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ERA5 – a new reanalysis

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Acknowledgments

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ECMWF HQ

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ECMWF reanalyses: Towards an Earth System reanalysis

1980	1990	2000	2010	
FGGE	ERA-15	ERA-40	ERA-Interim	ERA5

Atmosphere/land — ***adding ocean waves and stratospheric ozone***

Ocean, now including sea ice	ORAS3	ORAS4	ORAS5
Centennial atmosphere/land, and centennial and satellite-era coupled atmosphere/land/ocean	ERA-20C	CERA-20C	CERA-SAT
Enhanced land	ERA-Int/L	ERA-20C/L	ERA5/L
Atmosphere/land including atmospheric composition	GEMS	MACC	CAMS

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Atmosphere/land … *adding ocean waves and stratospheric ozone*

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Enhanced land: ERA-Int/L | ERA-20C/L | ERA5/L

Atmosphere/land including atmospheric composition: GEMS | MACC | CAMS

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Latest step for atmospheric reanalysis: ERA5

Replacement for ERA-Interim, currently in production, using:

- a 2016 (rather than a 2006) version of the ECMWF data assimilation system
- ~30km (rather than ~80km) horizontal resolution and 137 (rather than 60) levels
- new analyses of sea-surface temperature and sea-ice concentration
- various new and reprocessed satellite data records

providing:

- hourly output fields (already released for 2010-2016)
- an observational feedback archive
- uncertainty estimates from a 10-member ensemble data assimilation
- a land-surface analysis downscaled to ~9km horizontal resolution

from 1979 onwards, with:

- prompt operational extension forward in time
- subsequent extension to cover the period from 1950 to 1978

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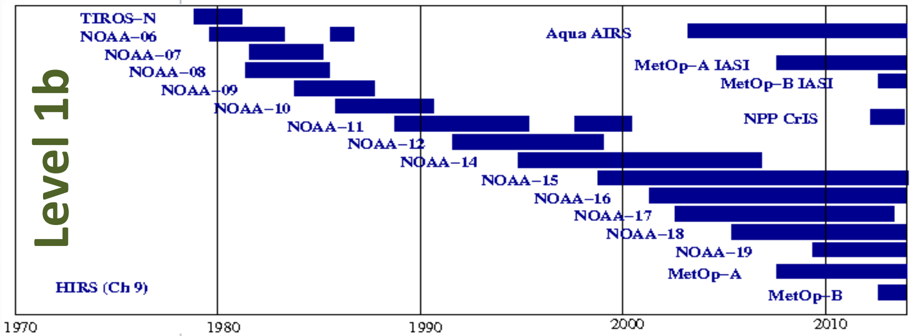
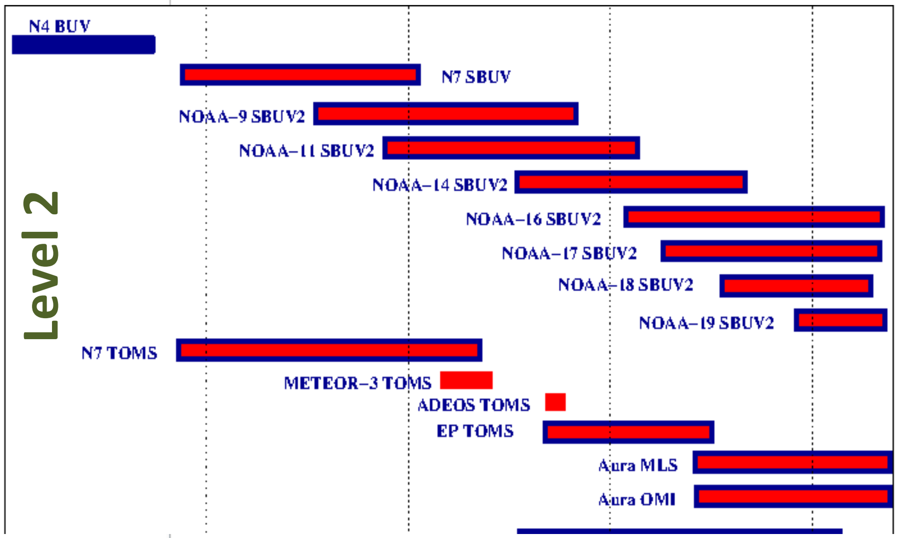
Changes in use of satellite data on ozone





- ERA5 assimilates ozone-sensitive infrared radiances from the HIRS,AIRS, IASI and CrIS instruments not used in ERA-Interim
- ERA5 assimilates MIPAS and GOME-2 retrievals from the ESA CCI not used in ERA-Interim
- ERA5 assimilates several reprocessed versions of datasets used in ERA-Interim
- ERA5 assimilates two datasets that have not been reprocessed since use in ERA-Interim

ERA5 also applies a variational bias correction to ozone data

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Other improvements to input data

Other newly reprocessed satellite datasets

- SSM/I and Meteosat radiances
- Atmospheric Motion Vectors from Meteosat, GMS, GOES, MTSAT and AVHRR
- soil moisture from ERS 1/2 and ASCAT-A
- radio occultation data from Metop, COSMIC, CHAMP, GRACE, SAC-C and TERRASAR-x

Newer satellite datasets not used in 2006 system fixed for ERA-Interim

- ASCAT, ATMS, CrIS, FY-3, IASI and Himawari

Improved usage of data

- "all-sky" assimilation of microwave imager data
- upgraded radiative transfer modelling for simulating observations, including variable atmospheric CO2, and variable CO2-cell pressures for SSU data
- bias correction of aircraft data and improved correction of radiosonde biases

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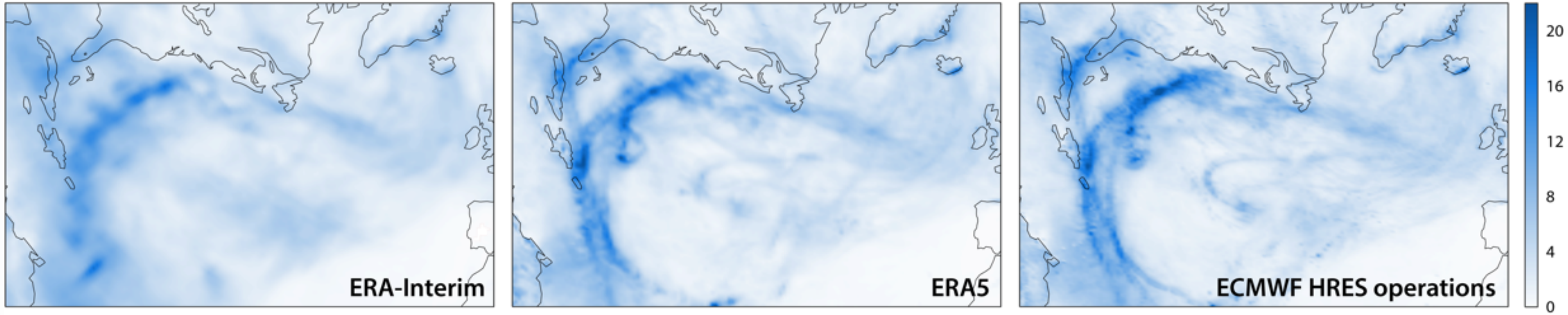
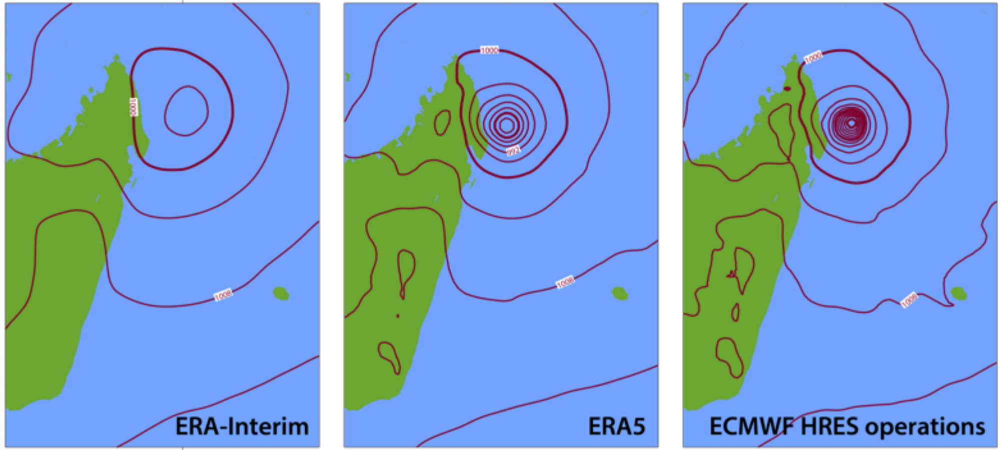
Horizontal resolution and depiction of tropical cyclones

