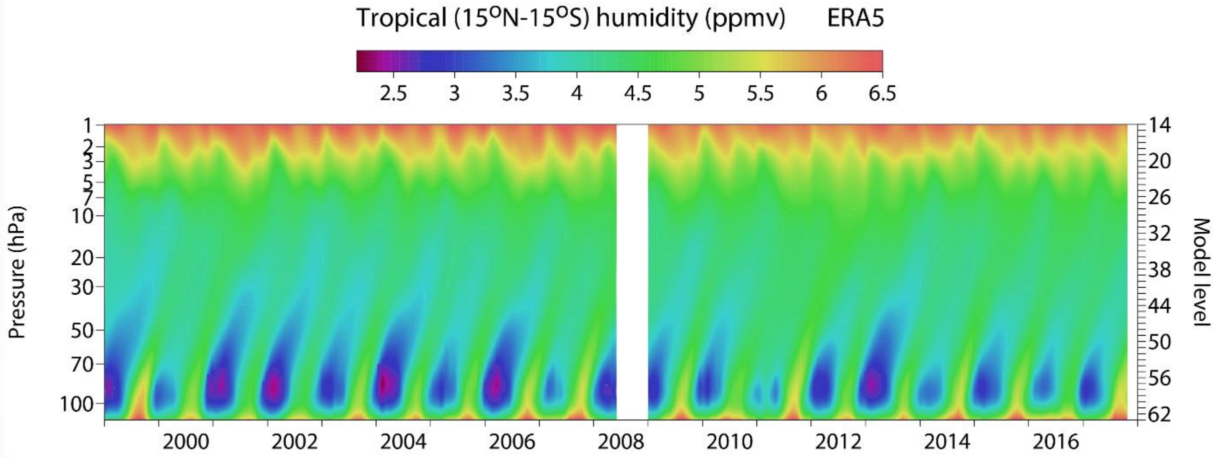


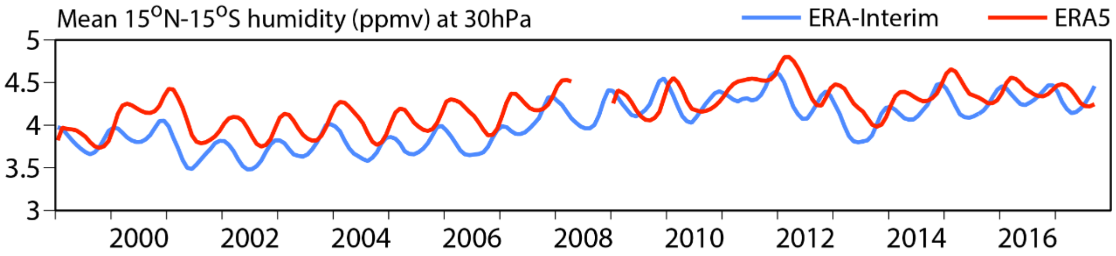


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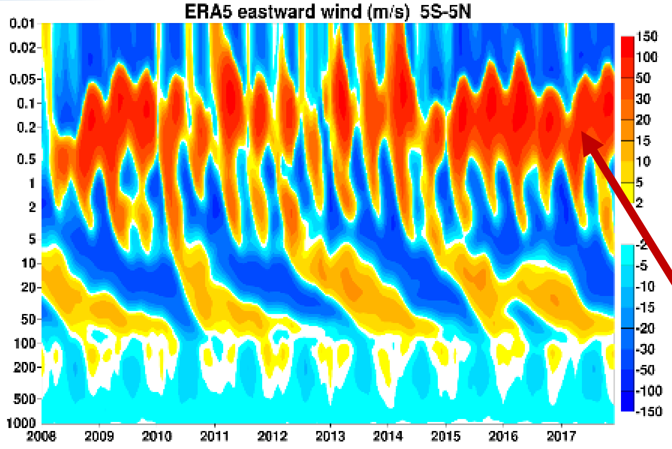
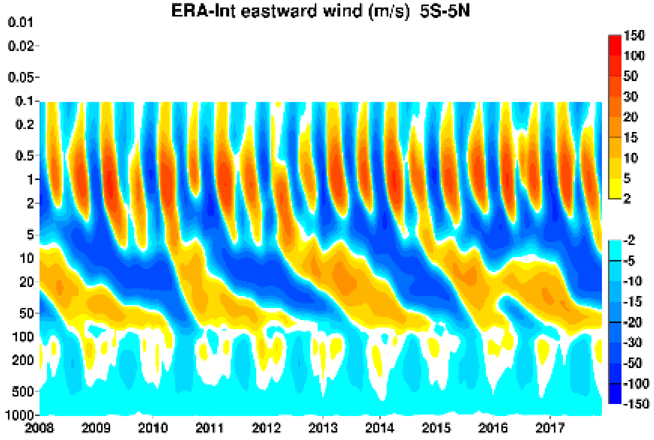
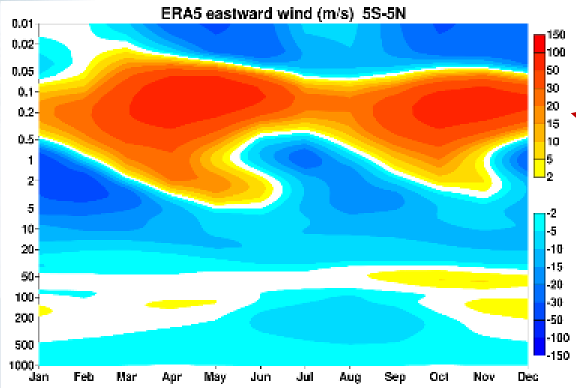
# Quasi-biennial oscillation
# Semi-annual oscillation

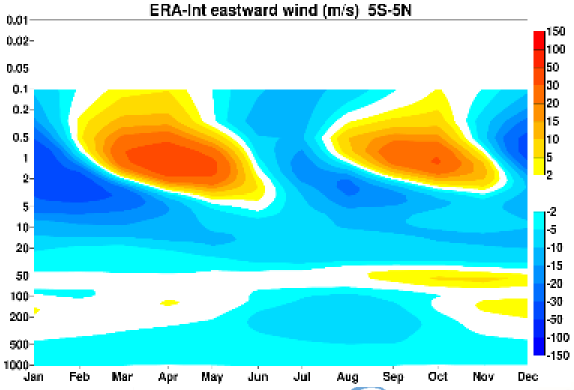



