The assimilation of radiances in the ECMWF ERA6 global reanalysis

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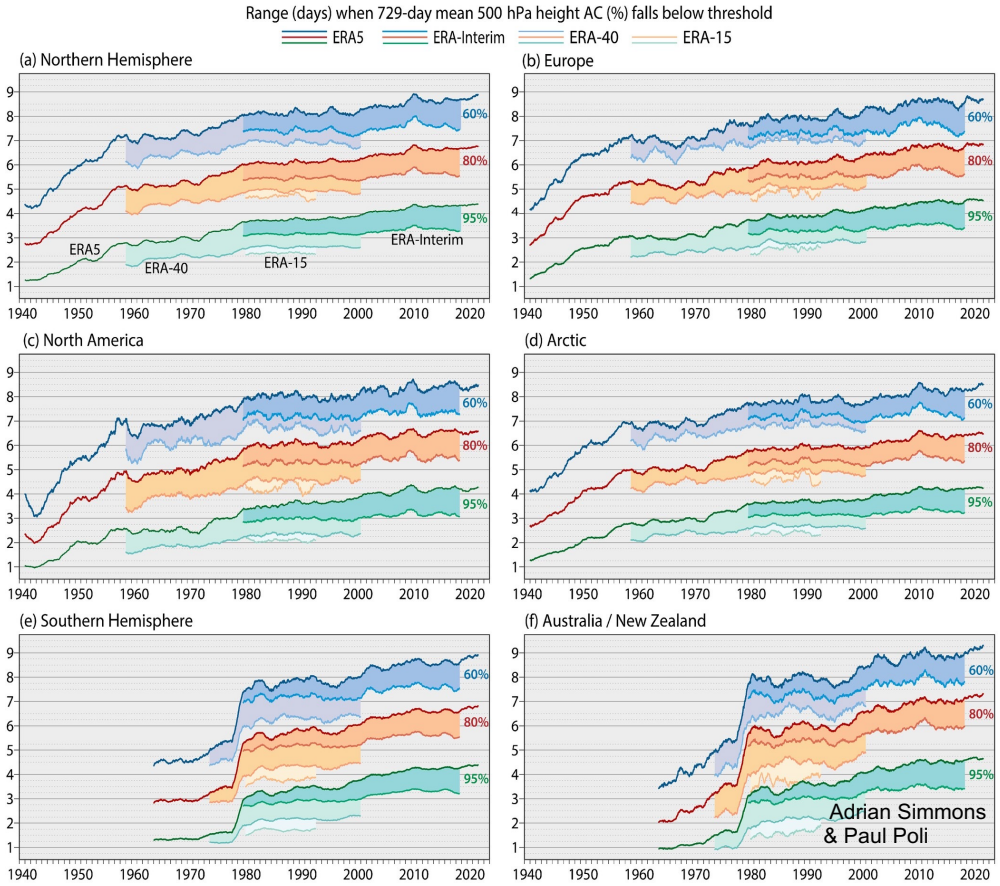
Overview

- **ECMWF atmospheric reanalyses**
  - Previous generations of atmospheric reanalyses
  - IFS developments between ERA5 & ERA6
  - Initial indications of ERA6 performance
- **Some specific aspects of ERA6 related to sounding data**
  - Reprocessed data (*e.g.* EUMETSAT reprocessed HIRS data)
  - Early satellite sounding data
  - Accounting for time varying CO_2 in assimilating IR data
- **Summary & aspects for WG discussions**

ECMWF atmospheric reanalyses

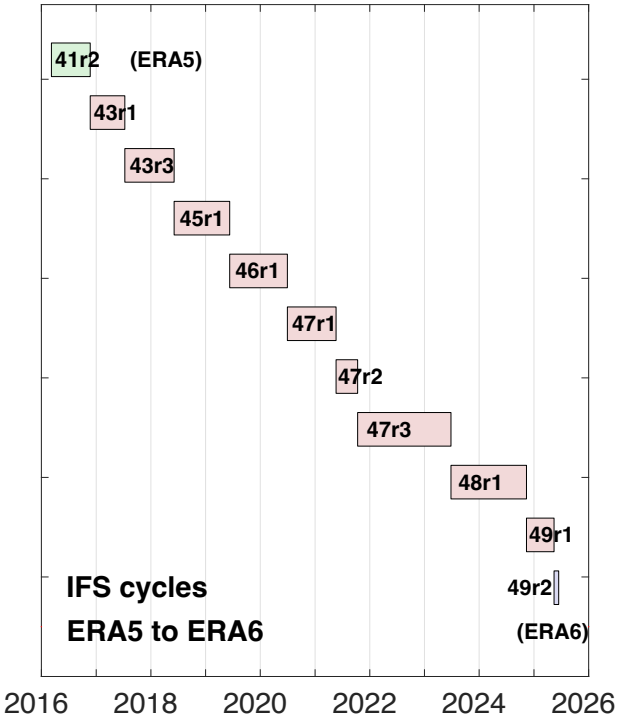


- **Most recent is ERA5, started in 2016, still runs in NRT**:
  - 31km horizontal resolution (ERA6 will be 14km)
  - hourly state estimates, 1940 – NRT
- **A popular ECMWF product**
  - > 20 000 citations (Hersbach et al, 2020)
  - user base > 200 000 since 2018
- **Supports a very wide range of applications, including, for example:**
  - climate trend assessments
  - studies of extreme events
  - training datasets for ML forecast models *(a topic for discussion in WGs)*
- **Next generation ECMWF reanalysis: ERA6**
  - Due to start production in Q2 2025
  - 1950 to ~2035
  - Expect to complete by 2028

For more details on ERA5:
- Hersbach *et al*, QJ, 2020
- Bell *et al*, QJ, 2021
- Soci *et al*, QJ, 2024

‘ *What do we get from ERA6 ? ’*

Integrated Forecasting System (IFS) upgrades since ERA5



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Data assimilation
- RTTOV 13.2
- Improved T2m assimilation
- VarQC & stratospheric balance
- Land surf
- Hourly alt
- Soft rece

Observatio
- Scene de
- Reduced
- All-sky &
- All-sky A
- F-18 SSM
- Improved
- MWS sup
- Improved
- Optimisa
- GNSS-R
- Improved

Model
- Wave model / land convection package
- Land surface model updates
- SPPT→ SPP
- Improved physics and numerics

