Characteristics of ERA5 and innovations for ERA6

Climate Change

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and many others !

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ERA5: *A full-observing-system global reanalysis for the atmosphere, land surface and ocean waves*

- Produced at ECMWF, by the **Copernicus Climate Change Service**
- >88,000 CDS users, >500 Tbyte of downloads per week

- Daily updates **5 days behind real time from 1959 onwards**
- Extension back to 1940 completed for 80%.

- **Hourly snapshots** at **31km resolution** up to about 80km height
- **Uncertainty estimate** from a 10-member ensemble at half resolution

- **ERA5-Land**: Dynamically downscaled land product at **9km**, 1950 onwards.

- Total dataset will be about 12 petabyte

Surface air temperature anomaly for August 2022
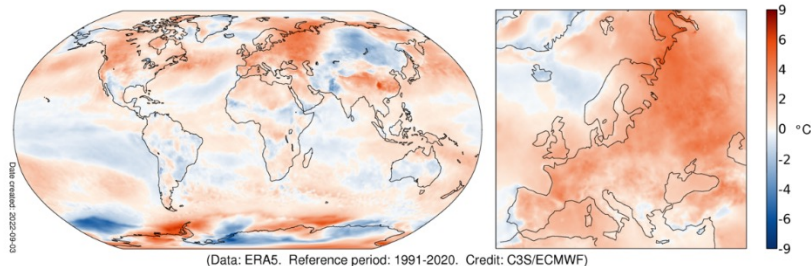
(Data: ERA5. Reference period: 1991-2020. Credit: C3S/ECMWF)

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Observation usage:
- Over 100 billion so far

Usage of external (gridded) products 'as is':
- SST and sea-ice cover
- GHGs, aerosols, TSI, (diagnostic) ozone

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Strength and success of *the ERA5* reanalysis

**Reconstruction of the past weather and climate:**
- ✓ **Input:** integrator of all observations we have
- ✓ **Output:** convenient and as accurate as possible 'maps without gaps' of 3D atmosphere (+ other domains)

State-of-the-art:
- ✓ Redo historical weather using a modern but fixed NWP system
- ✓ For extended period back in time, but at lower resolution
- ✓ Maintained close to NRT
- ✓ Made available to users in a convenient way

Multiple classes of applications:
- ✓ Study of **specific events** or phenomena:
  - • accurate (3D) synoptic situation; i.e., **the weather of the day**

- ✓ **Climate monitoring:**
  - • Accurate recent synoptic situation + **consistent 30-year climate**

- ✓ **Climate** applications:
  - • low-frequency variability of **the mean state**
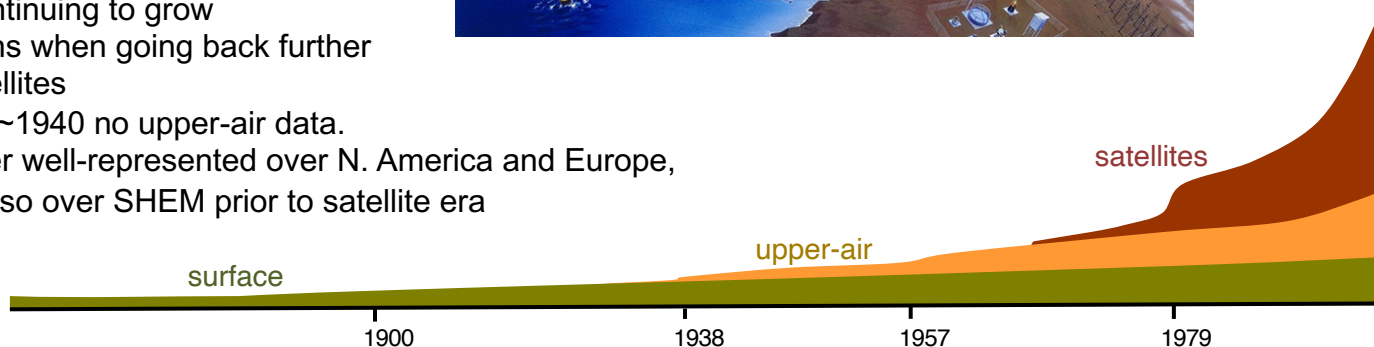 - • Statistics of, e.g., extremes
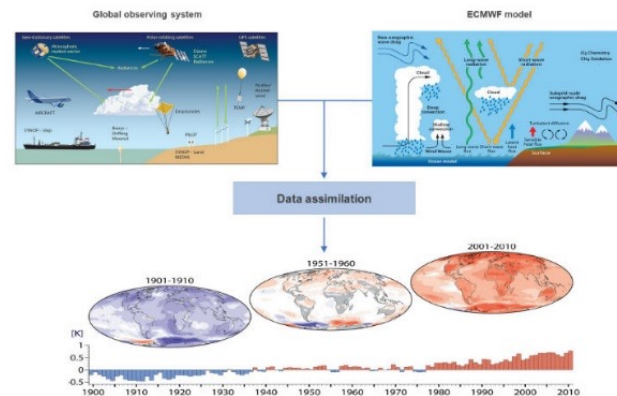
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Data sources:
- many **satellites**
- **Upper air**: weather balloons, aircraft, etc.
- **surface** observations

