Implementation and results of the kappa residual ionospheric correction in ROM SAF processing

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ROM SAF processing

ROM SAF has now four processing modes:

- Near real-time (NRT):
  - Based on EUMETSAT Secretariat Level 1B data (bending angles)
  - Delivered less than 3 hours after measurement
- Offline:
  - Based on EUMETSAT Secretariat Level 1A data (excess phases; Metop)
  - Delivered from less than 5 days to up to 6 months after measurements
  - Evolution is driven by new scientific developments and subsequent product upgrades
- Climate Data Record (reprocessing):
  - Based on EUMETSAT Secretariat reprocessed Level 1A data (excess phases)
  - CDR v1.0 also based on UCAR CDAAC reprocessed/post-processed excess phases
  - Generated approximately every other year (CDR v2.0, v3.0, v4.0 … to come)
- Interim Climate Data Record (ICDR):
  - Based on EUMETSAT Secretariat Level 1A data (excess phases; Metop)
  - Extending the latest CDR in time, having optimum consistency with and lower latency than the system used to generate the CDR

Ionospheric correction

Standard linear correction:

$$\alpha_{LC}(a) = \frac{f_1^2 \alpha_1(a) - f_2^2 \alpha_2(a)}{f_1^2 - f_2^2}$$

Ignoring B-field and other complications (Healy and Culverwell, 2015):

$$\alpha_{LC}(a) - \alpha_{true}(a) \approx -\kappa(a)[\alpha_1(a) - \alpha_2(a)]^2$$

$$\kappa(a) = \frac{3}{8\pi} \frac{f_1^2 f_2^2}{(f_1^2 - f_2^2)^2} \frac{r_m \sqrt{r_m^2 - a^2}}{aH}$$

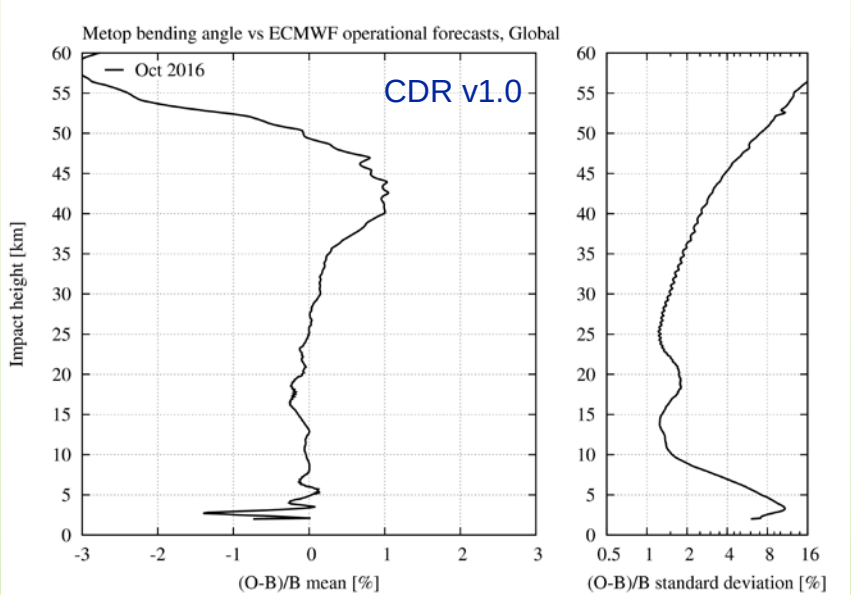
- New ROPP subroutine based on this (kappa-correction) with $r_m = 6670$ km and $H = 60$ km
- Can be readily extended to more complicated functions for $\kappa(a)$
- So far only in unofficial ROPP code at DMI

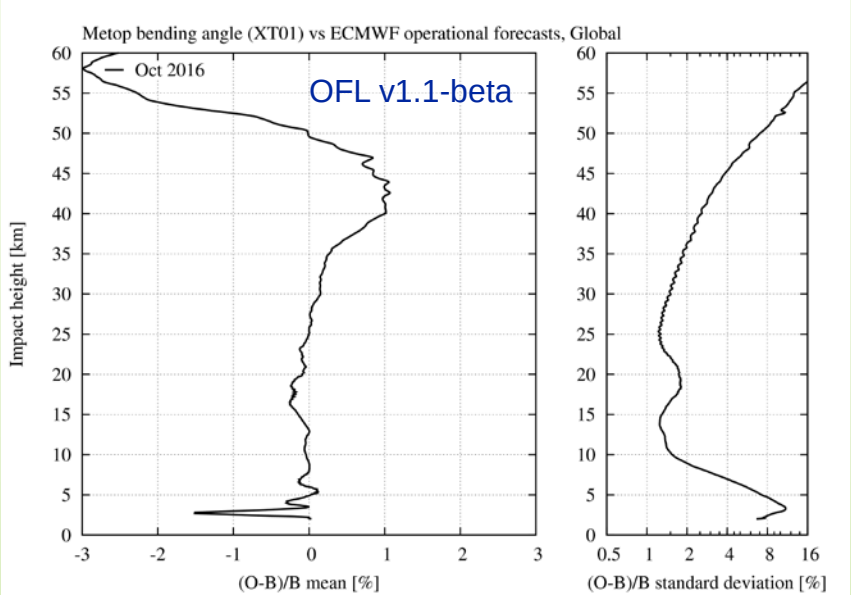
ROPP: Radio Occultations Processing Package – ROM SAF software deliverable