QBO consistent between ERA5 and ERA-Interim




Too strong Mesospheric jet in ERA5 (41r2)

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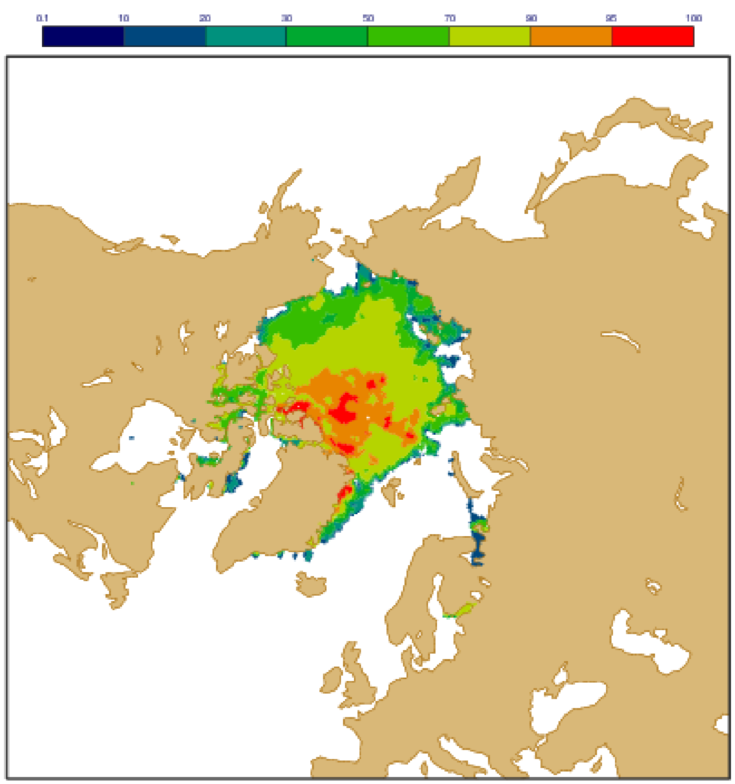
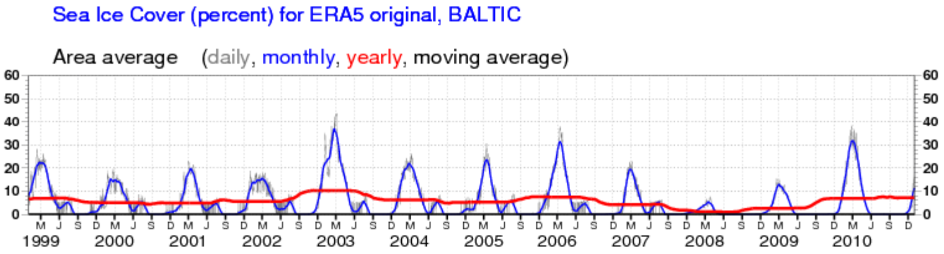
# ERA5 sea-ice issue over the Baltic in Summer (26 July 2006)