ERA5 daily uses about:
- **53,000** observations in 1950
- and **26 million** in 2021

- Amounts are continuing to grow
- Less observations when going back further
  - No satellites
  - Before ~1940 no upper-air data.
  - Weather well-represented over N. America and Europe,
  - but not so over SHEM prior to satellite era

satellites

upper-air

surface

1900   1938   1957   1979

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We maintain a list of known issues in the ERA5 online documentation:
- https://confluence.ecmwf.int/display/CKB/ERA5%3A+data+documentation#ERA5:datadocumentation-Knownissues

The NWP system is tuned for today's observation coverage:
- Today: analysis is dominated by (anchor) observations
- Past: need more model glue; can lead to problems in case of **systematic model bias**
  - Mostly an issue for some climate applications in certain domains

Inherent challenges of the NWP system used (IFS Cy41r2, operational 2016):
- Some systematic errors are also present today, like for energy fluxes, precipitation
- Small but systematic jumps of surface wind in hourly product
- Too much snow over mountainous regions
- At isolated locations, occasionally very strong winds (part-resolved), 'rain bombs'

Uncertainty estimate:
- Error of the day: evolution over time OK, but spread too small
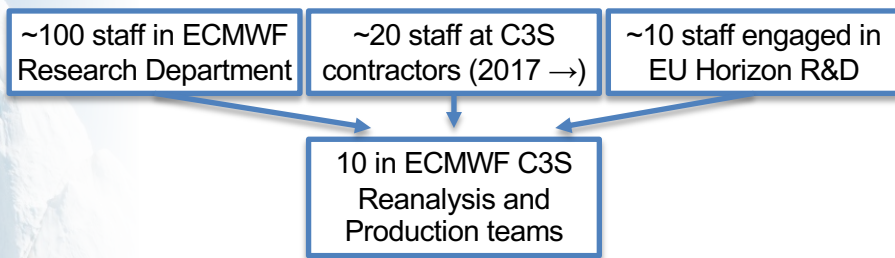- No information on error estimate of the mean state

Other issues:
- QC bug for snow (under control for ERA5T, though)
- Challenging assimilation of historical tropical cyclones based on limited information
- Local inconsistencies in (SST/ sea ice) forcing
- Continuity between production streams

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ERA6 will benefit from an additional 8 years of R&D at ECMWF & improved compute capacity

~100 staff in ECMWF Research Department

~20 staff at C3S contractors (2017 →)

~10 staff engaged in EU Horizon R&D

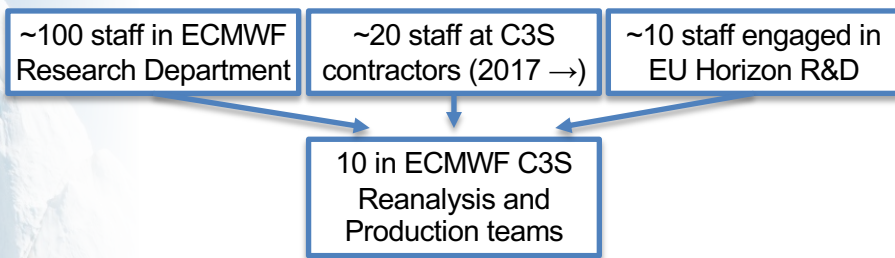10 in ECMWF C3S Reanalysis and Production teams