Mean precipitation rate (mm/day) for September 2017



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



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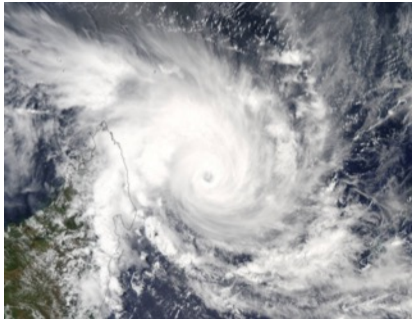

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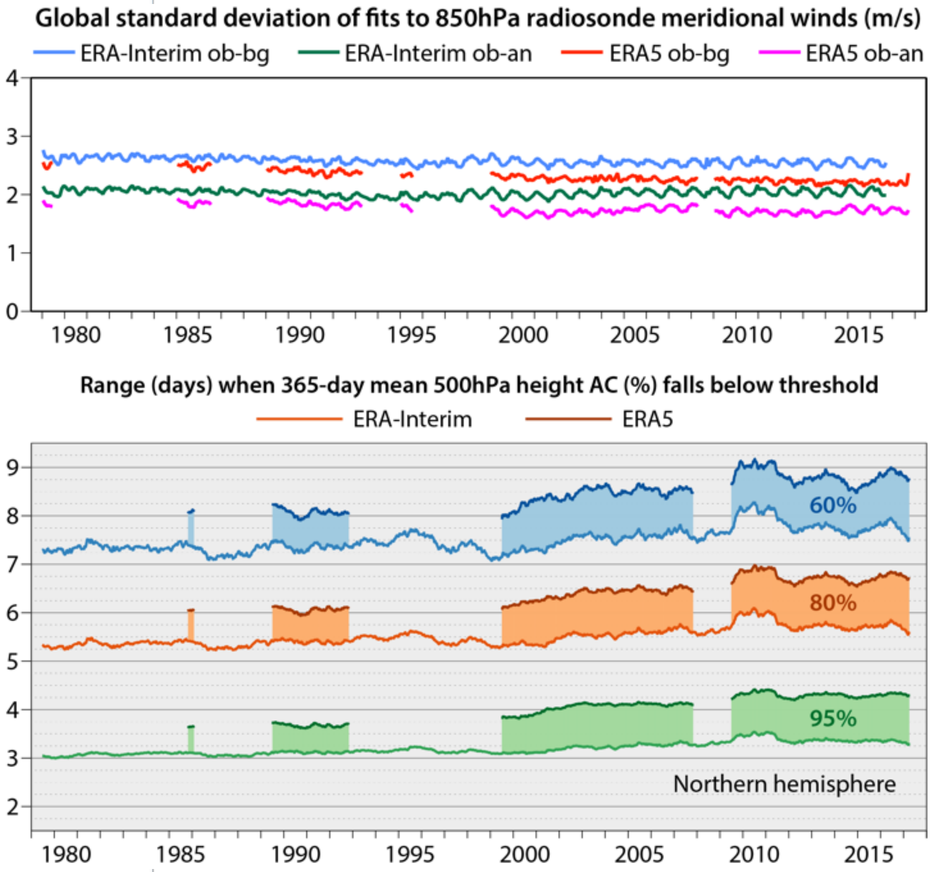
Variations in data fits and forecast skill over time



Standard deviations of (observation-background) and (observation-analysis) are generally smaller in the troposphere for ERA5 than for ERA-Interim, particularly at 850hPa.

ERA5 medium-range forecasting scores are significantly higher than those from ERA-Interim, particularly later in the period.

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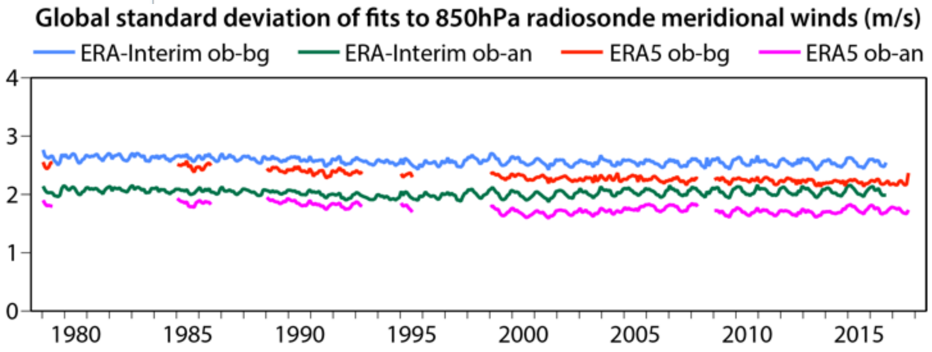

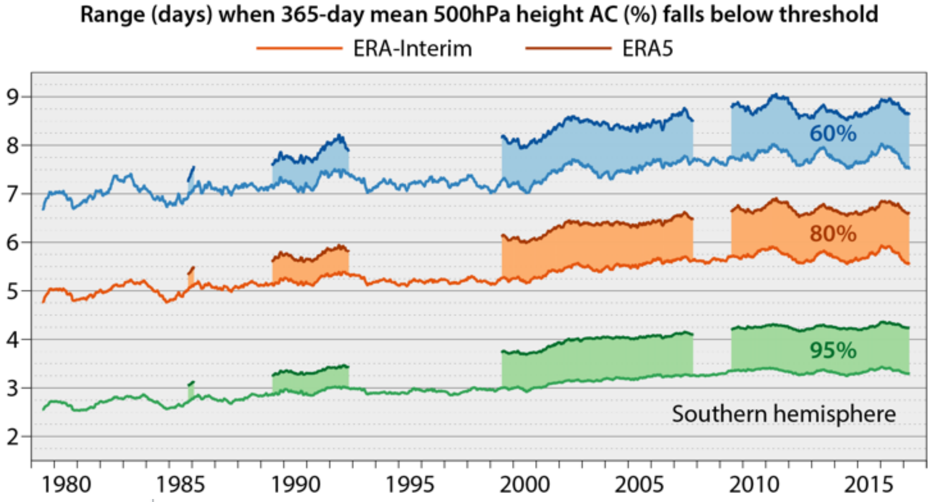

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ERA5 medium-range forecasting scores are significantly higher than those from ERA-Interim, particularly later in the period.

Data assimilation error statistics have been re-derived using the observing system as it was in 1979 for ERA5 production streams from 1979 and 1986.

Global hydrological balance

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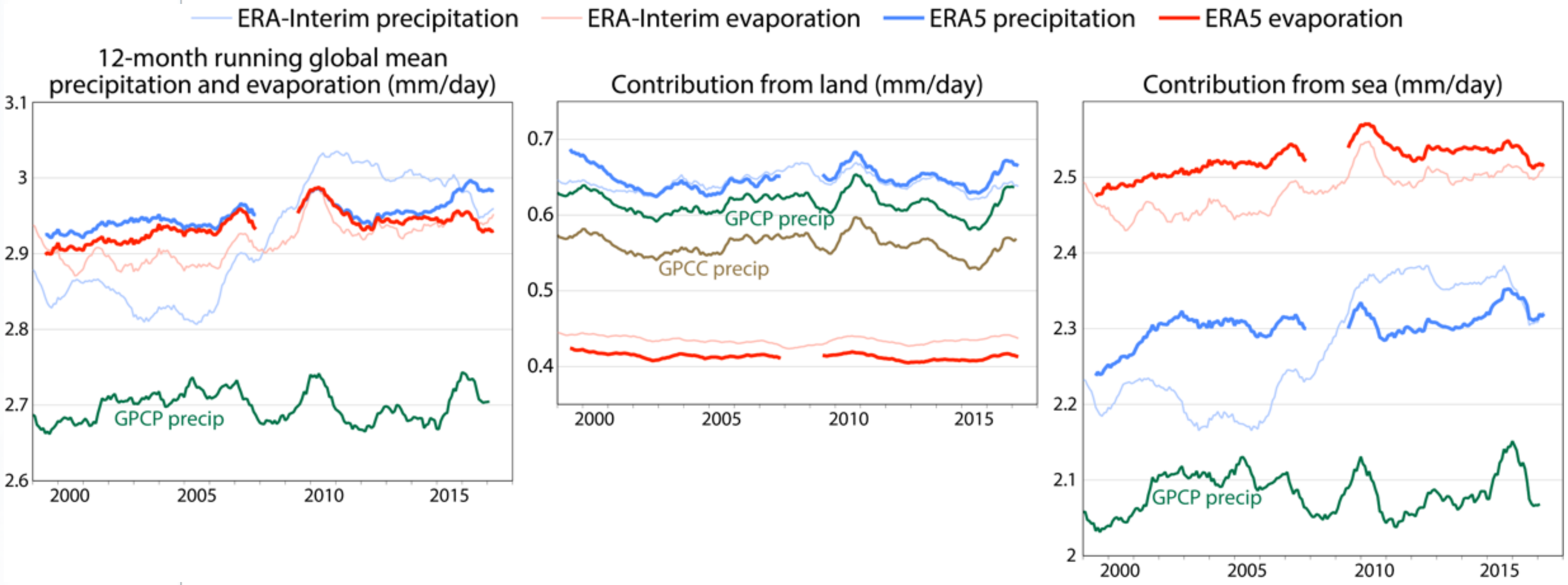

ERA5 is closer to global balance of precipitation and evaporation than ERA-Interim is, particularly from 1999 onwards, apart from divergence over last two years.