Implementation plan for kappa-correction

- Operational in ROM SAF Offline (OFL v1.1) processing in early 2020
  - Following an operational readiness review after which also Offline Metop-C will become operational
  - Where we will also transition to use ERA5 instead of ERA-I for 1Dvar products and sampling error correction for Level 3 products
- Operational in ROM SAF near real-time processing later in 2020
  - Following another operational readiness review after which algorithms used in NRT processing will become identical to the ones in Offline processing
  - In NRT we will still use EUMETSAT Level 1B bending angle as input and operational ECMWF forecasts for 1Dvar products
- In the next ROM SAF reprocessing scheduled for 2021 (CDR v2.0)
- Then in the ICDR v2.0 as a continuation of the CDR v2.0
- Also to be implemented in a future version of ROPP (likely ROPP 11)

Bending angle statistics – kappa-correction

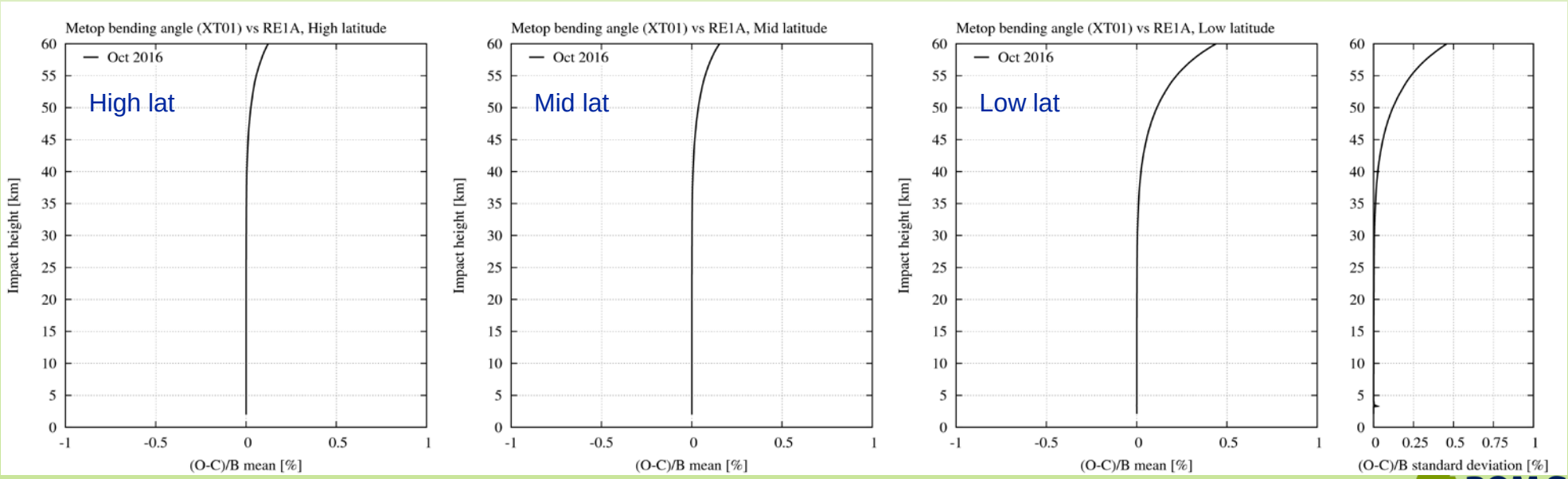