- **Improved resolution (HRES @ 18km or better)**

- **Improvements in model bias**

- **Exploiting more observations & using more optimally:**

  - Newly available in IFS since 2016 ERA5 model cycle
  - Reprocessed (**see Joerg's talk - Tuesday**)
  - Rescued data (satellite and in-situ **see Paul's talk - Tuesday**)

- **Improved realism of near-surface quantities and radiative forcing**
  - **vegetation** cover and type, **LAI, lake** cover and properties, the **urban tile**
  - New, and more species of, **aerosols** and **GHG's**

- **Improved ocean wave physics**
  - wave physics upgrade

- **4D-Var DA developments**
  - Dynamically evolving B_{cli}
  - EDA developments

- **Land DA developments**
  - Revised conventional observation feedback for T2m, RH2m and snow analyses

- **Ocean DA developments**
  - ERA6 will be forced by ORAS6 and OCEAN6 fields

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Extension of ERA5 to 1940
Few upper air observations
→ model bias exposed

The impact of model bias on stratospheric temperatures

lower stratospheric cold biases
in original production → ERA5.1

VTPR stratospheric channels
used VarBC – reinforcing
model bias.
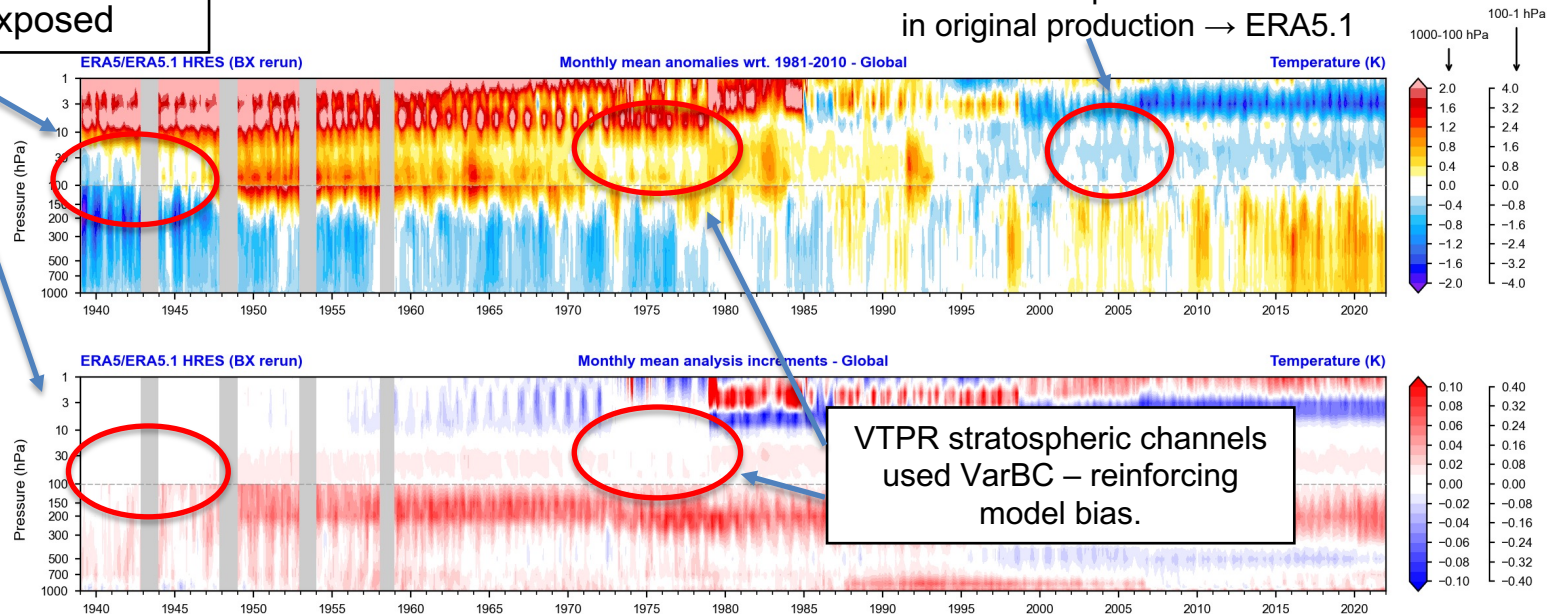
- Discontinuities most evident in the stratosphere, esp. above 10 hPa
- Caused by interplay of model biases & changing observing system
- **Improved forecast model biases, data assimilation methods (WC 4D-Var) & reprocessing of observations will play a role in minimising these effects**