49r2

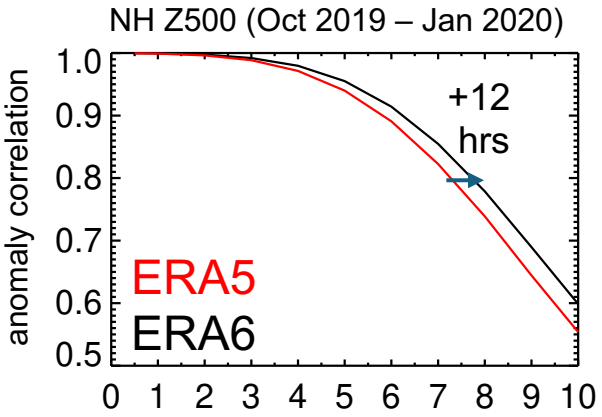
Data assimilation & Observations
- Outer-loop coupling updates
- 1D-OI → SEKF: soil and snow temp analysis
- **Orbital bias correction for AMSU-A and ATMS**
- VarBC for surface pressure
- **Time varying CO_2 for IR assimilation**

Model
- Time varying solar forcing
- O_3(t) for HLO
- Revised aerosol
- Revised wave model bathymetry
- Non-orographic GW drag changes
- Reduced vertical diffusion in stable conditions

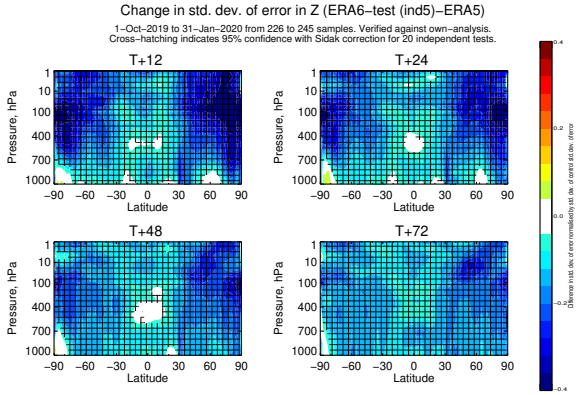
https://confluence.ecmwf.int/display/FCST/Changes+to+the+forecasting+system

+ analogous technical developments, incl. HPC upgrade

ERA6 performance in pre-production tests

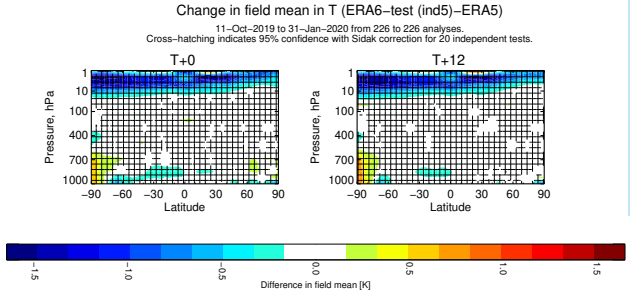


By this metric (remember slide 3) improvements from ERA5 to ERA6 are in-line with those achieved in previous generations of reanalyses