Variations of ERA5 precipitation over time from 1999 onwards match quite well the variations in the independent observationally-based GPCC and GPCP estimates, particularly over land.

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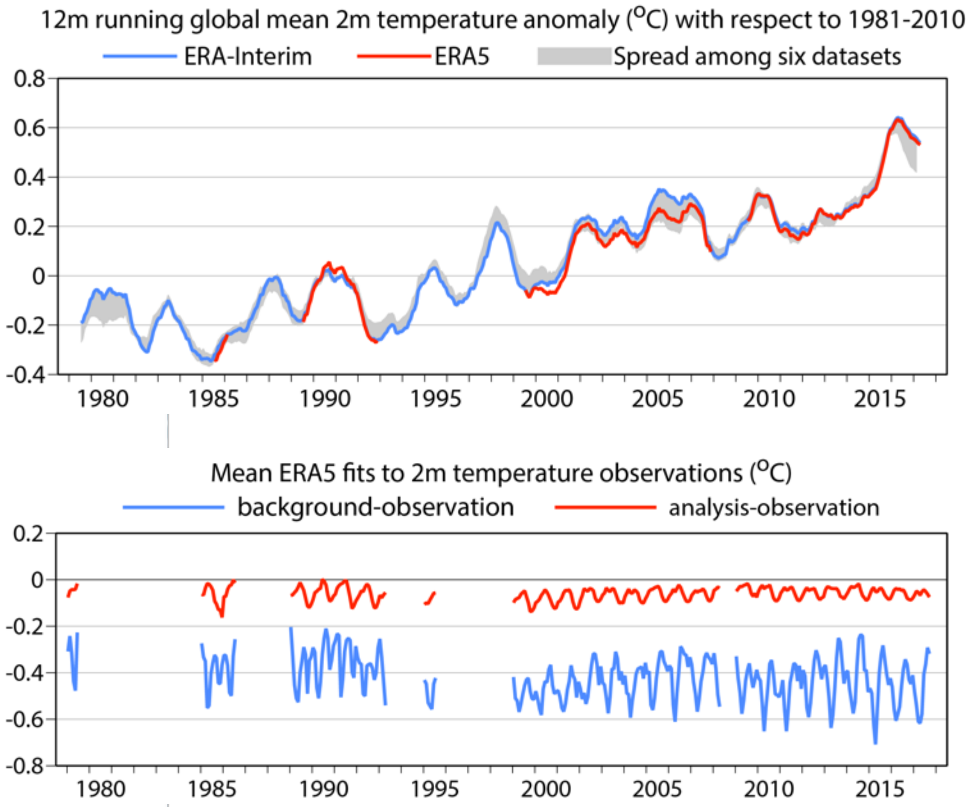
Global-mean surface air temperature



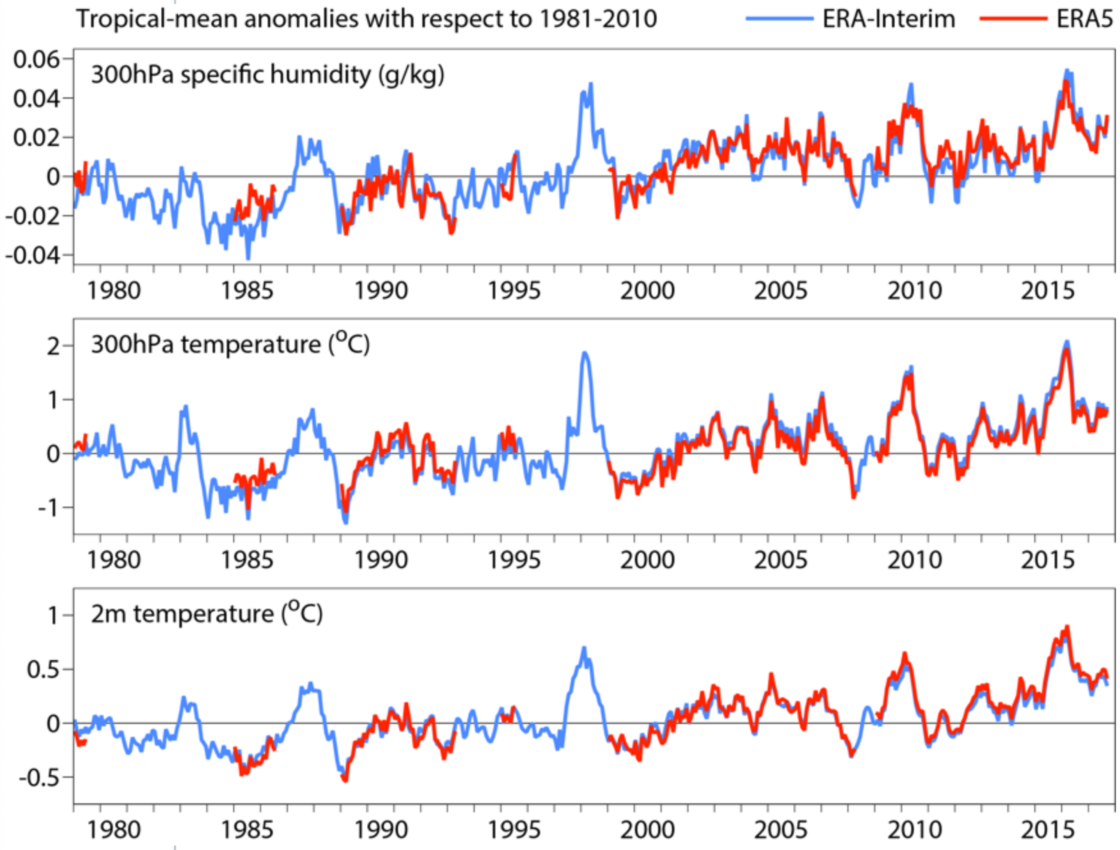
ERA-Interim temperatures are adjusted over sea to compensate for a warmer sea-surface temperature analysis prior to 2002.

ERA5 produces similar time variations (without need for adjustment), but is relatively cool in 2005 and 2006. It is more in line with other datasets for these years.

The analysis fits the temperature observations closely, with little change over time in its small cold bias.

1981-2010 reference for ERA5 is the ERA-Interim reference adjusted by the average difference between ERA5 and ERA-Interim over available months

Tropical temperature and upper tropospheric humidity



There is good agreement between ERA-Interim and ERA5 concerning the relationship between surface and upper-tropospheric tropical-mean temperature variations, and the corresponding variations in upper-tropospheric humidity

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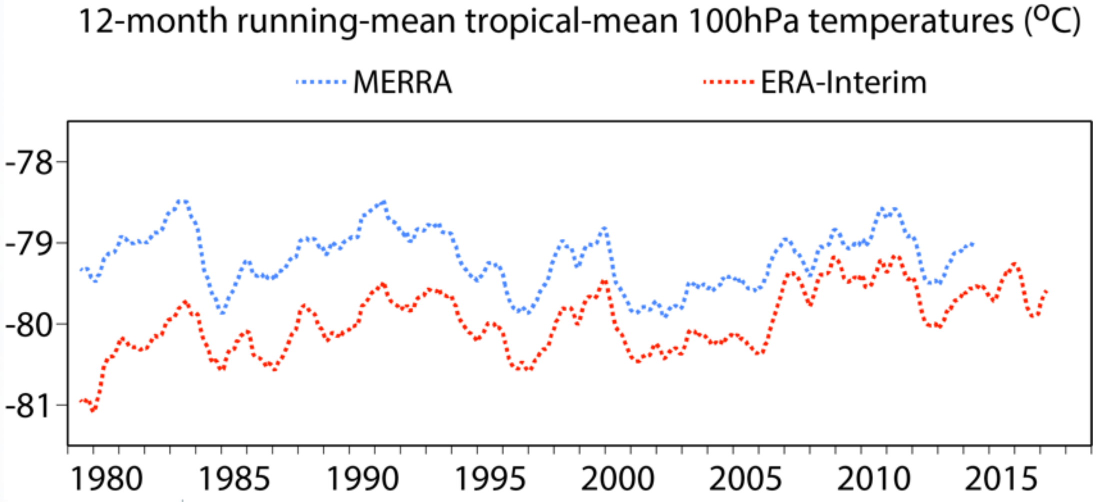
Tropical tropopause temperature

MERRA is warmer than ERA-Interim throughout.