Early satellite data rescue (focus on pre-1979)
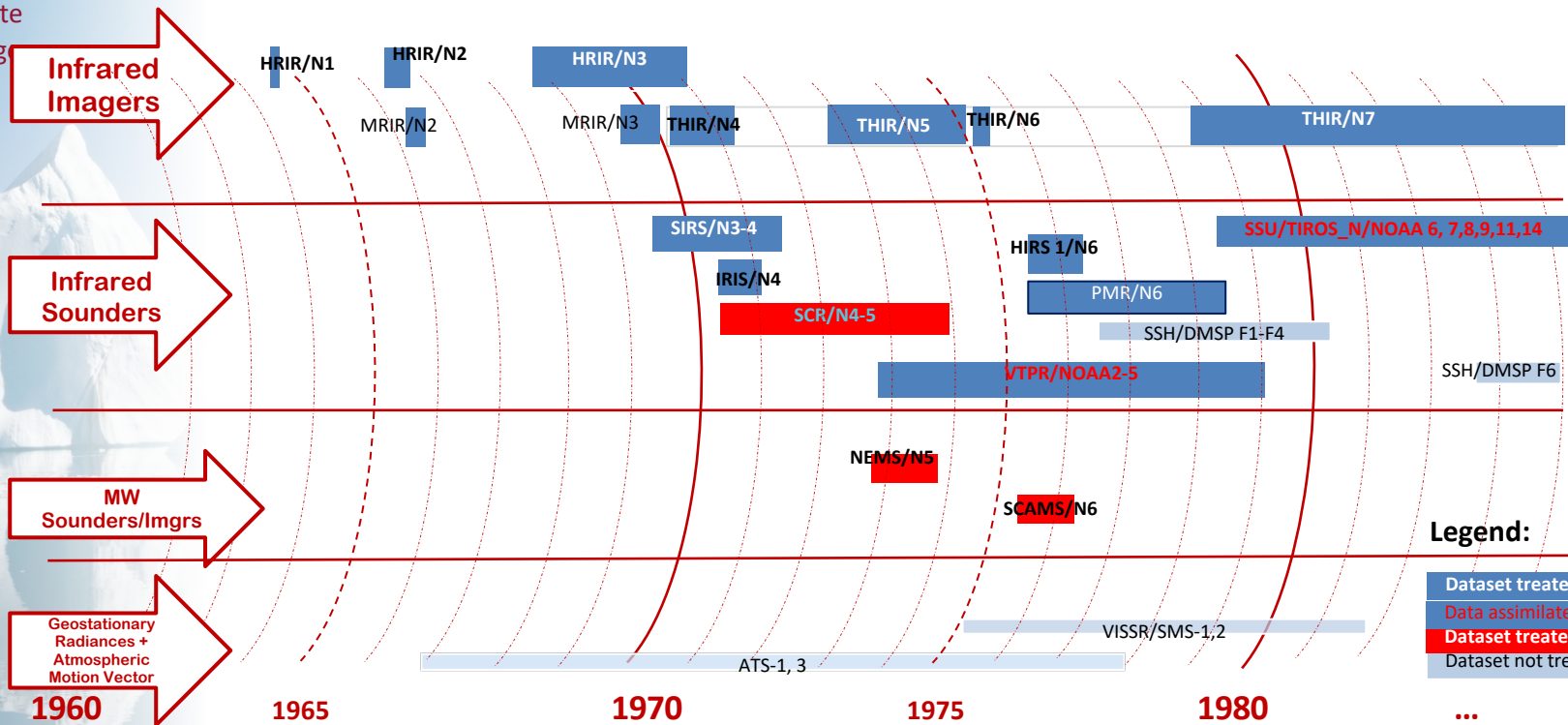
Geolocation problems with early satellite data

- VTPR exhibits geolocation errors of up to 400 km.
- For the Nimbus sensors such as THIR, there are often problems with the anchor points used for geolocation at the poles.
- These problems can be fixed by recalculating the geolocation using modern software.