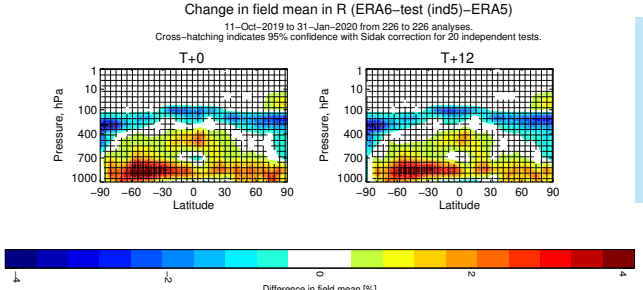


Mean state changes

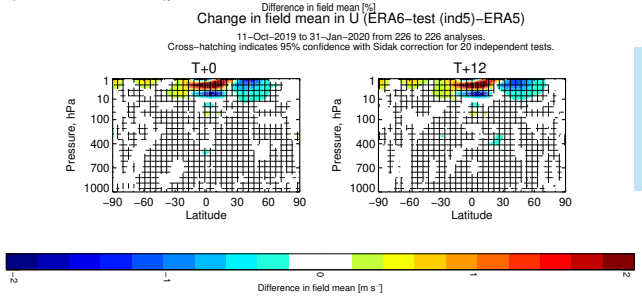
Temperature



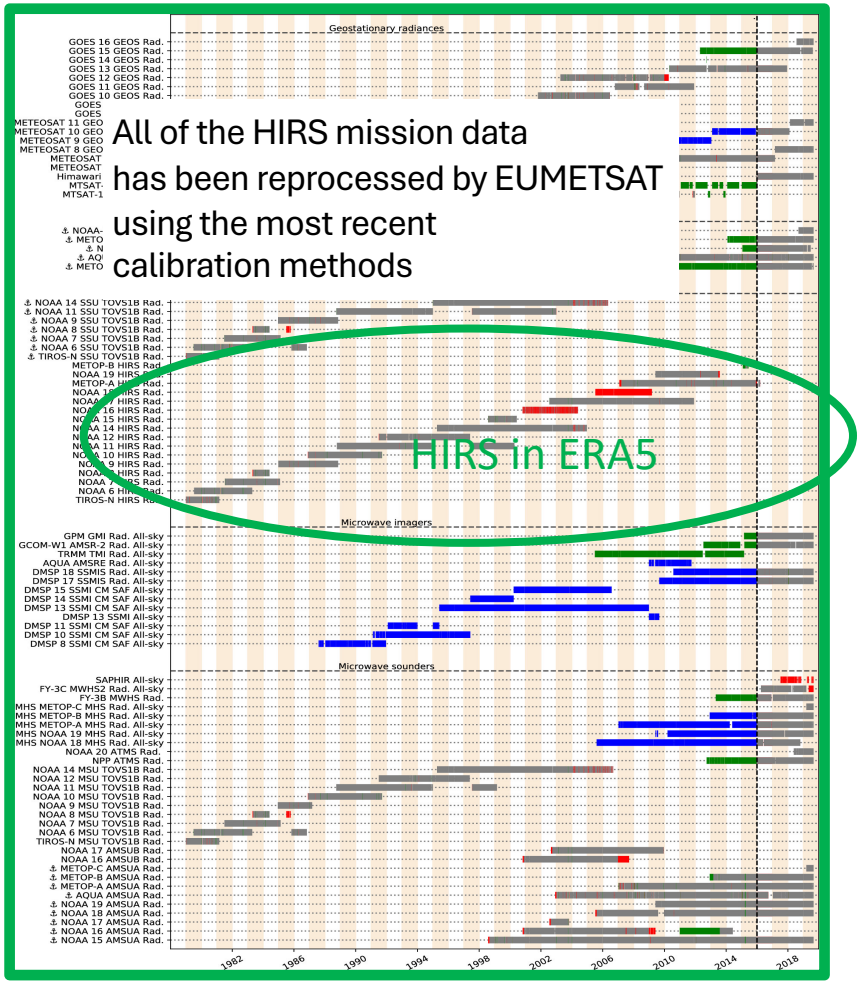
Humidity



Winds



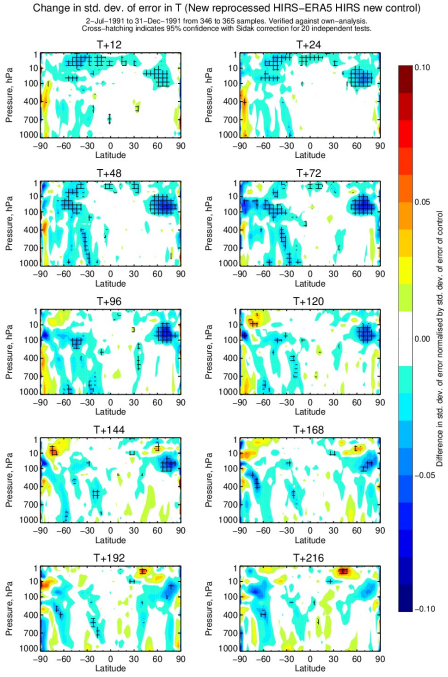
The assimilation of reprocessed radiances in ERA6



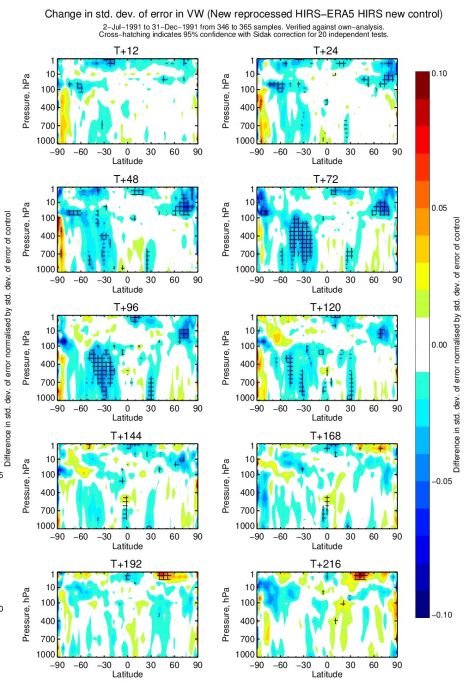
Improved analyses and forecasts
Using EUMETSAT reprocessed HIRS data

(blue areas below represent smaller errors for the test with reprocessed HIRS, relative to a control using HIRS data assimilated in ERA5)

Temperature

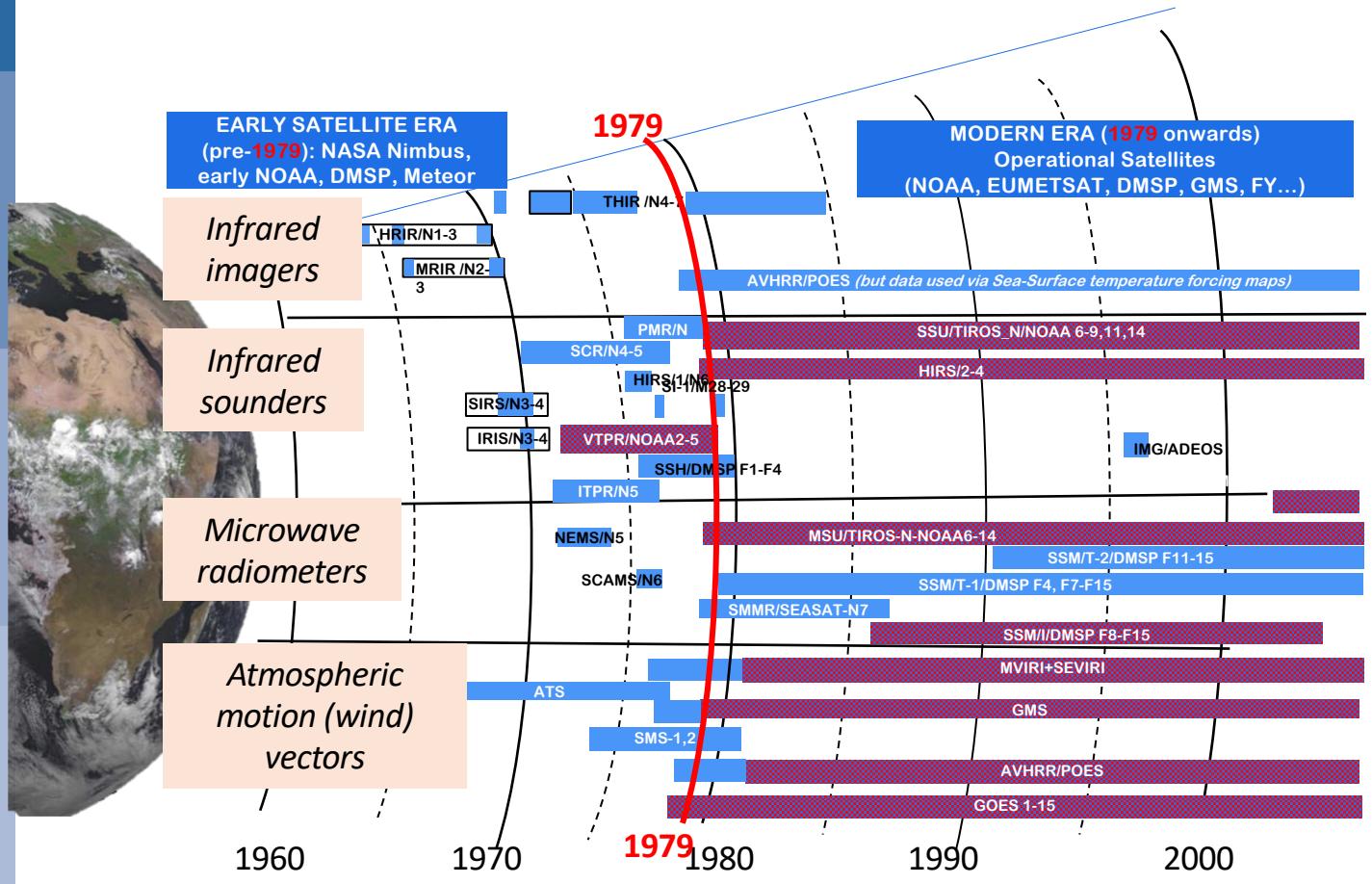


Winds



Other reprocessed radiance datasets to be assimilated in ERA6 include:
MHS, Meteosat-FG Geo radiances, SSM/T-1 and SSM/T-2