## ERA5 original




**ERA5 uses OSI-SAF reprocessed data before September 2007**

- Passive microwave radiometers suffer from land contamination
- Leads to spurious ice each Summer over the Gulf of Finland

# ERA5 sea-ice issue over the Baltic in Summer (26 July 2006)

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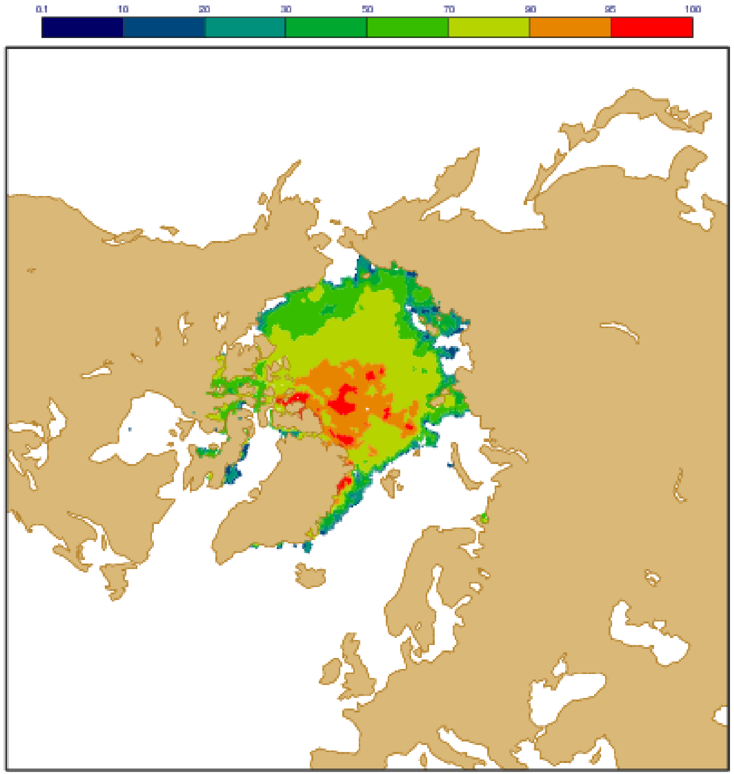
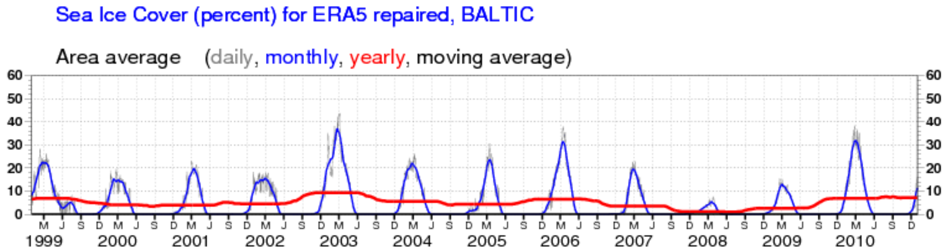
## ERA5 final