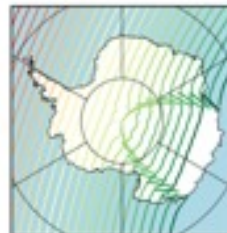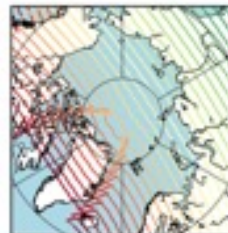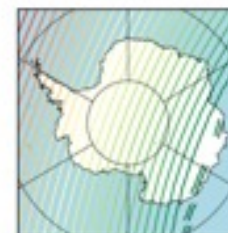**VTPR geolocation errors**

Original geolocation
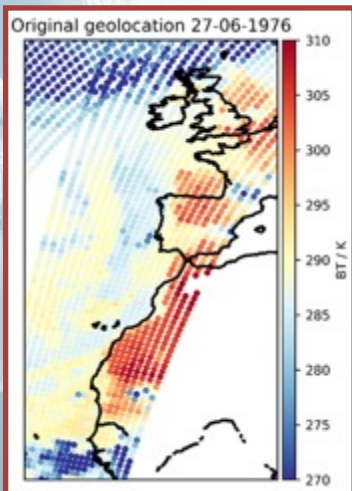
Corrected geolocation

THIR Nimbus 4

Original geolocation 27-06-1976

Coming in Copernicus
C3S
Phase 2

Original geolocation   Updated geolocation

Tom Hall, Univ. of Reading
(C3S2_314)

**BT (K) for VTPR window channel
(11.97 μm)**

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The **ERA5** reanalysis provides **hourly snapshots** of the atmosphere, land surface and ocean waves for **over 70 years**
- Very popular dataset on the **CDS**: https://cds.climate.copernicus.eu/#!/home
- We closely monitor the production and quality of ERA5; we know about a number of issues
- Main challenges are related to the strongly evolving observing system

We have started preparations for ERA6:
- Higher resolution and based on an additional 8 years of R&D at ECMWF, enhanced coupling
- Better and more observations; together with C3S contractors
- Address ERA5 challenges:
    - counter-act systematic model error
    - improve the uncertainty estimate
    - further limit discontinuities between production streams

We receive a lot of feedback from our users and listen to them: **we are user-driven**

Further reading:
- ERA5 online documentation
- The ERA5 journal papers (Hersbach et al, 2020, Bell et al., 2021), Simmons et al., 2020, 2021, 2022
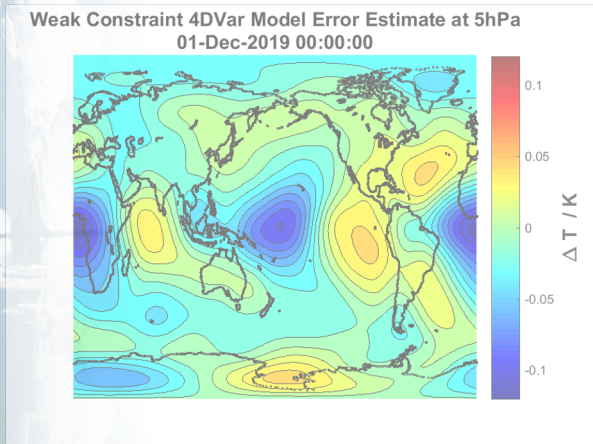- Many, many journal papers.
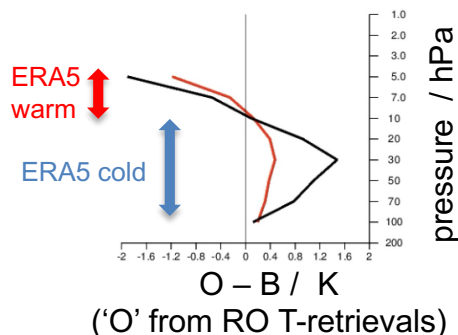
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Extra slides

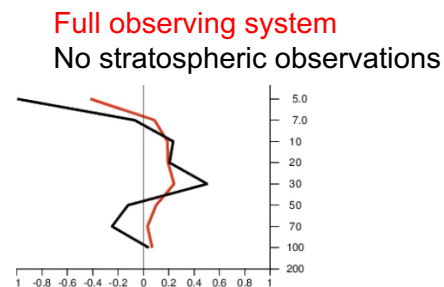# Treatment of stratospheric biases using Weak Constraint 4D-Var

- Weak constraint 4D-Var analyses large scale biases in the stratosphere, operational since 2020
- Effective in reducing temperature biases in the stratosphere
- Several options under test for ERA6 (*e.g.* WC 2006 → present, WC model error used before 2006)