Early satellite sounding data being prepared for ERA6



Preparations for ERA6 include:

- **Rescue and Assessment** of radiance observation from pre-1979 sensors
- Showed the impact of **IRIS at ITSC-24**
- **Priorities for ERA6 are:**

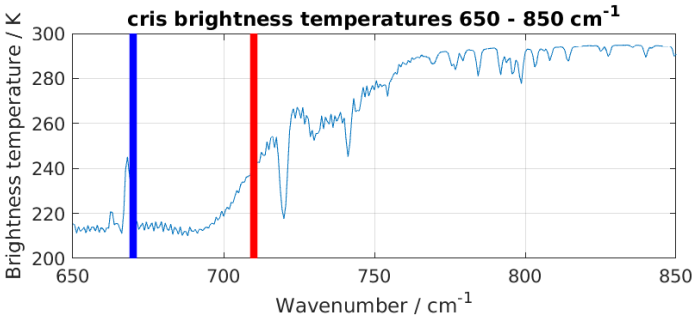
  - SSM/T-1, SSM/T-2 NEMS & SCAMS (MW)

  - SSH, SIRS & SCR (IR)

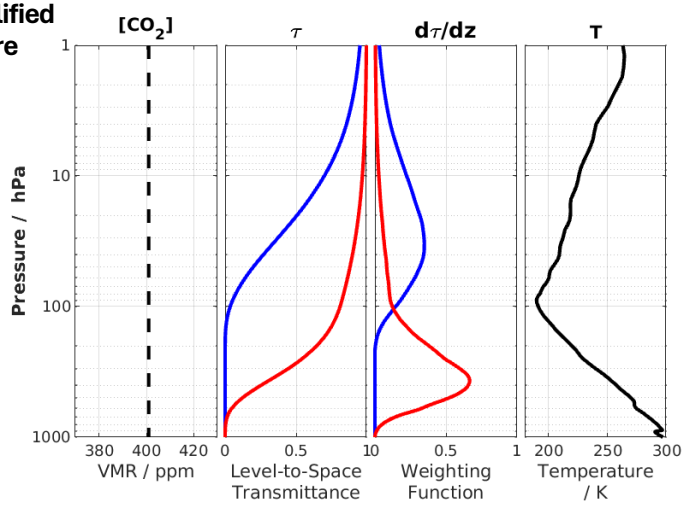
Data not yet assimilated in ERA

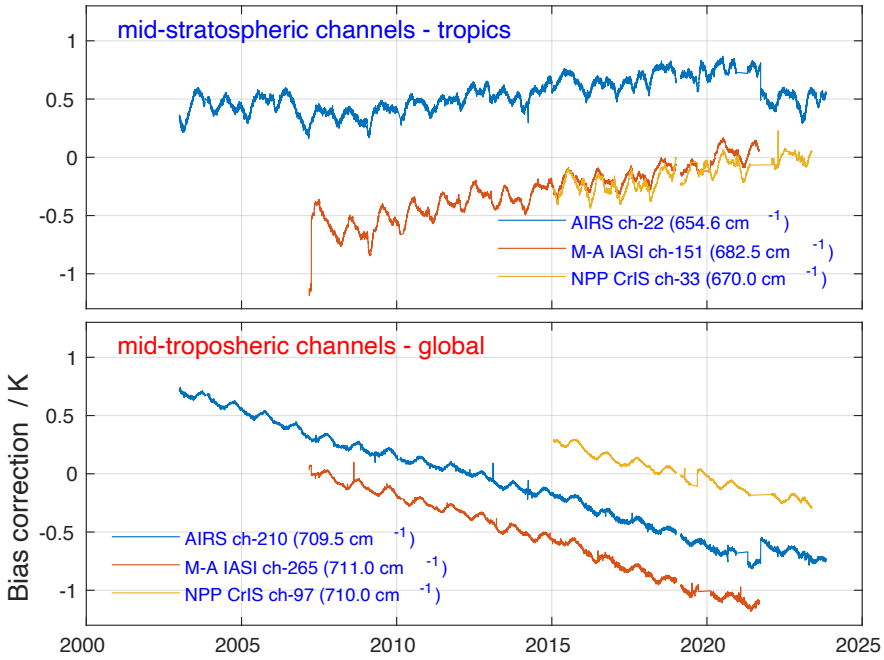
Original or earlier-reprocessed data version assimilated in ERA5

The treatment of CO_2 in the assimilation of advanced IR sounder observations in ERA5