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**Decided to re-run the HRES only (the 'repair' runs)**

- Re-instate check on SST (but now for > 3 Celsius)
- In addition fix Antarctic problems for 1979, 1986 and 2004
- Ice over the Caspian, and improve on SST over Great Lakes
- Improve ozone in the polar night
- Some improvements in blacklist (e.g., MSU-4 NOAA-10 in 1986)

- Run in yearly streams
- Stick to original VarBC coefficients to minimize seams

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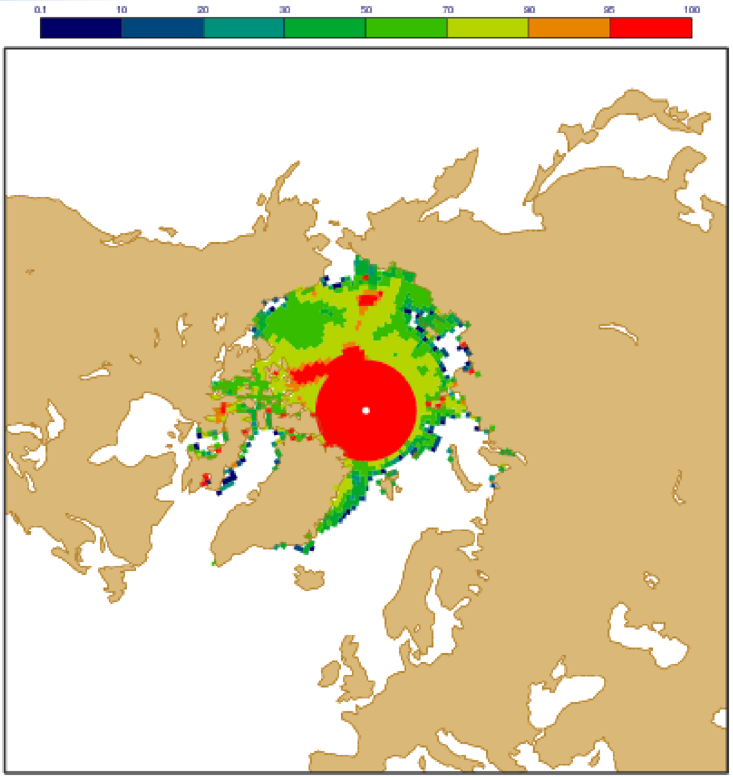
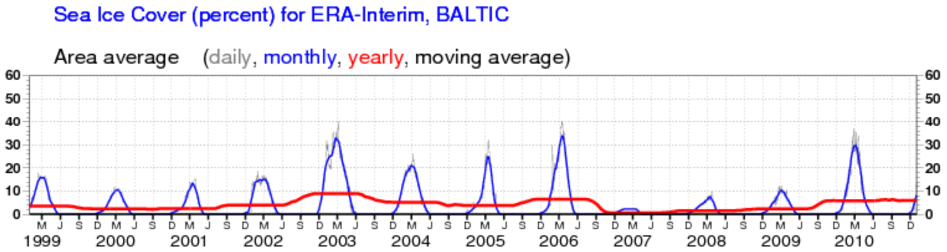
# ERA5 sea-ice issue over the Baltic in Summer (26 July 2006)

## ERA-Interim

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**ERA-Interim has some issues too**