Significant amounts of GPSRO data assimilated in ERA-Interim but not MERRA

Tropical tropopause temperature

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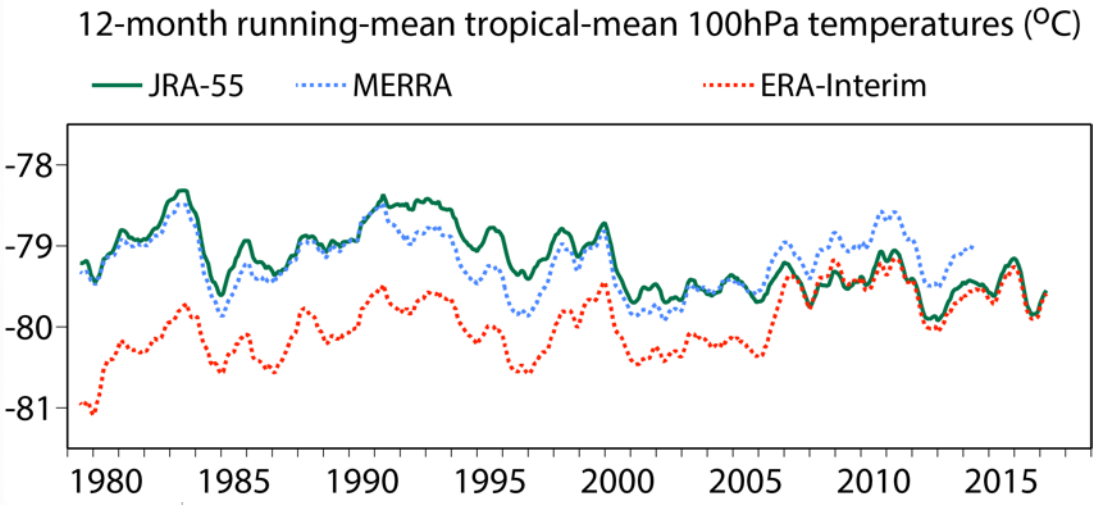

Significant amounts of GPSRO data assimilated in ERA-Interim and JRA-55

MERRA is warmer than ERA-Interim throughout.

ERA-Interim and JRA-55 assimilate GPSRO data, and come together in 2006. ERA-Interim warms and JRA-55 cools when significant amounts of GPSRO data start to be assimilated.

Tropical tropopause temperature

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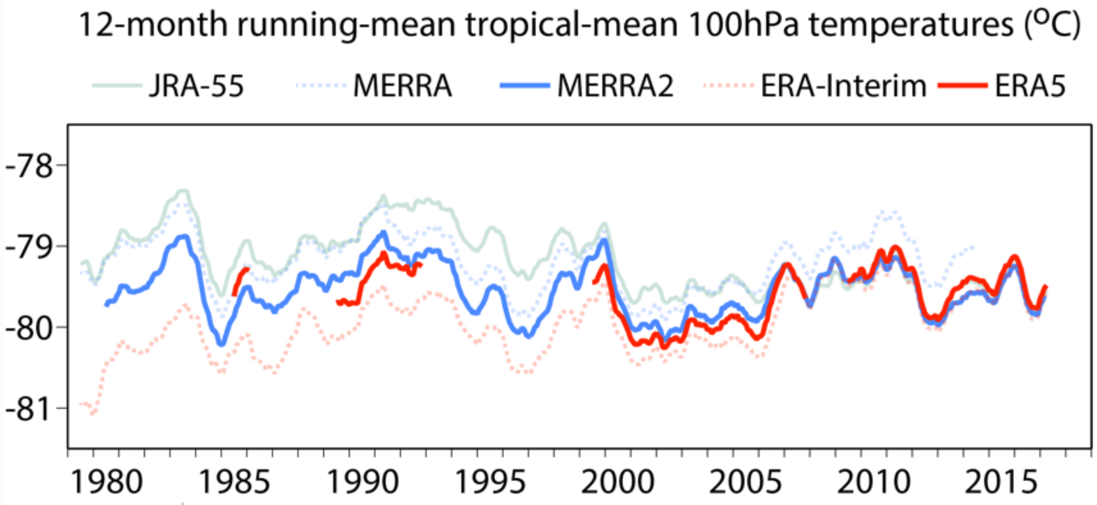


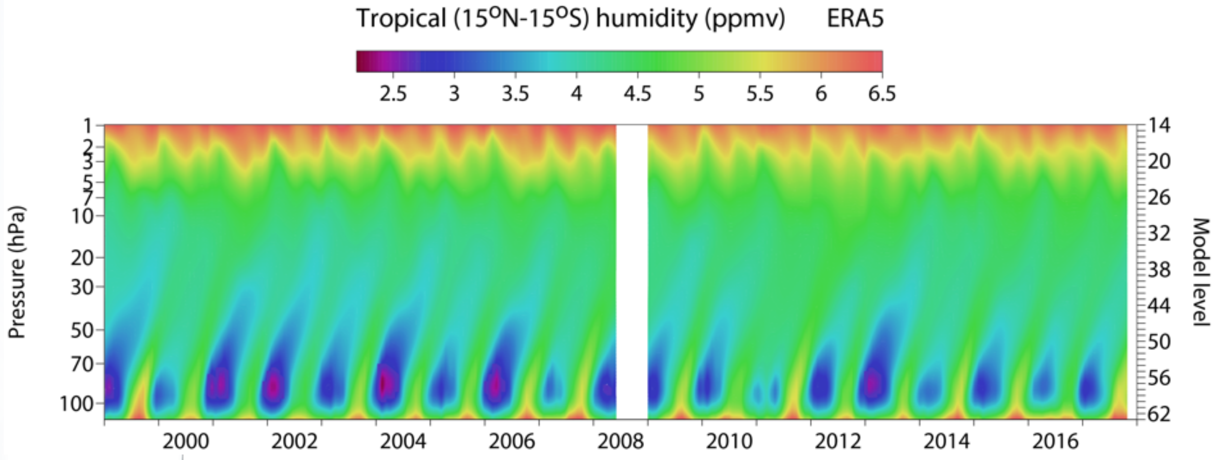
Significant amounts of GPSRO data assimilated in all except MERRA

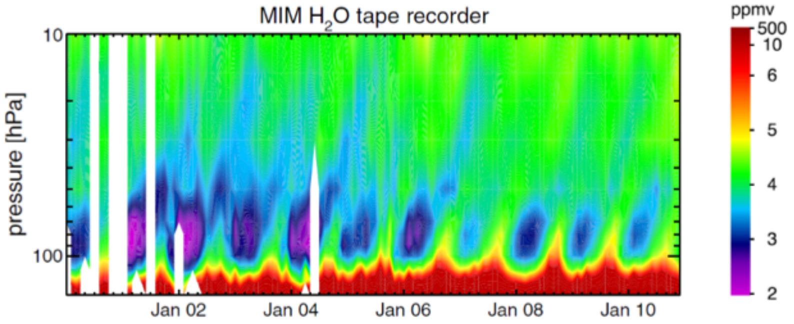
MERRA is warmer than ERA-Interim throughout.

ERA-Interim and JRA-55 assimilate GPSRO data, and come together in 2006. ERA-Interim warms and JRA-55 cools when significant amounts of GPSRO data start to be assimilated.

ERA5 and MERRA2 also assimilate GPSRO data. They come together in 2006 along with ERA-Interim and JRA-55, but are much closer throughout.

Tropical stratospheric humidity





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.