Weak Constraint 4DVar Model Error Estimate at 5hPa
01-Dec-2019 00:00:00

Strong Constraint 4D-Var
'ERA5-like' configuration

ERA5 warm

ERA5 cold

pressure / hPa

O – B / K
('O' from RO T-retrievals)

Using WC model error
'ERA6-like' configuration

Full observing system
No stratospheric observations

- **In addition, new** developments in the radiation scheme are expected to significantly reduce stratospheric biases **at source**, leaving WC to deal with residual biases

- We aim to estimate mean state uncertainties

→ amplitude of T biases reduced by a factor of 2-3 in the stratosphere when using WC 4D-Var model error forcing

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Ensemble of Data Assimilations (EDA)
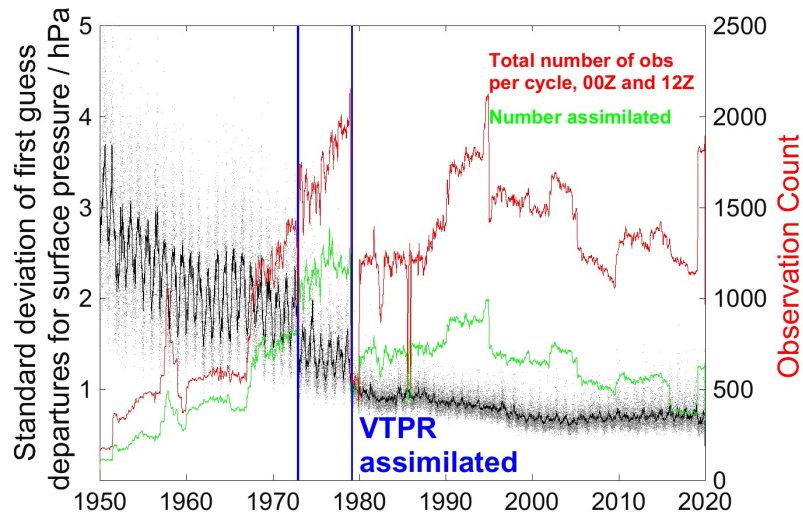analysis spread (a proxy for '*synoptic*' analysis error)
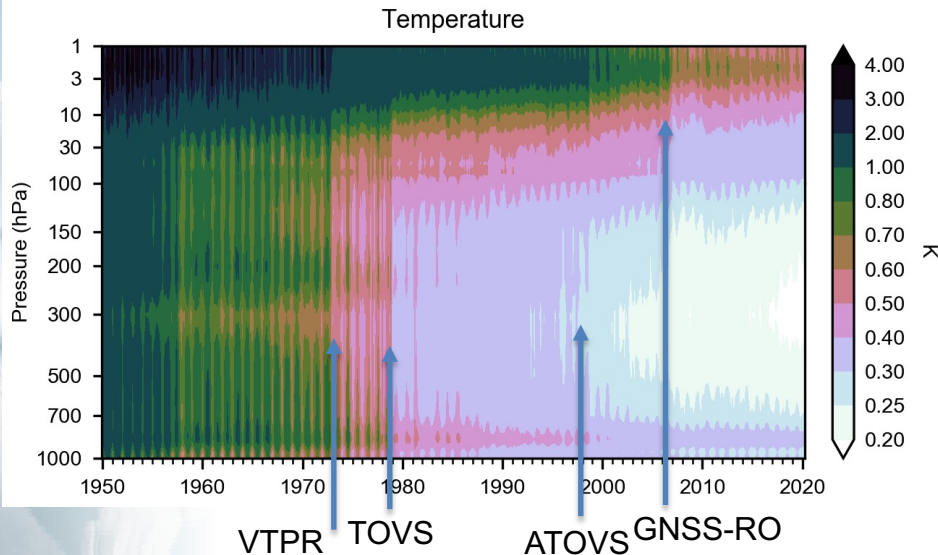
Temperature

Vertical Temperature Profiling Radiometer (VTPR)
- 8-channel IR sounder. 'HIRS predecessor'
- Flown on NOAA2 - 5 (Nov 1972 - Feb 1979)
- Same L1 data assimilated in ERA-40 & JRA-55

Impact of VTPR
Background fits to surface pressure observations 1950-2020
Southern Hemisphere

→ pre-1979 satellite data can significantly improve the quality of reanalyses