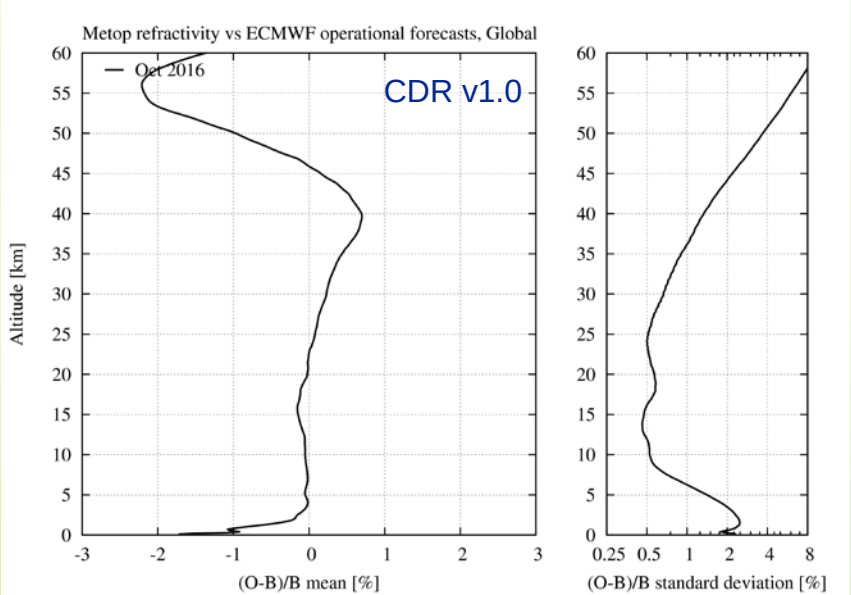
Oct 2016 as example

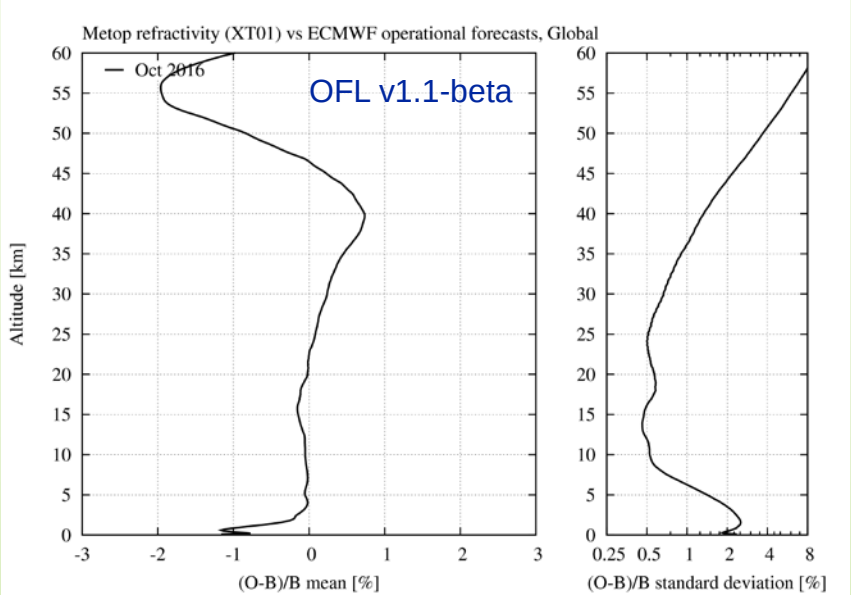
Kappa-correction can be seen as a subtle change in the (O-B)/B mean

Direct comparisons below gives the size of the kappa-correction in %



Refractivity statistics – kappa-correction





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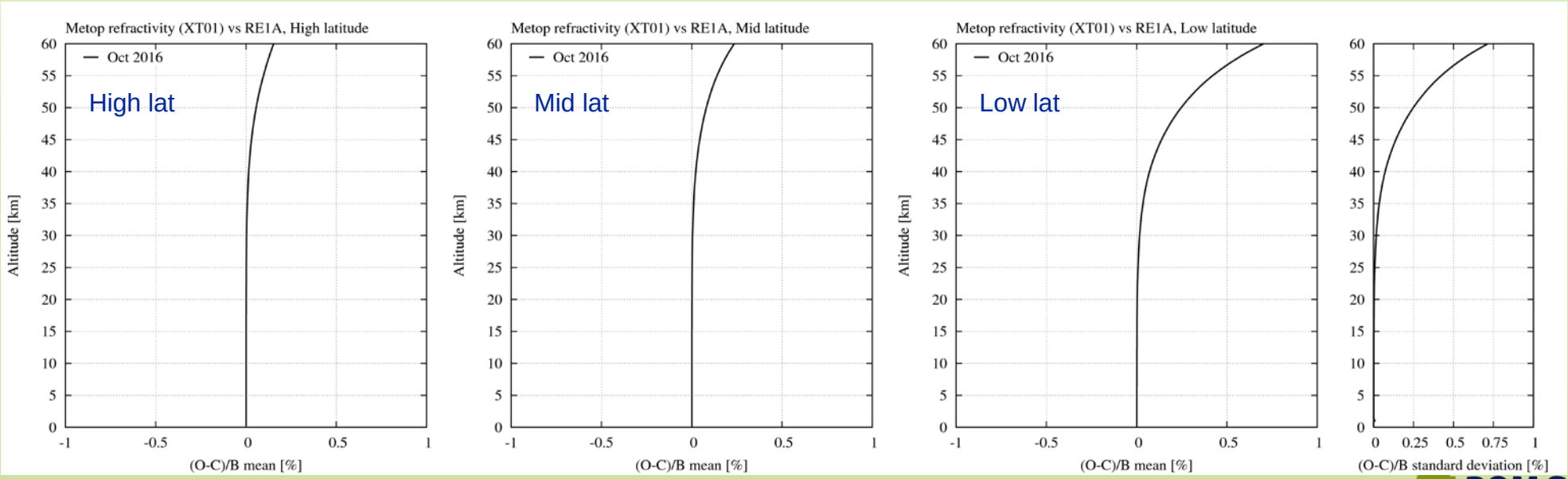
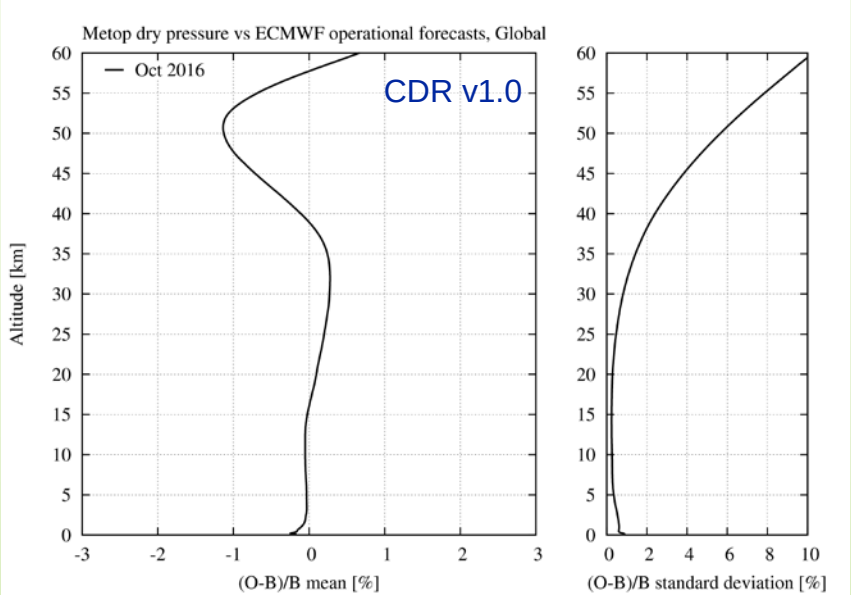
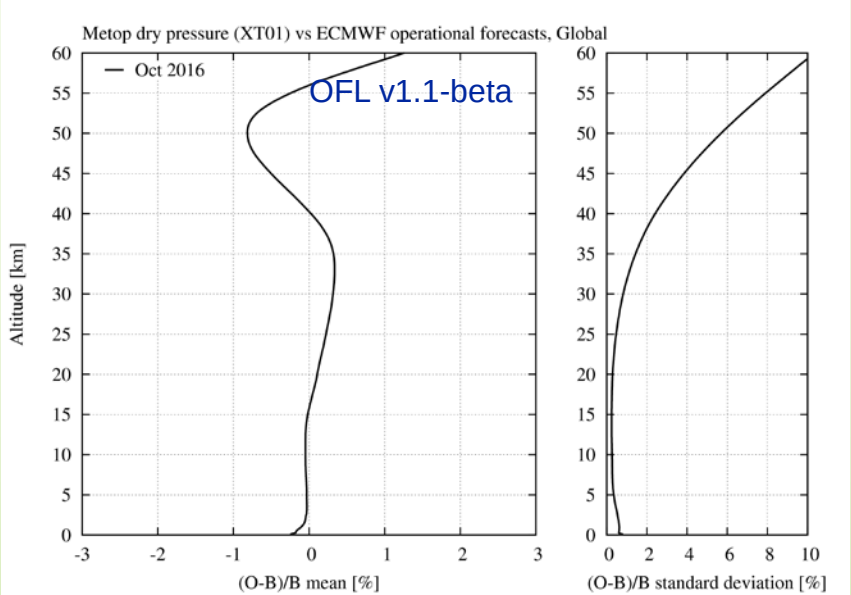