Tropical stratospheric humidity

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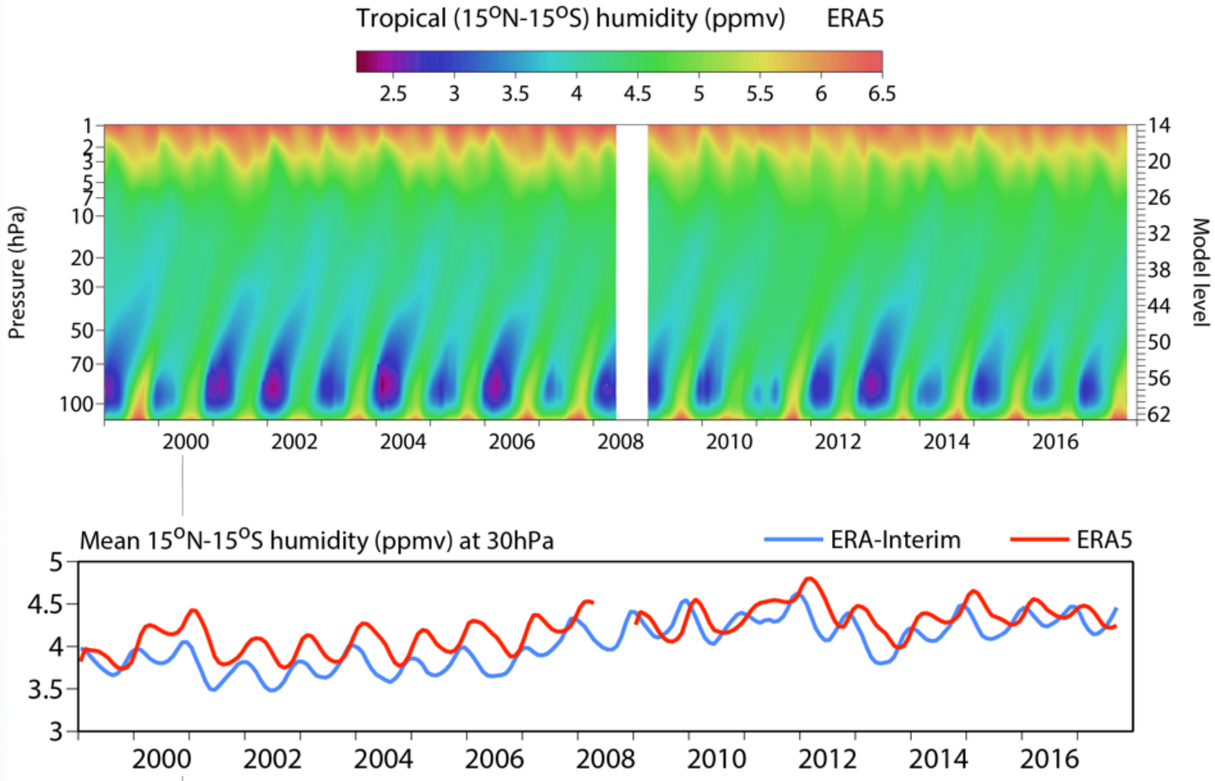

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Moistening of lower stratosphere during boreal summer

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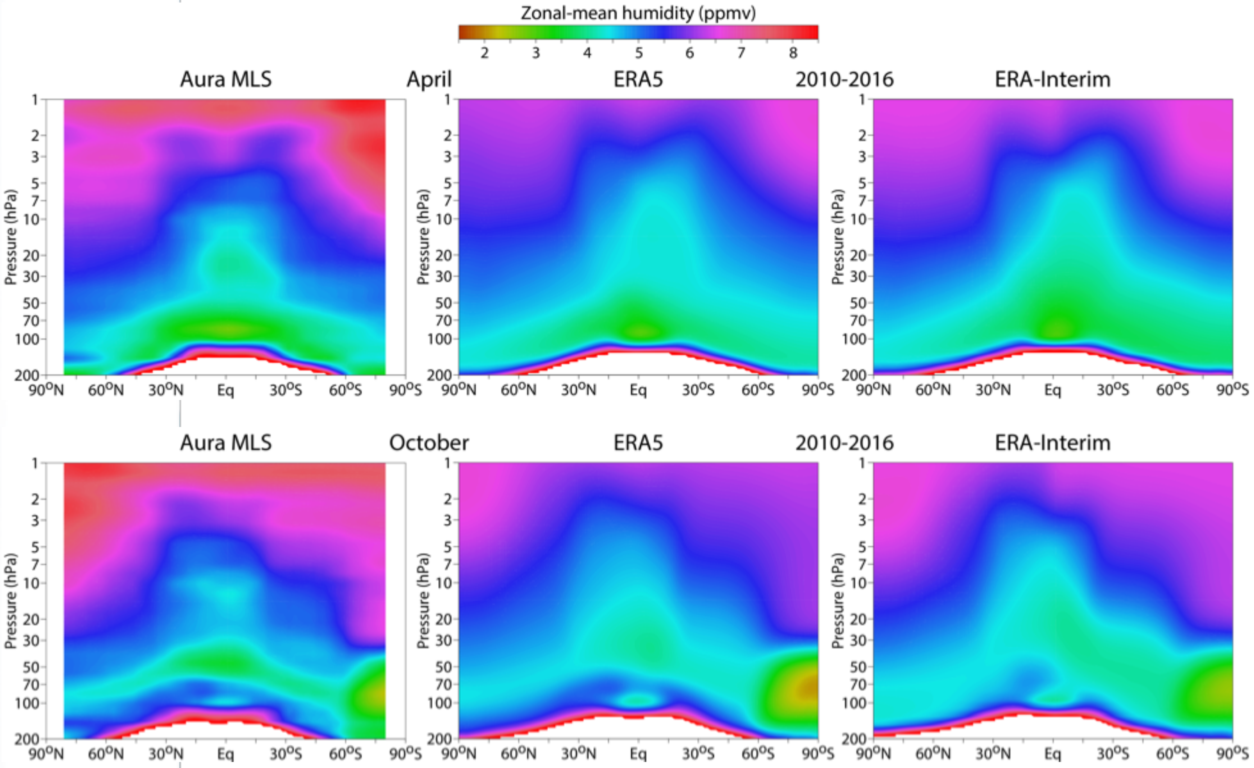

ERA5 is on average moister than ERA-Interim in the lower stratosphere.

This comes from increased moistening during boreal summer, countered by greater drying in boreal autumn and winter.

The methane oxidation parametrization used for both ERA5 and ERA-Interim is based on UARS HALOE data that have lower values in the upper stratosphere than the AURA MLS values. It will be adjusted in the next operational cycle of the ECMWF forecasting system. The MLS data shown here are from the SWOOSH database (Davis *et al.*, 2016).

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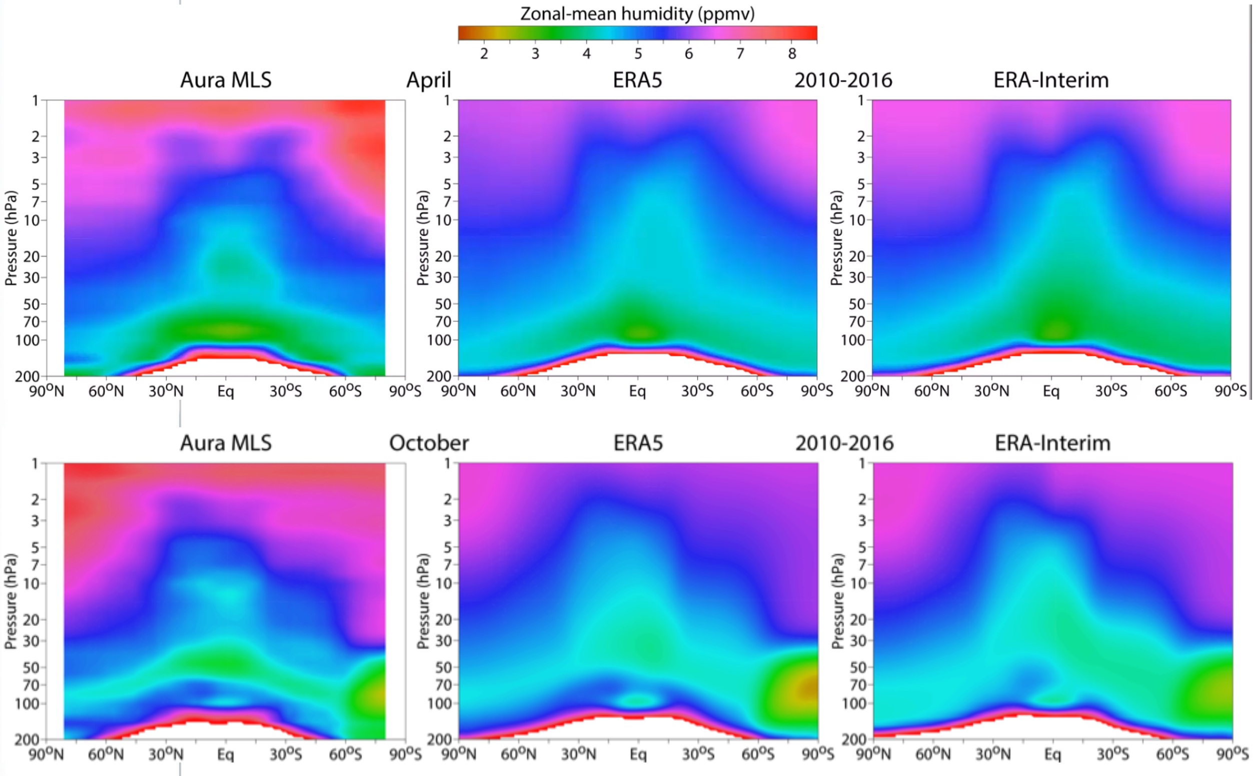