# Lower stratospheric temperature

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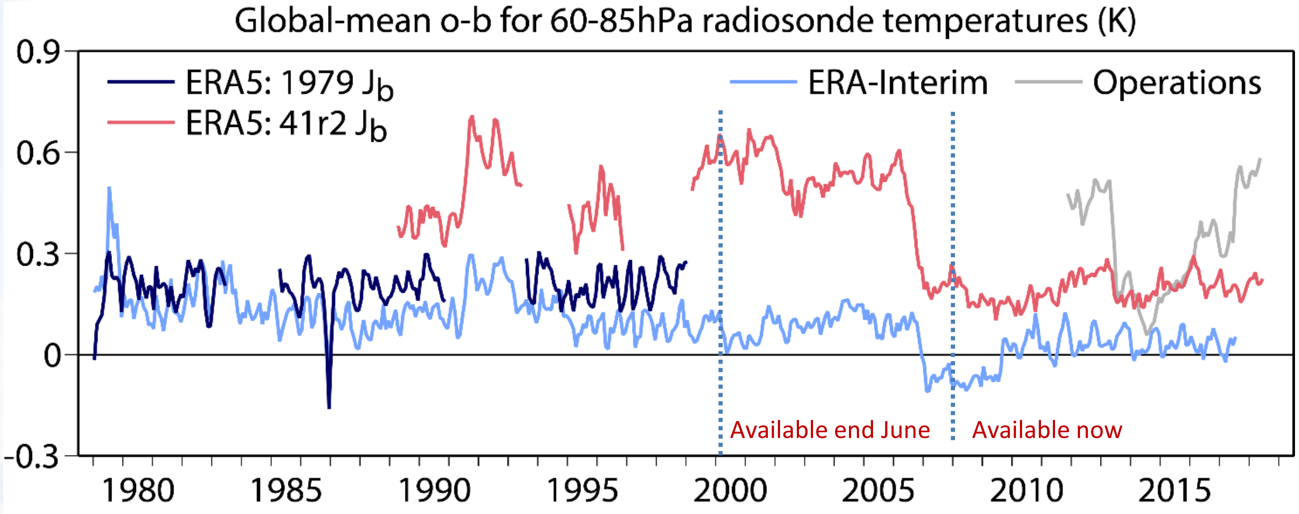


- ERA5 (41r2) has a large lower stratospheric cold bias

- **41r2 Jb** (modern observing system) is not able to provide large-scale corrections from radiosonde data
  Only when abundant (anchored) GPSRO (2006 onwards) are assimilated the situation improves

- **1979 Jb** does a much better job pre-GPSRO, (especially for Pinatubo in 1991)
- Need to see where to make the transition around 1998-2000 (introduction AMSU-A)

- Peak at end of 1986 due to spin-up MSU-4 NOAA-10 to be fixed in repair run

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# Upper stratospheric temperature

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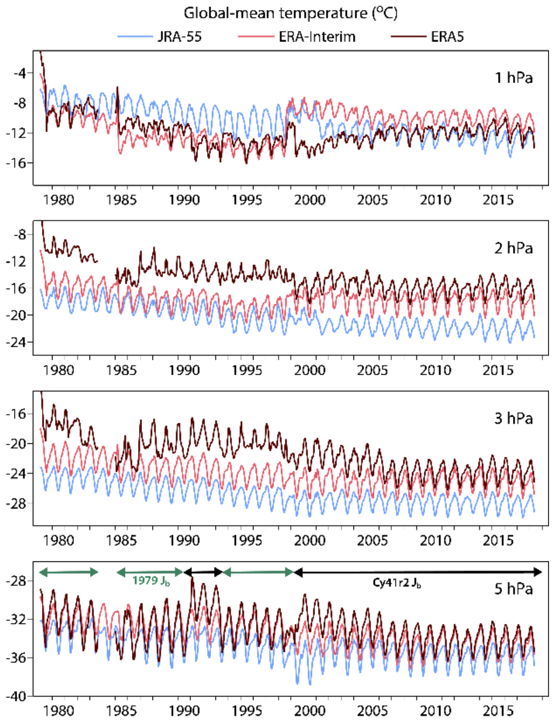