Dry pressure statistics – kappa-correction





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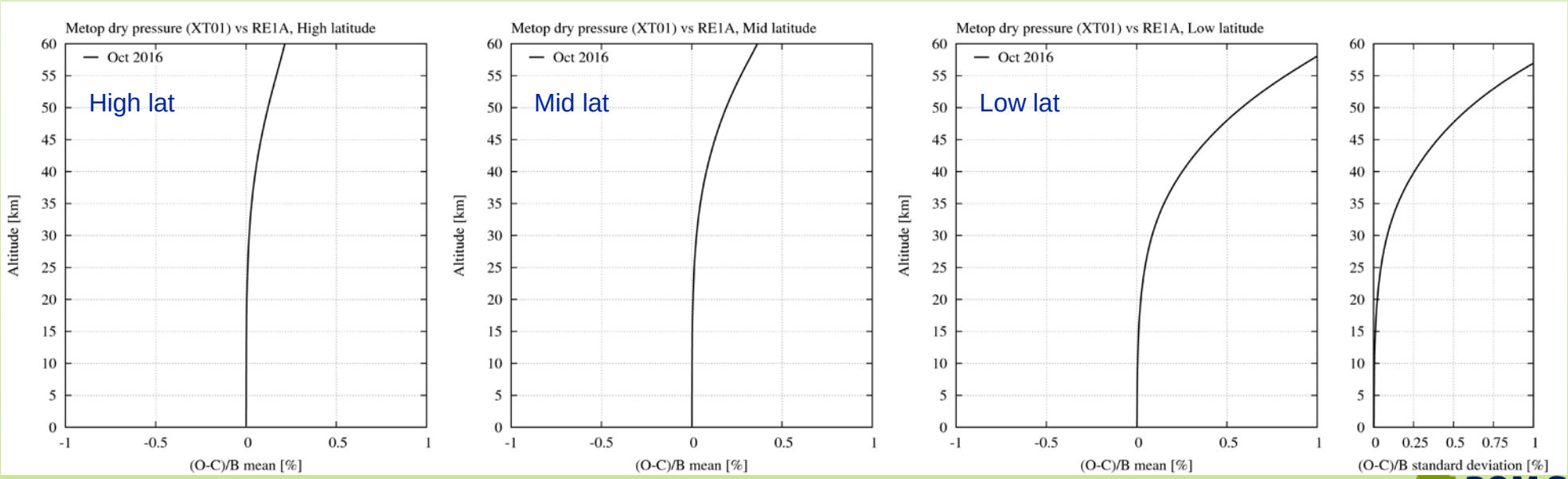
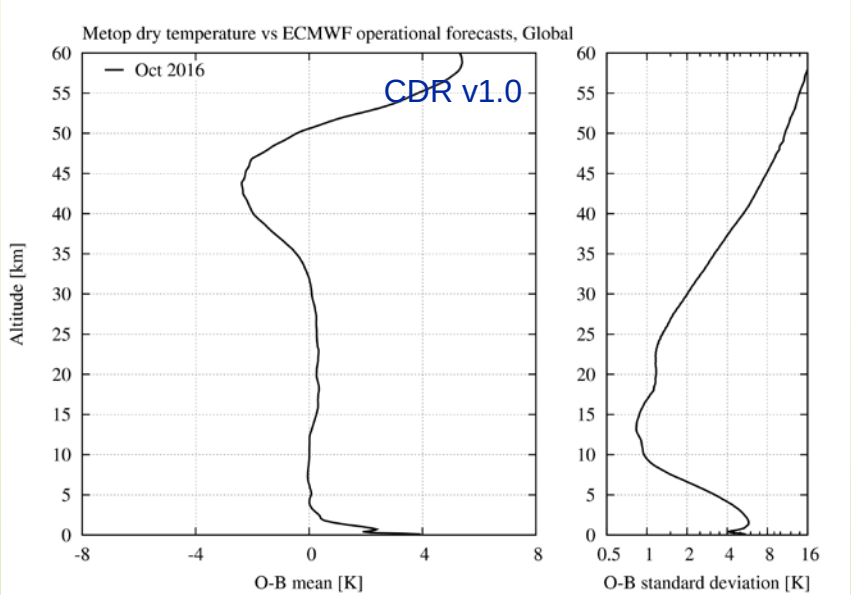
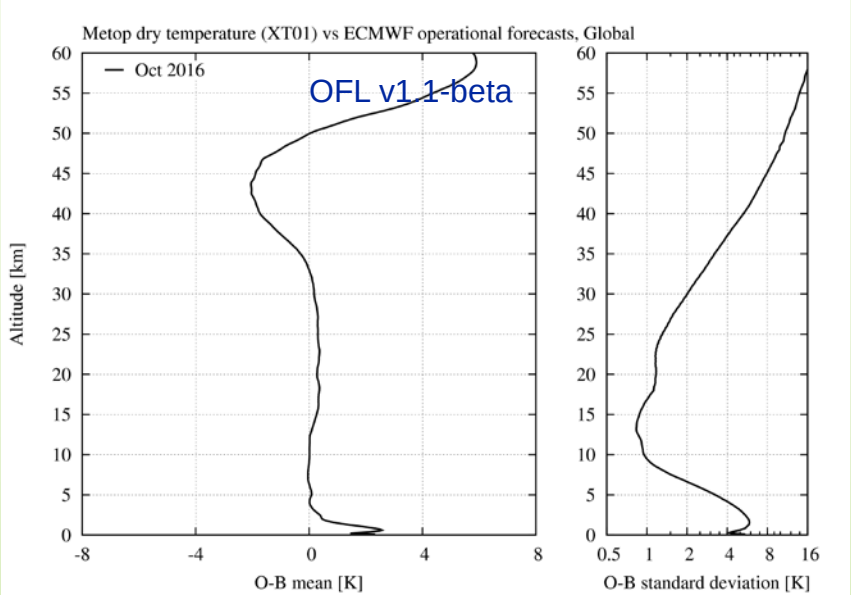