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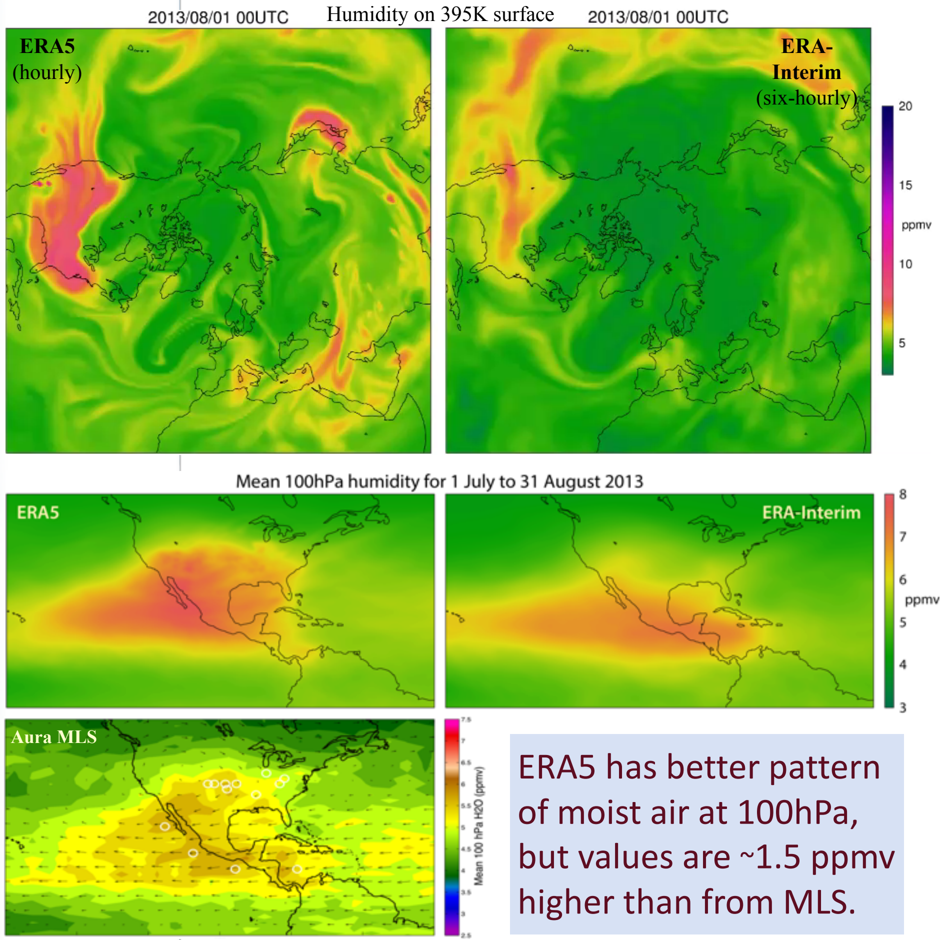
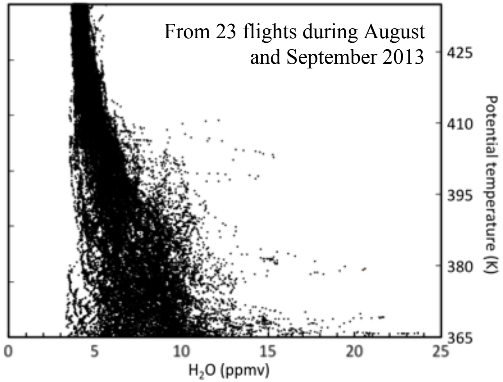


ERA5 is moister on the 395K isentropic surface than ERA-Interim in August 2013, and shows more instances of convective moistening.

Aircraft laser hygrometer data also show convective moistening during this month, but indicate lower values (Herman *et al.*, 2017).



ERA5 has better pattern of moist air at 100hPa, but values are ~1.5 ppmv higher than from MLS.

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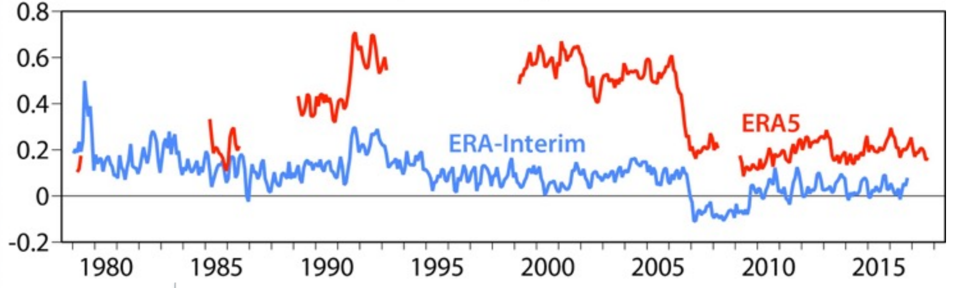
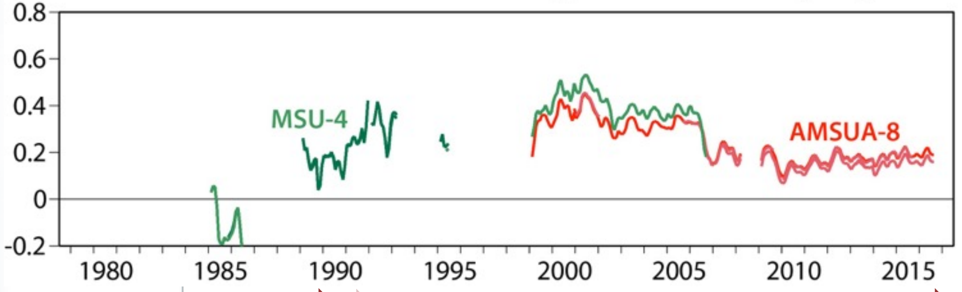
Global stratospheric temperature bias

Global-mean of (observation - background) differences for radiosonde temperatures (K) between 60 and 85hPa



Differences (ERA5 - ERA-Interim) in estimated brightness temperature biases (K) from instruments with no substantial change in calibration or quality control



Data assimilation background error structure functions have been re-derived using the observing system as it was in 1979

Significant amounts of GPSRO data assimilated

The ERA5 forecasts have a cold bias in the lower stratosphere that is controlled by assimilating GPSRO data, but not by assimilating radiosonde data alone.

Radiosonde data are also ineffective for anchoring satellite radiance biases in ERA5. Bias estimates are anchored instead by the model, and radiance assimilation reinforces rather than corrects model error.

ERA5 also captures less of the warming due to the 1991 eruption of Mt Pinatubo.

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Global stratospheric temperature bias

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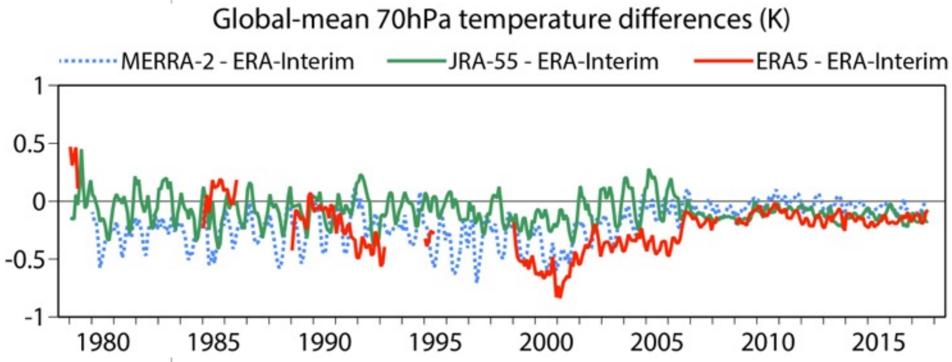

When significant amounts of GPSRO data are assimilated there is quite good agreement between ERA5, JRA-55 and MERRA-2, and each is a little colder than ERA-Interim.

JRA-55 is generally close to ERA-Interim before then, apart from an annual cycle.

MERRA-2 appears to have a quite large cold bias prior to the year 2000. Cold bias in ERA5 will likely run from around 1991 to 2006.