Shifts associated with $J_b$ are particularly large at 5hPa

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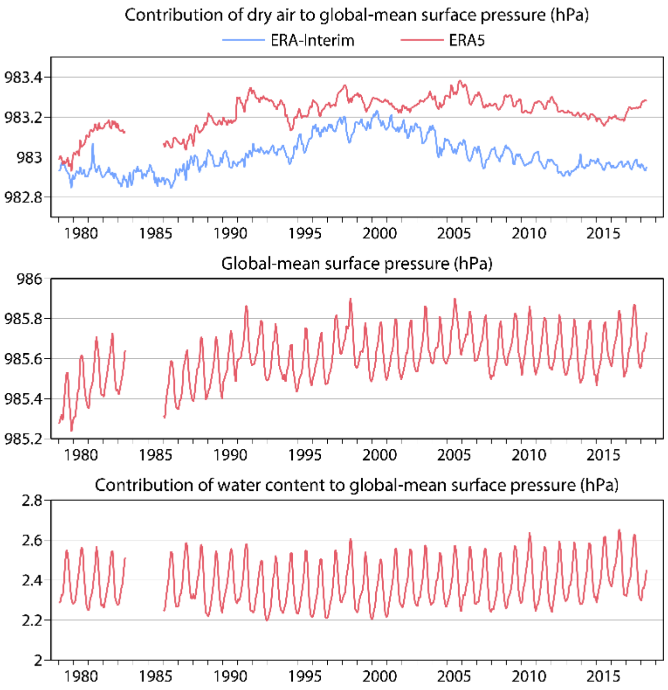
# Global dry mass




More consistent than ERA-Interim, from the 1990s

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# Continuity between streams

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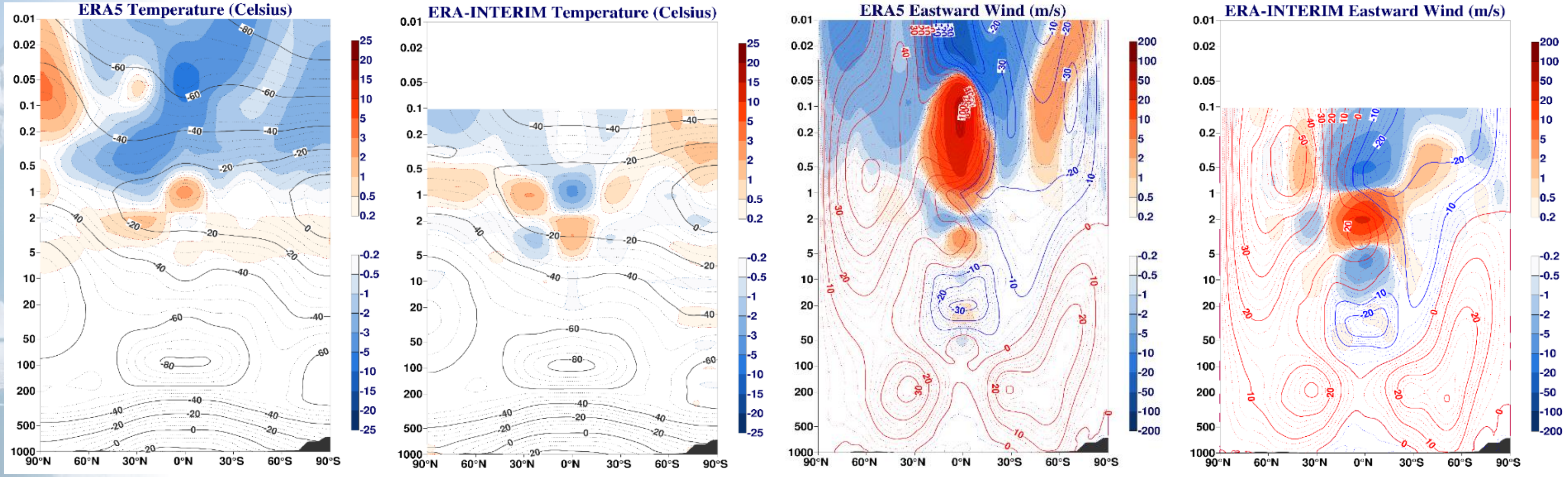
Overlap during October – December 2009




- Continuity in ERA5 is generally better than ERA-Interim in the troposphere and stratosphere
- Continuity in ERA5 is generally poor in the mesosphere