Dry temperature statistics – kappa-correction

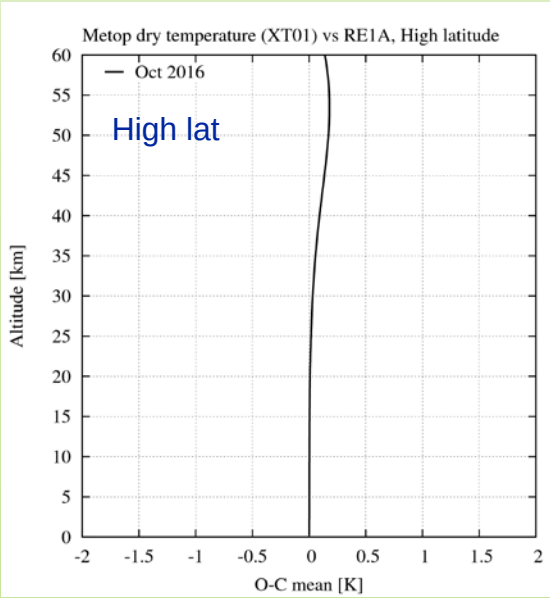


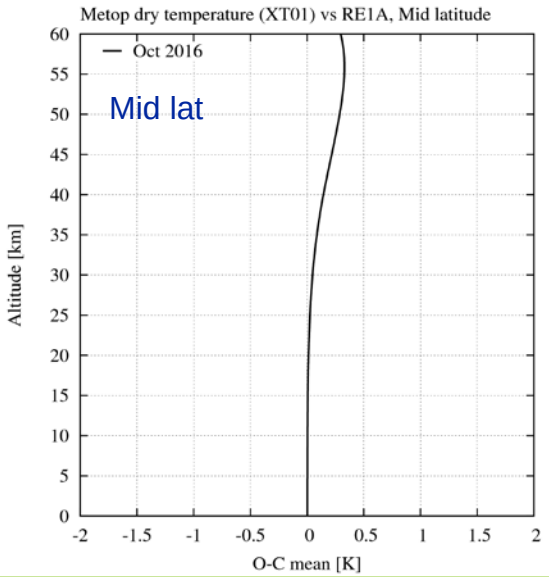


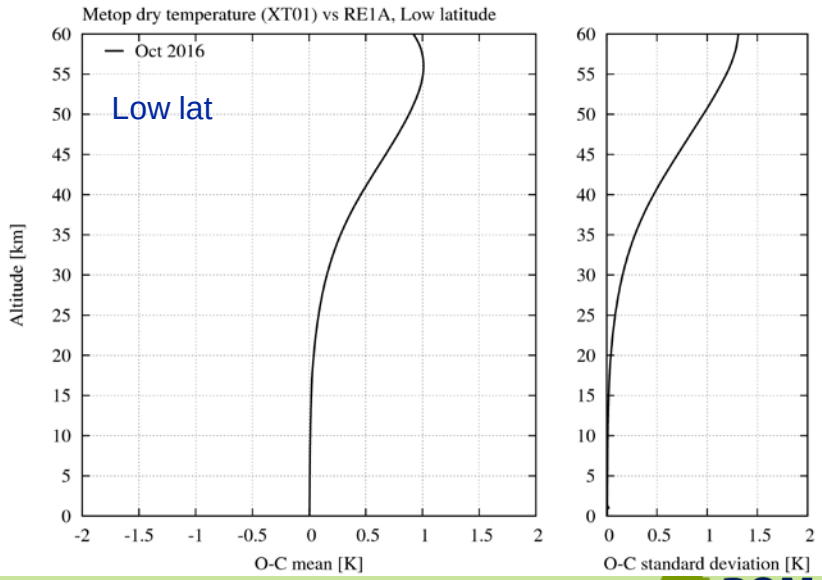
Oct 2016 as example

Kappa-correction can be seen as a subtle change in the (O-B)/B mean

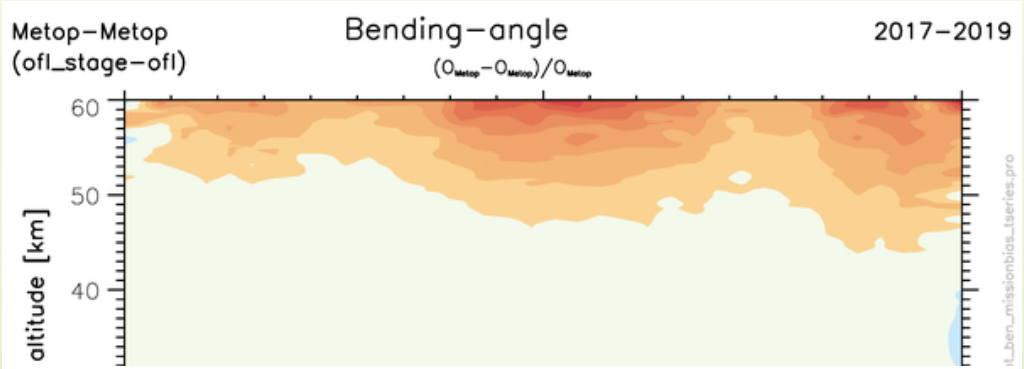
Direct comparisons below gives the size of the kappa-correction in Kelvin