Simplified picture

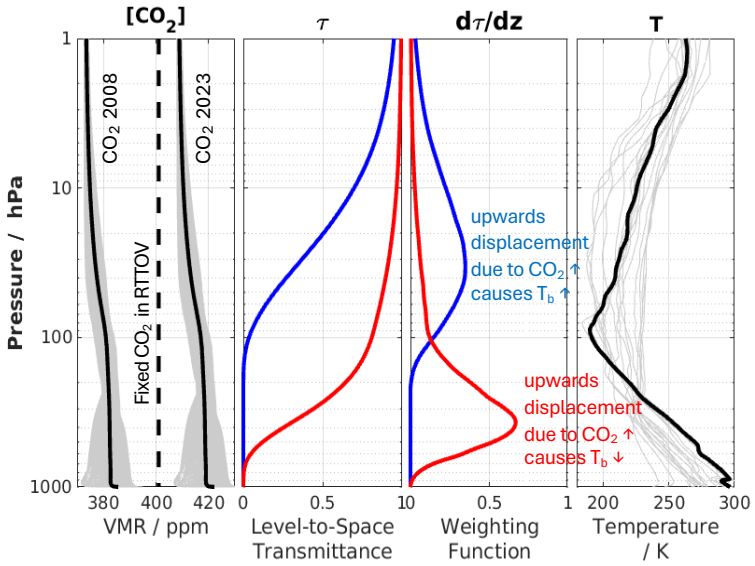


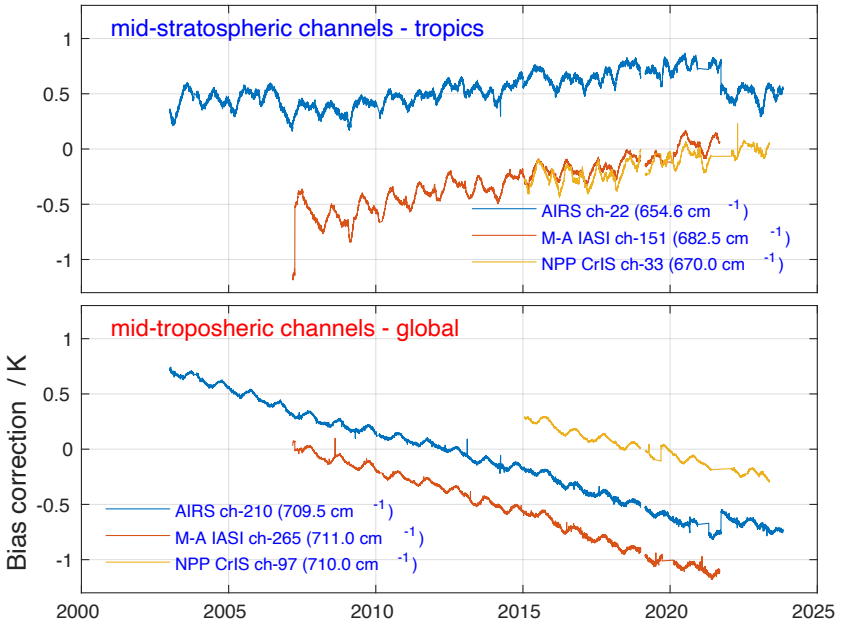


If [CO_2] is constant in space & time in the real world,
and the observation operator (RTTOV) represents this correctly
⇒ there should be no bias associated with this aspect of the RT modelling of IR radiances.

… but we do see time varying biases in IR sounding channels, as a result changing [CO_2] (RTTOV assumed fixed CO_2 for the advanced IR sounders in ERA5)

The treatment of CO_2 in the assimilation of advanced IR sounder observations in ERA5



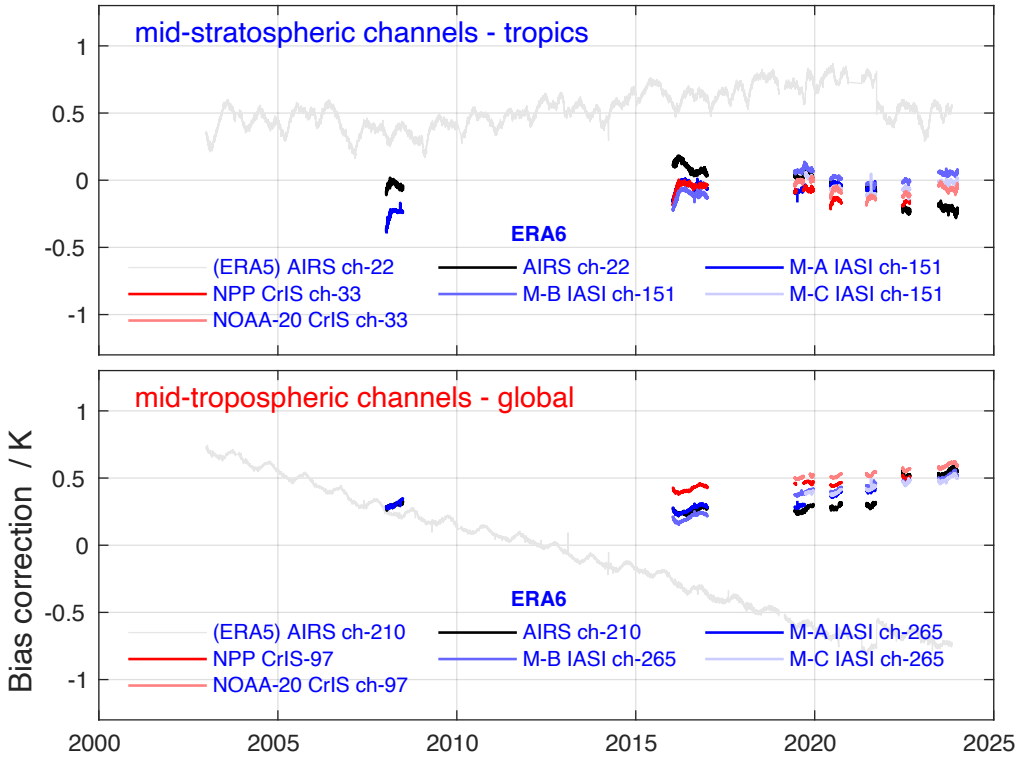


Two effects of changing $[CO_2]$ – when a fixed $[CO_2]$ profile is assumed in RTTOV :

1. **Long-term drift in biases** (analysed by VarBC) due to upwards drift in weighting functions in time
2. **Complex state-dependent biases** (due to $[CO_2]$(time, space) **and** T(time, space))

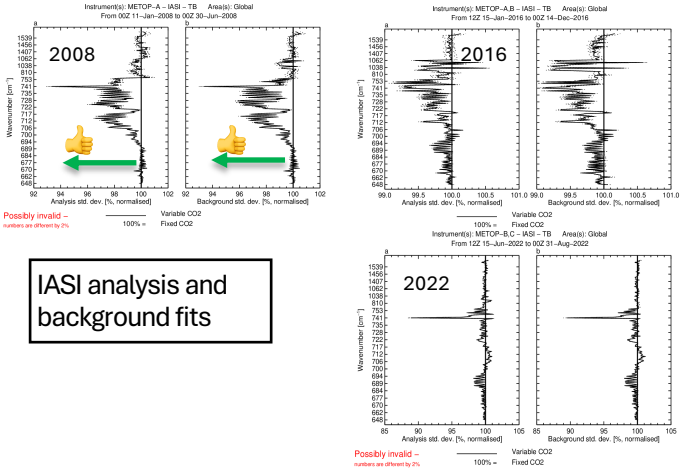
Expect to **improve (1)** & **reduce the impact of (2)** by using a more realistic CO_2 climatology (CO_2 (latitude, time))

Performance of the variable CO_2 scheme in ERA6 pre-production testing: Impact on bias corrections



Based on testing in 2008 - 2023:

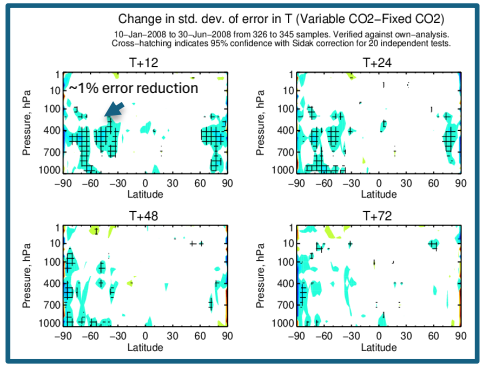
- Long-term drift in bias corrections eliminated for the hyperspectral IR instruments (AIRS, IASI and CRIS)
- Much improved inter-satellite biases
- Background and analysis fits improved for IR sounders (see below) and most independent observations



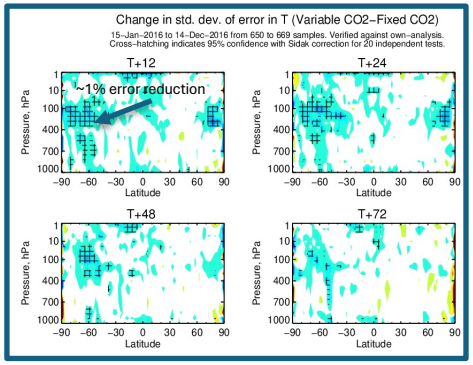
IASI analysis and background fits

Performance of the variable CO_2 scheme (vs fixed CO_2) in ERA6 pre-production testing: Impact on forecasts

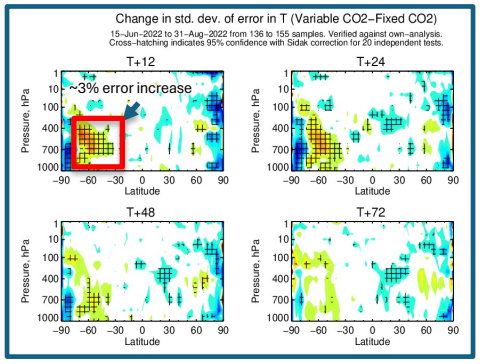
2008 (Jan - Jun)



2016 (Jan - Dec)

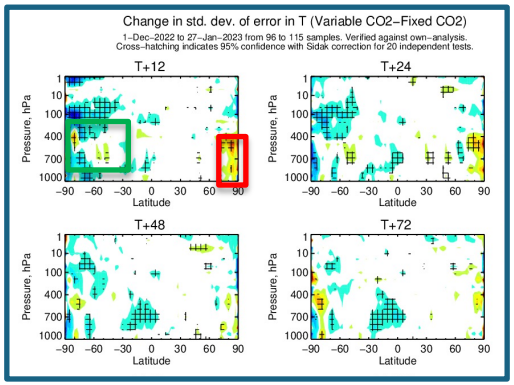


2022 (Jun - Aug)



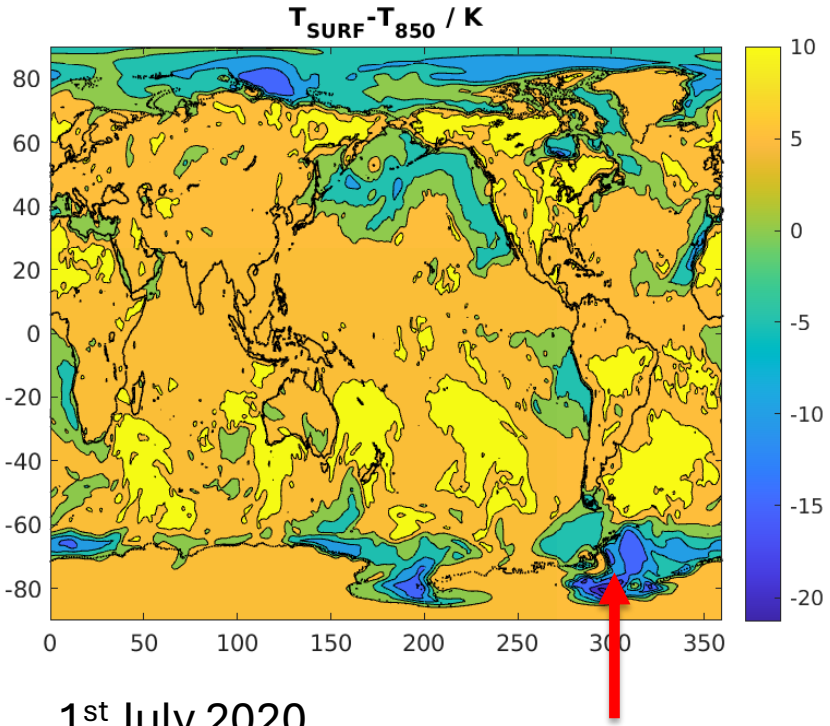
very similar results in summers 2021 and 2023