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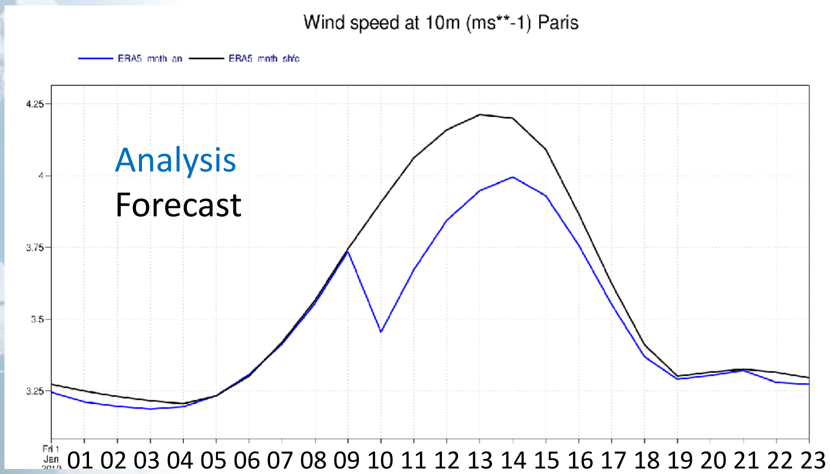
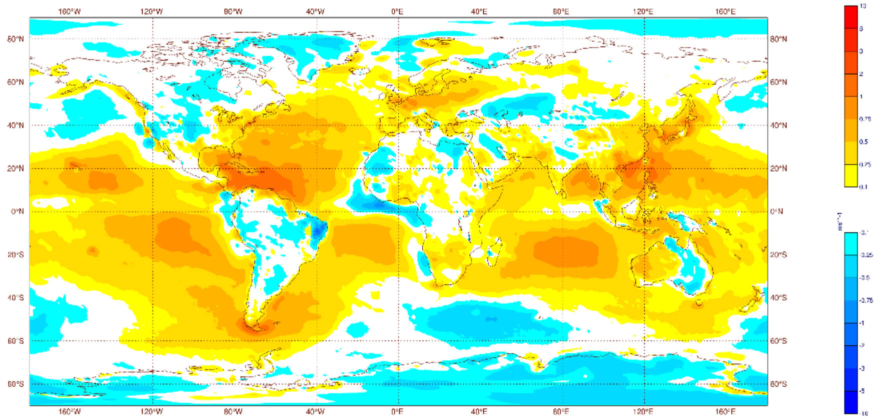
# Diurnal cycle of 10m wind speed

Climate Change

Discovered by EDF




3rd derivative of 10m wind speed



Annual climatology 2010-2017

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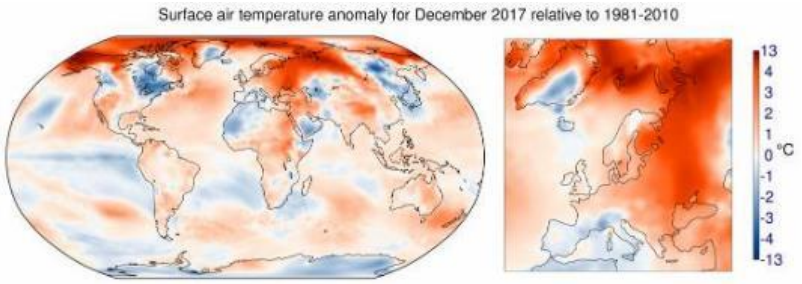
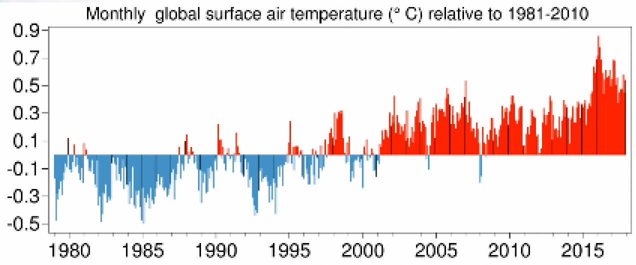
# Monthly climate monitoring

Climate Change

## Thanks to Freja Vamborg

The Copernicus Climate Change Service (C3S) includes in its product portfolio, reanalyses and a climate monitoring facility. These two products are being used to monitor the climate by providing monthly updates for several Essential Climate Variables (ECVs). The monthly updates are posted onto the Copernicus website ([https://climate.Copernicus.eu/monthly-maps-and-charts](https://climate.Copernicus.eu/monthly-maps-and-charts)) within a few days of the end of each month. In the future it will be extended, but currently the main source of content is the ERA-Interim global reanalysis.