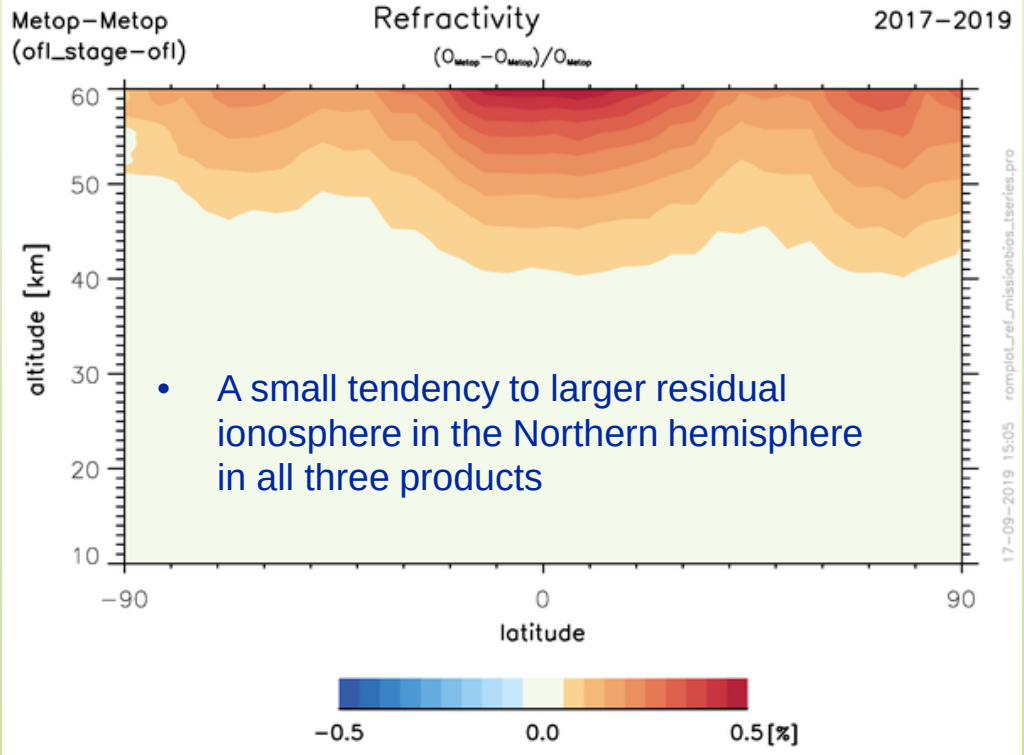






Zonal mean differences – kappa-correction



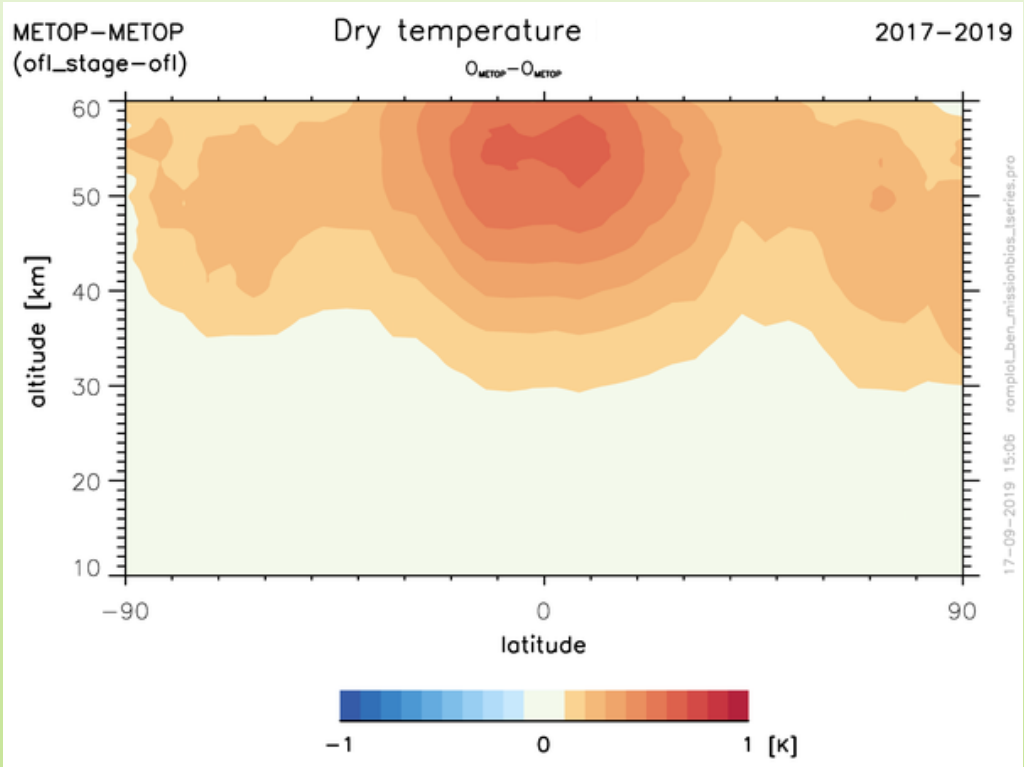


- A small tendency to larger residual ionosphere in the Northern hemisphere in all three products