2022 Dec - 2023 Jan

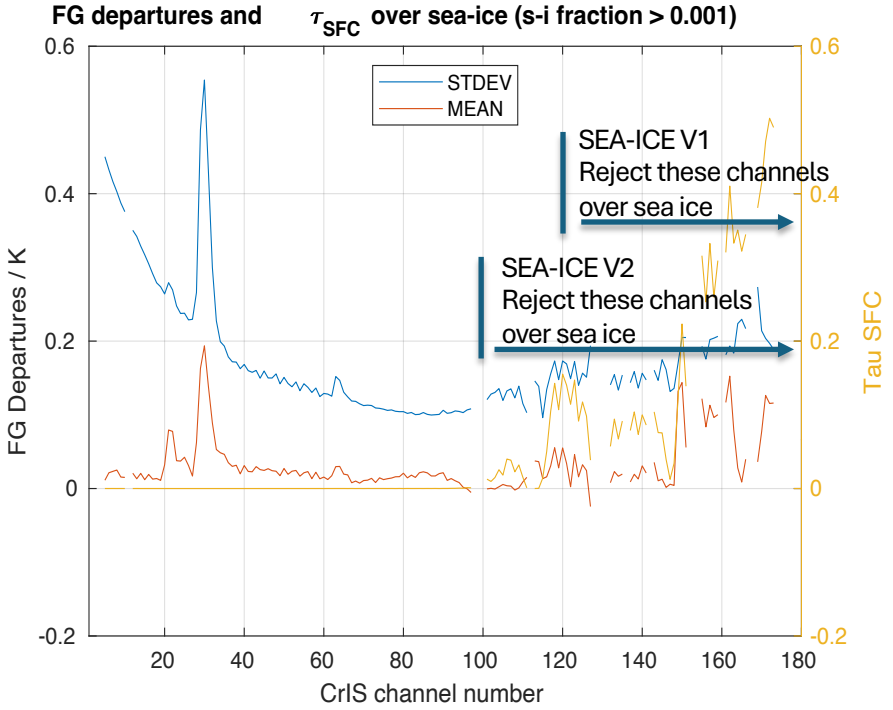


- Performance in 2008 and 2016 generally positive (in fact from 2008 – 2019)
- Locally degraded performance (~3% in T) in southern mid-high latitudes in SH winter in recent years (2020-23)
- Likely caused by change in observation errors & channel selection in late-2019, coupled with challenges of assimilating IR observations over sea-ice in polar winter:
  - Uncertainties in emissivity in sea-ice covered areas
  - Representation of very strong temperature inversions over sea-ice in polar winter
  - Performance of cloud detection in areas of strong inversions

Temperature inversions at high polar latitudes & departure statistics / surface-space transmittance for CRIS

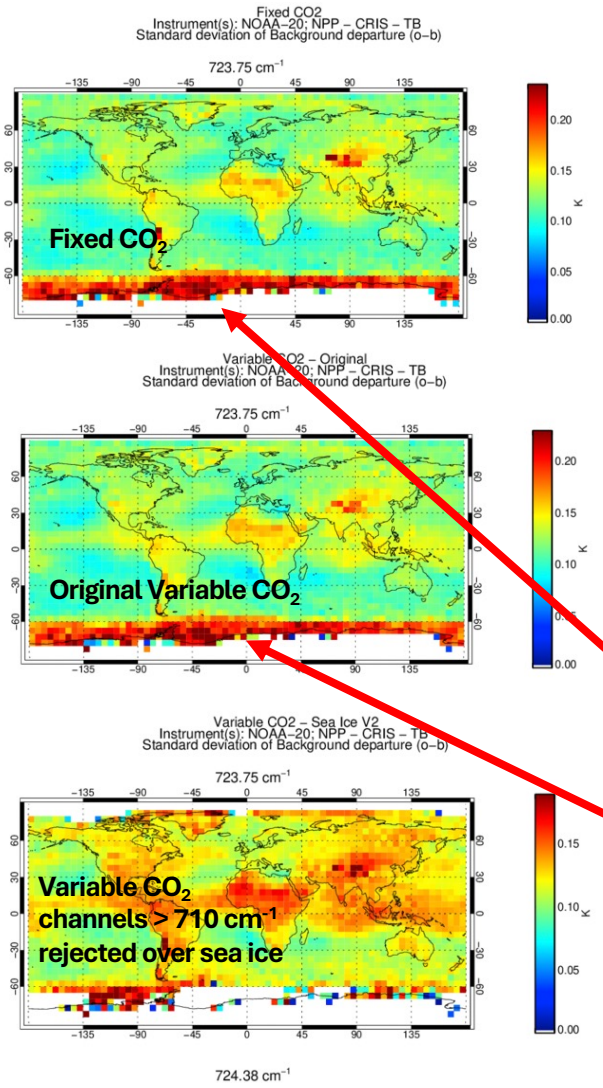


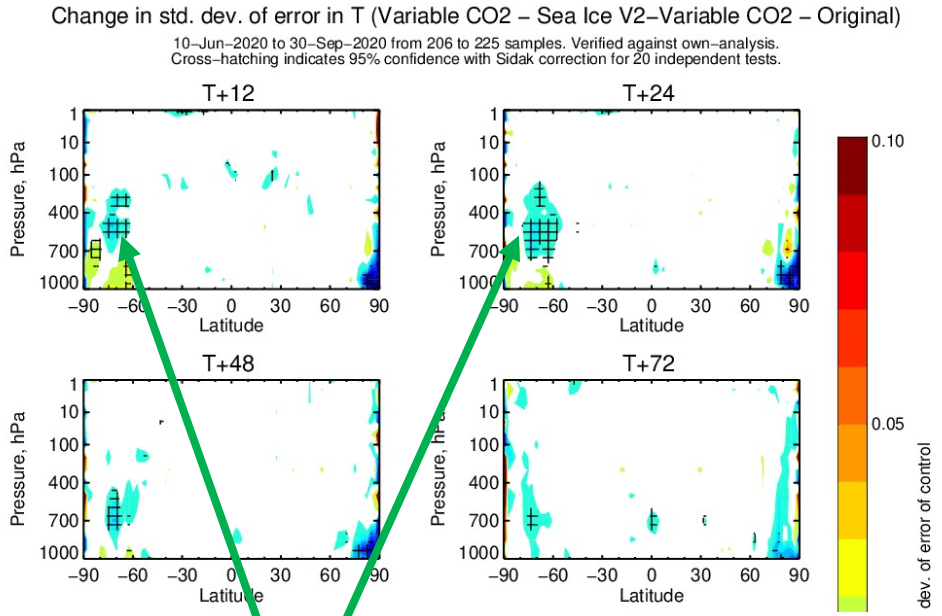
1st July 2020



Strong temperature inversions over sea-ice (20K) – perhaps not well represented in the model ?

Background departure statistics for CRIS surface viewing T-sounding channels



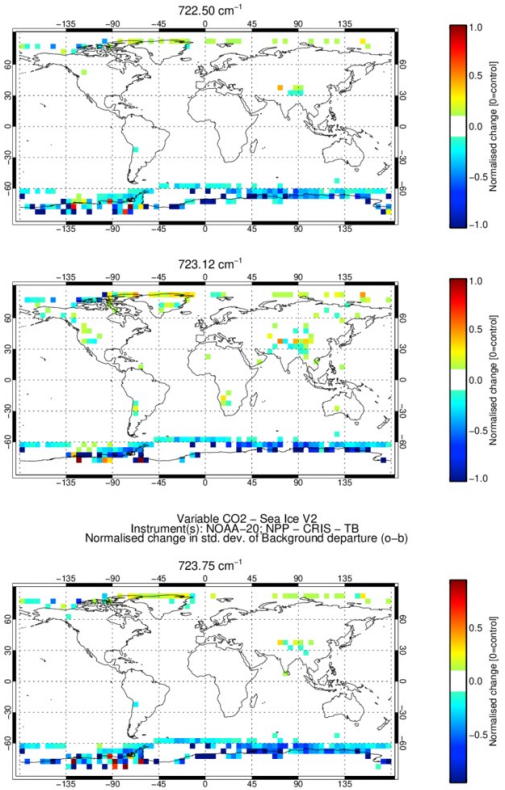


Rejecting surface sensitive channels over sea-ice improves temperature forecasts (at least based on own-analysis verification)

For surface sensitive IR channels, in both fixed- and variable- CO_2 experiments, departures are significantly elevated in sea-ice areas.