Globally, the warmest and second warmest instances of each month of the year occurred between October 2015 and December 2017, with the warmest instances of each month of the year occurring from October 2015 to September 2016. Consequently, this latter period is the warmest twelve months on record and had a temperature 0.64°C above the average for 1981-2010. 2016 is by far the warmest calendar year on record: its global temperature of 0.62°C above average compares with the value of 0.53°C for 2017, the second warmest calendar year, and 0.44°C for 2015, the third warmest calendar year. The spread in the global averages from various temperature datasets has been unusually large in 2016 and 2017, and some datasets rank 2017 colder than 2015. The main reason for the spread stems from differences in the coverage of the polar regions and from differences in the estimates of sea-surface temperature. All datasets agree that the last three years were the warmest on record.

# Summary and Final remarks

Climate Change

**ERA-Interim is outdated and will be replaced by ERA5**

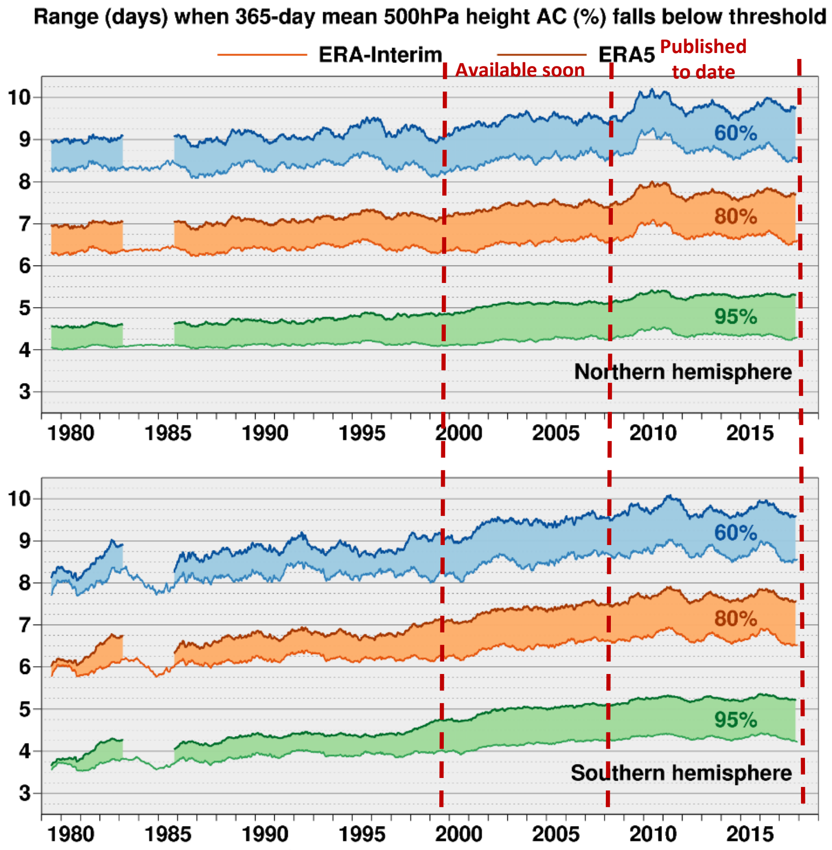
**As part of the Copernicus Climate Service, at ECMWF, the production of ERA5 is well underway:**

- 31km global resolution, from 1950, hourly output, uncertainty estimate.
- **To date ERA5 2008-2017 is publicly available**
- Release of other periods will be done in stages data access via the **Climate Data Store** soon.
- By end 2018: 1979 onwards.
- C3S User service Desk, Knowledge Base, FAQ's, user support

**The performance of ERA5 is very promising in the troposphere.**

- Winds and Ocean waves
- improved global hydrological and mass balance
- reduced biases in precipitation,
- refinement of the variability and trends of surface air temperature.

**ERA5 is freely available and a timely product is to be available one week behind real time (Q3 2018)**

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