Data assimilation background error structure functions have been re-derived using the observing system as it was in 1979

Significant amounts of GPSRO data assimilated

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Global stratospheric temperature bias

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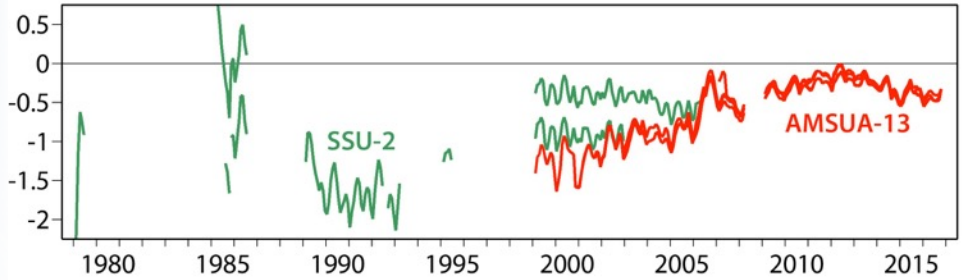
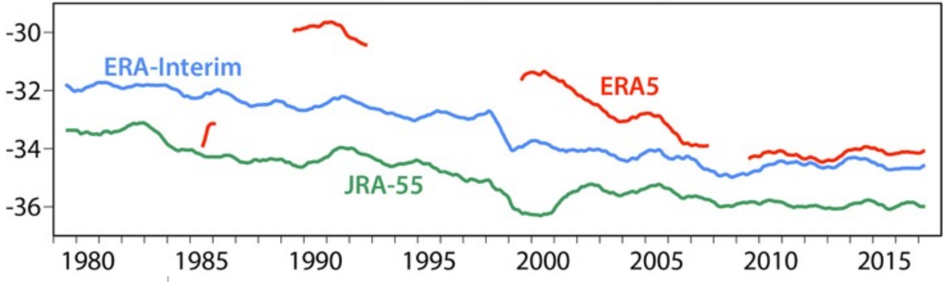
Differences (ERA5 - ERA-Interim) in estimated brightness temperature biases (K) from instruments with no substantial change in calibration or quality control



12-month running mean global 5hPa temperatures (°C)



Data assimilation background error structure functions have been re-derived using the observing system as it was in 1979

Significant amounts of GPSRO data assimilated

AMSUA-13 bias estimates vary little over time when significant amounts of GPSRO data are assimilated. Before then, AMSUA-13 biases shift over time in ERA5 due to dependence on assimilated SSU data and ineffective anchoring by radiosonde data.

This damages trends in upper stratospheric temperatures.

These trends are also damaged by the change in structure functions made for the pre-1990s production streams.

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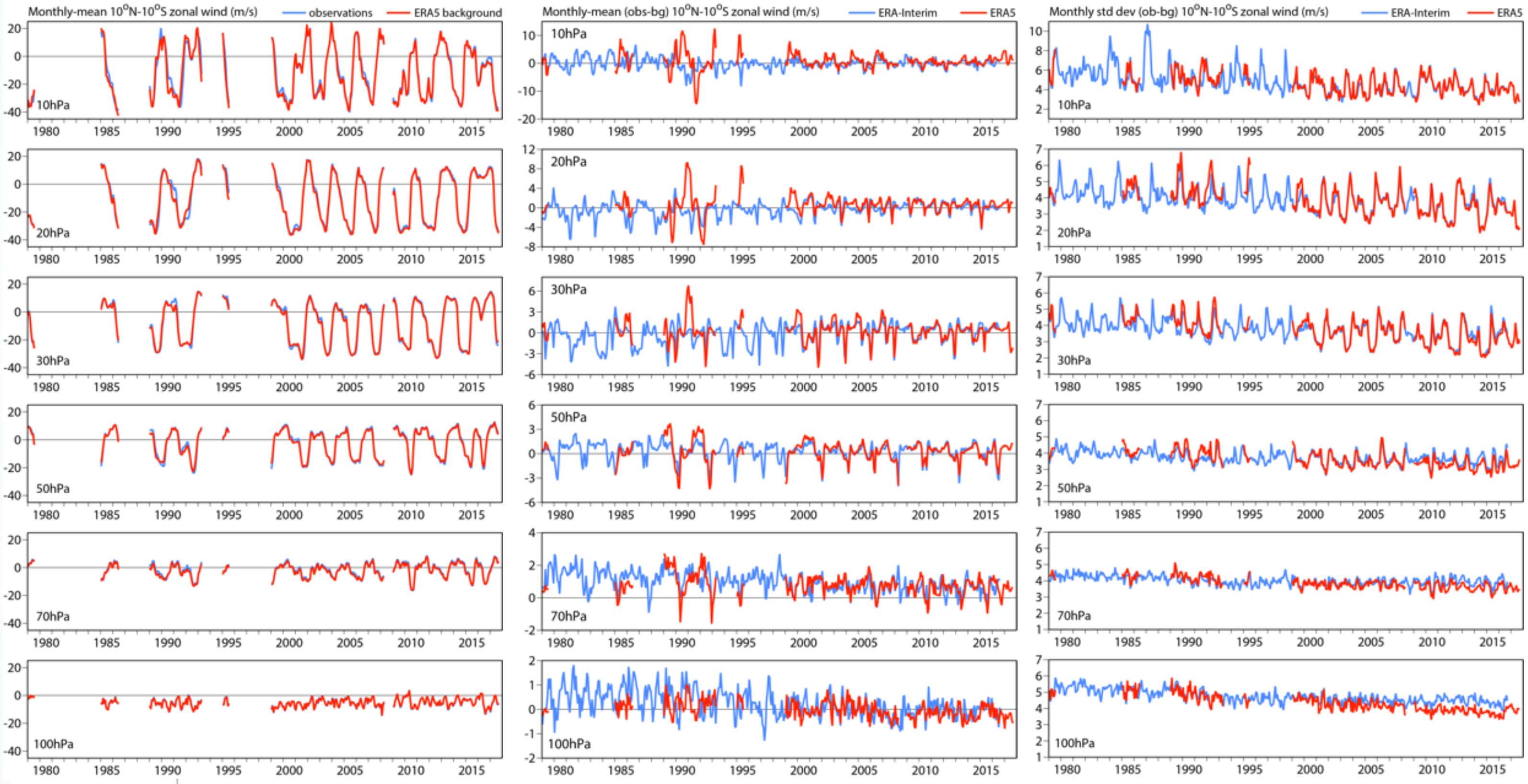
Tropical stratospheric zonal winds



ERA5 performs a little better than ERA-Interim for recent years, but is poorer for the 1990s

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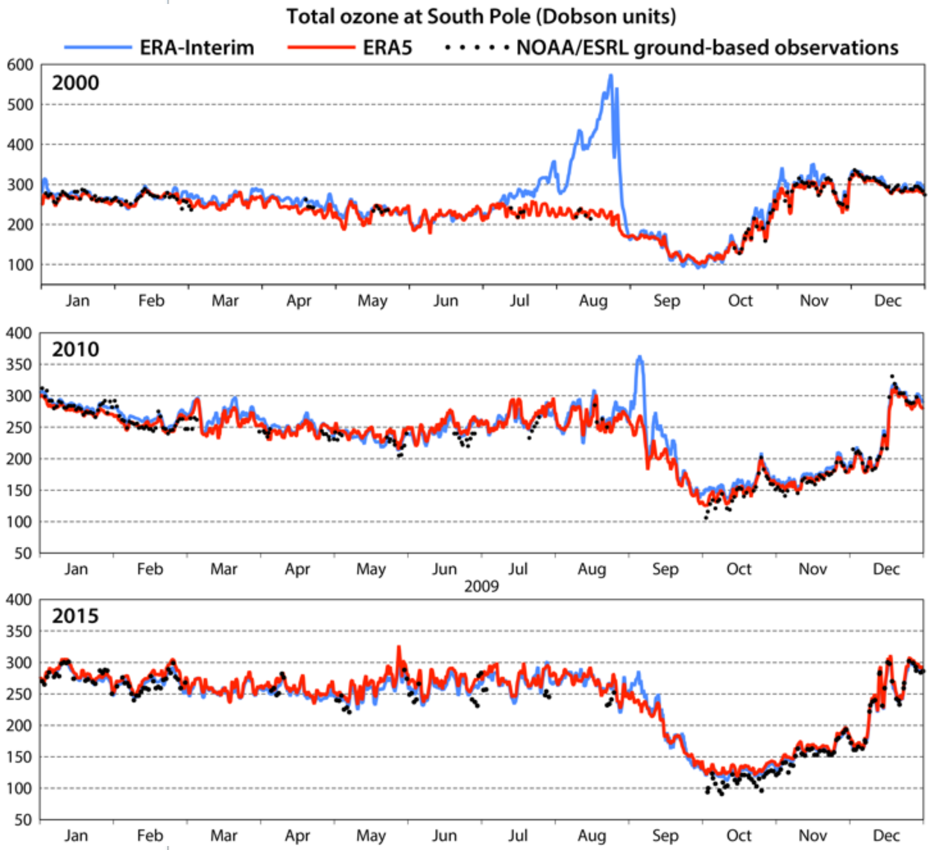
Ozone over the South Pole