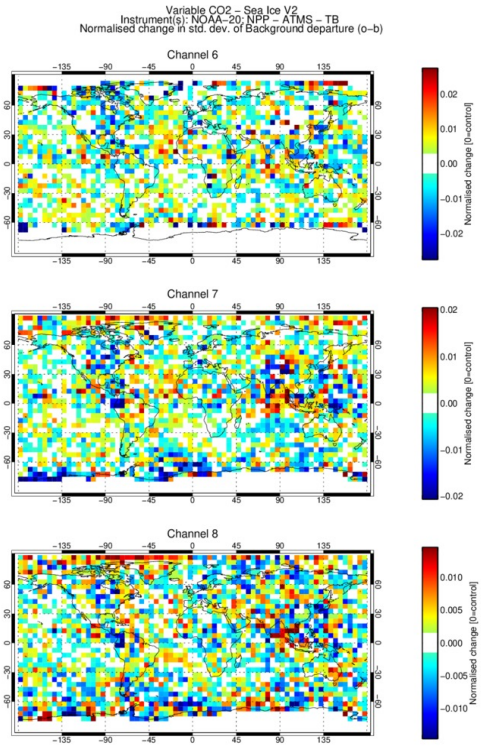
Impact of sea-ice V2 variable CO_2 fix *versus* original variable CO_2 experiment

Improved background fits for CRIS obs in the vicinity of sea-ice

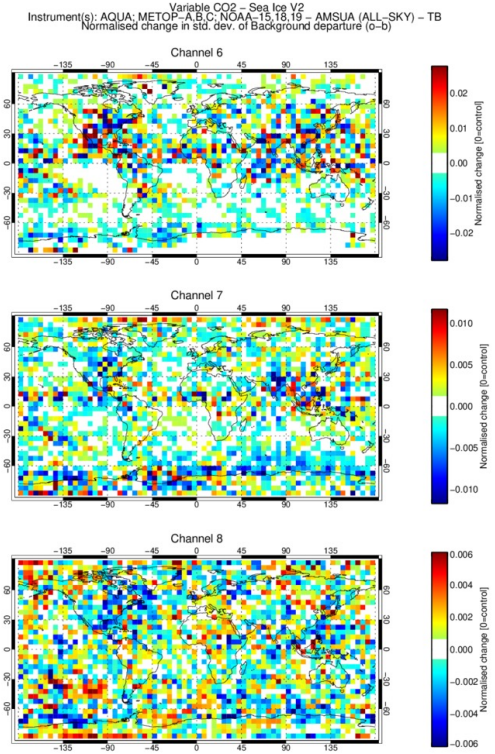


Improved background fits for independent obs: Tropospheric channels of AMSU-A and ATMS

ATMS



AMSU-A



Summary

- **Production of ERA6**, building on 9 years of developments of the IFS, will commence in Q2 2025. Indications so far are that improvements over ERA5 will be similar to the improvements realised in previous generations of reanalyses

- **Reprocessed and early sounding data**. ERA6 will assimilate several reprocessed operational radiance datasets (including HIRS & MHS) and some early satellite datasets from the 1970s *never assimilated before*

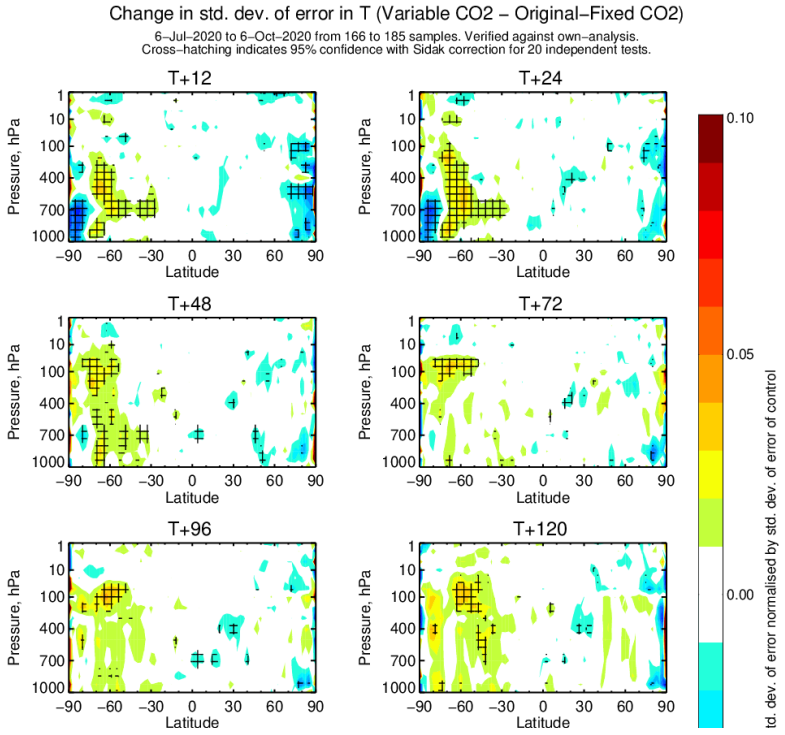
- **Improved treatment of CO_2** in the assimilation of IR sounding data is a significant advance over the fixed CO_2 scheme used in ERA5 & has been shown to eliminate the drift in bias corrections, improve inter-satellite biases & results in better (re-forecast) performance, but …

    - Testing has highlighted an issue **over sea-ice in polar night**. Still not fully understood, but partly mitigated by screening surface sensitive IR channels over sea-ice

    - **The bias of ~0.4K (analysed by VarBC) for tropospheric sounding channels, consistent between hyperspectral sensors, remains unexplained** (RT model, model bias, bias in CO_2 climatology, … ?). [*perhaps for NWP / RT / Climate WGs] : Could a cross NWP-centre comparison of analysed biases shed light on the root cause ? Is that available already ?*

Variable CO_2 vs Fixed CO_2 Summer 2020 Experiments

Original variable CO_2
Versus
Fixed CO_2



Sea-Ice V2 variable CO_2
Versus
Fixed CO_2