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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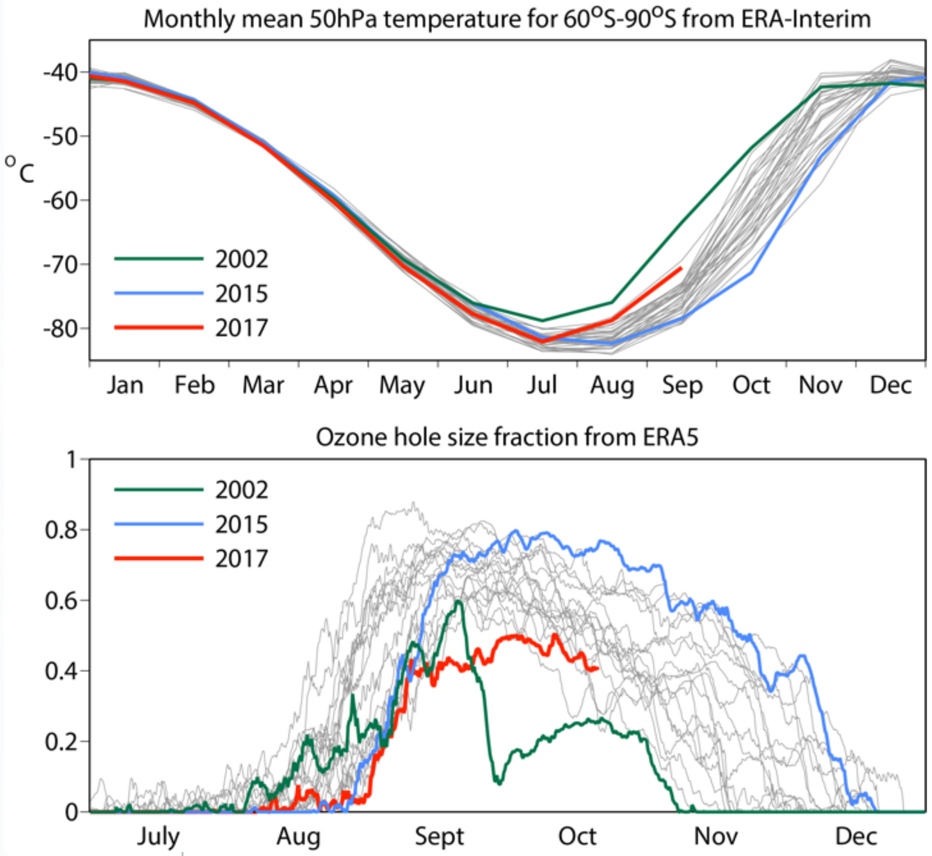
Variability of the ozone hole and polar temperatures



Based on ERA-Interim temperature analyses for 1979-2017, and ERA5 ozone analyses for 1991, 1992, 1999-2007 and 2009-2017.

Size fraction is the area where total-column ozone is below 220 DU expressed as a fraction of the area south of 60°S.

2002 stands out as extreme, but 2017 is also noteworthy for its relatively warm temperatures and small ozone hole.

2017 is the year with the lowest maximum ozone-hole area.

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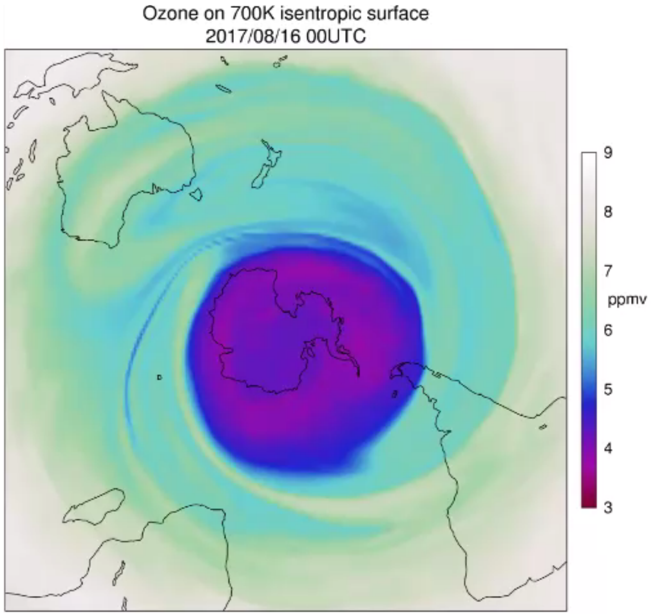
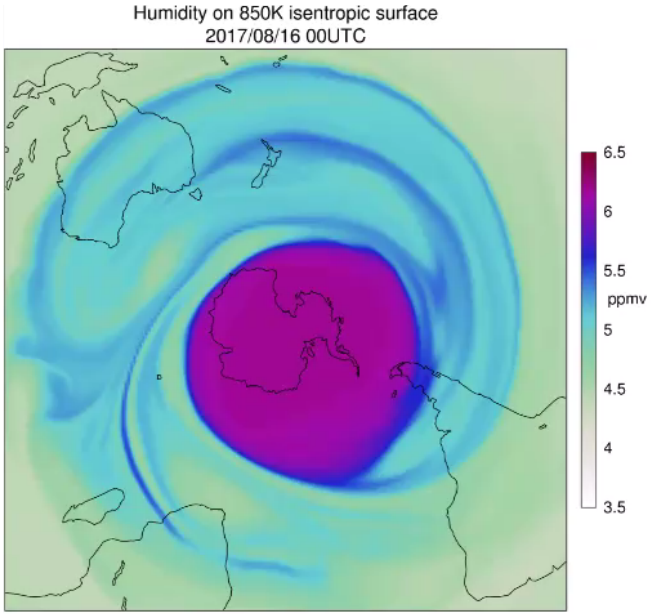
The 2017 ozone hole





Ozone on the 700K surface changes 12-hourly due to assimilation of satellite data, and changes also due to parametrised processes during the background forecasts. Humidity on the 850K surface is not influenced directly by assimilation of humidity data, and parametrised processes cause little change. Data assimilation exerts control on both variables through changes to the advecting winds.

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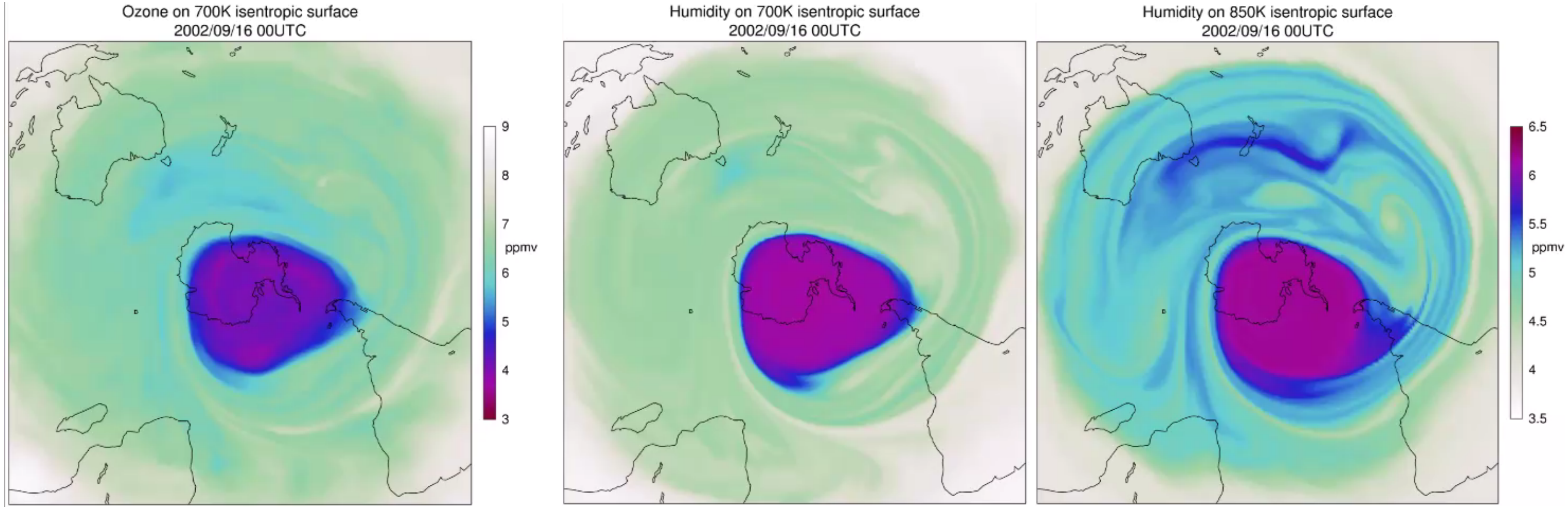
The 2002 vortex breakdown



The 12-hourly changes to ozone on the 700K surface are larger in 2002 than 2017.

There is less coherence between the 700K and 850K levels after the initial vortex split in 2002. Several smaller vortices form and decay at both levels.

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In summary

Performance of ERA5 in the troposphere is generally better than that of ERA-Interim:

- improved global hydrological and mass balance
- smaller biases in precipitation
- refined temperature variability and trends
- better fit to observations and better medium-range forecasts

Performance of ERA5 is mixed in the stratosphere and mesosphere:

- better tropopause temperatures and lower-stratospheric humidities in the tropics
- sharper representation of small-scale dynamical features
- better late-winter ozone distributions in the Antarctic
- larger temperature biases, which vary more over time; better from late 2006
- problematic tropical winds at high levels

Prospects:

- good overlap from 2007 should enable merging with ERA-Interim where needed
- issues to be addressed for ERA6 are clear,
  and some progress is already being made