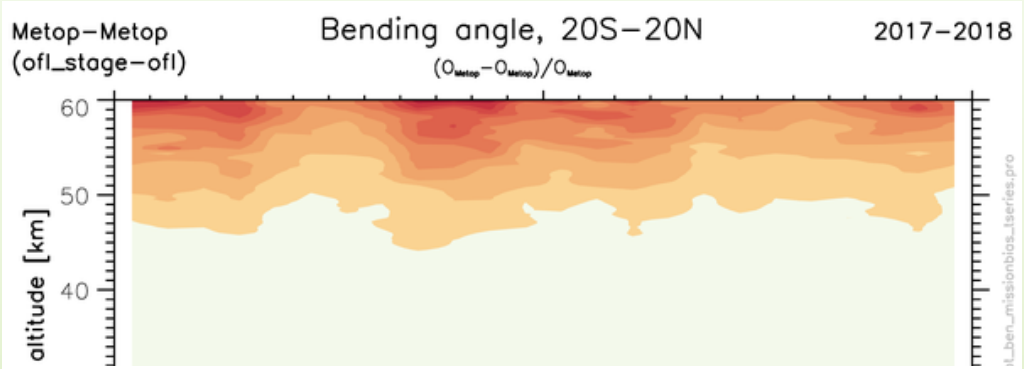
OFL v1.1-beta – OFL v1.0

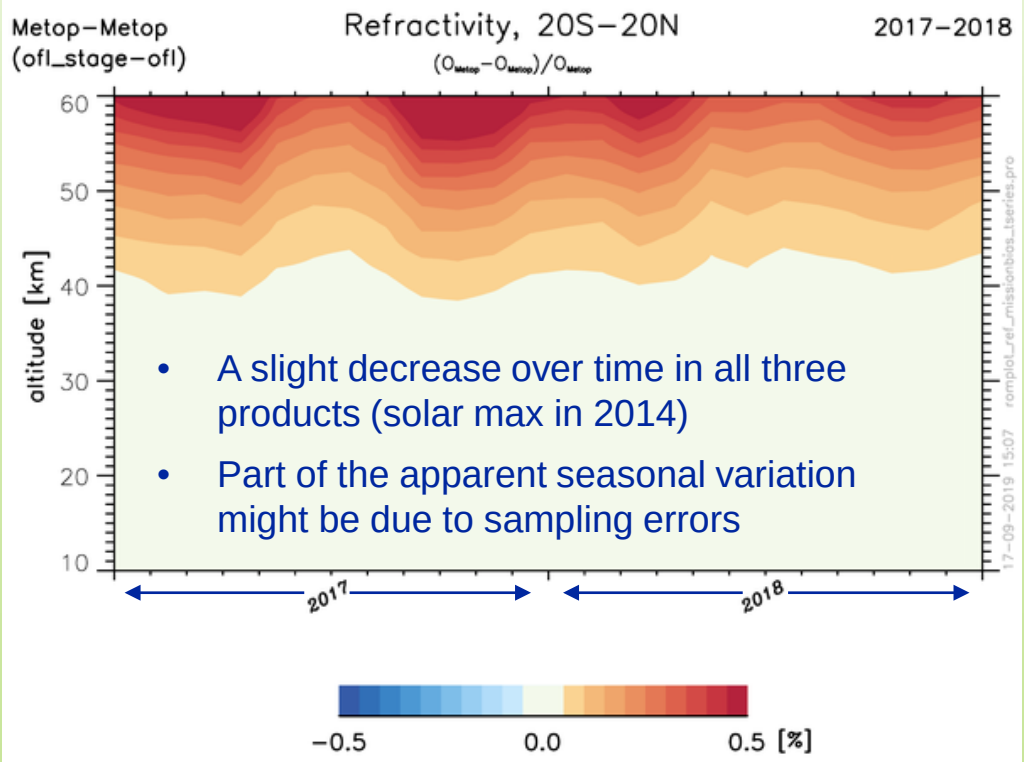
Jan 2017 – May 2019

- OFL v1.1 to become operational early next year
- First operationally processed month will be August 2019 (ERA-I to ERA5 transition)



Time series – kappa-correction





- A slight decrease over time in all three products (solar max in 2014)
- Part of the apparent seasonal variation might be due to sampling errors

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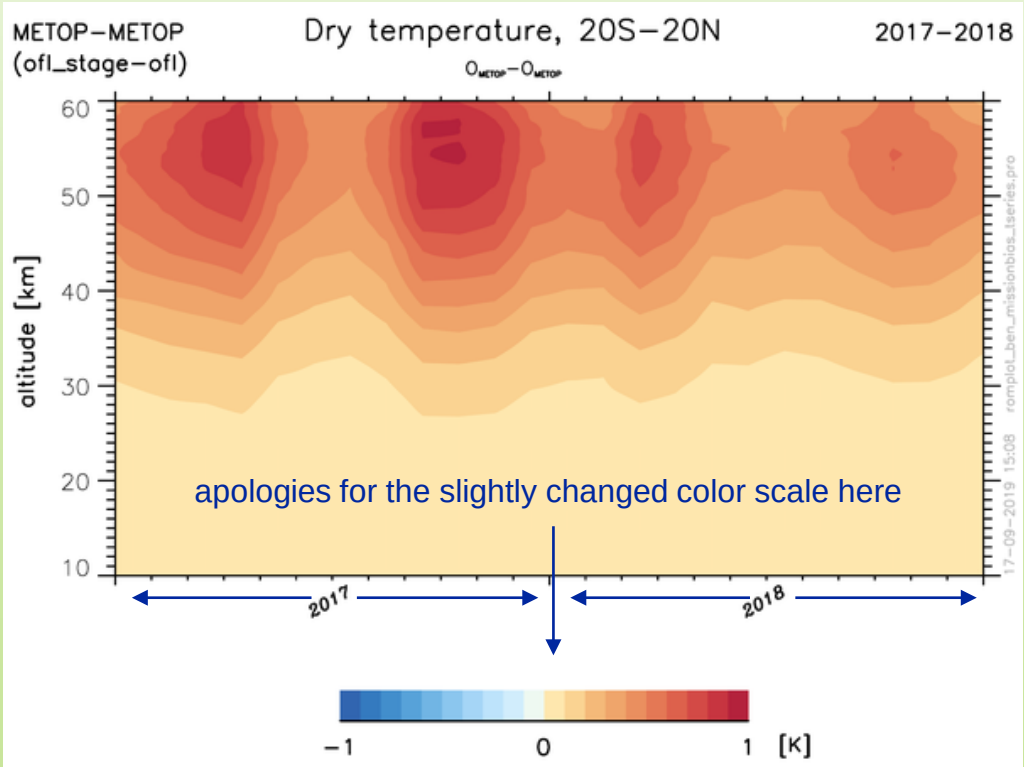
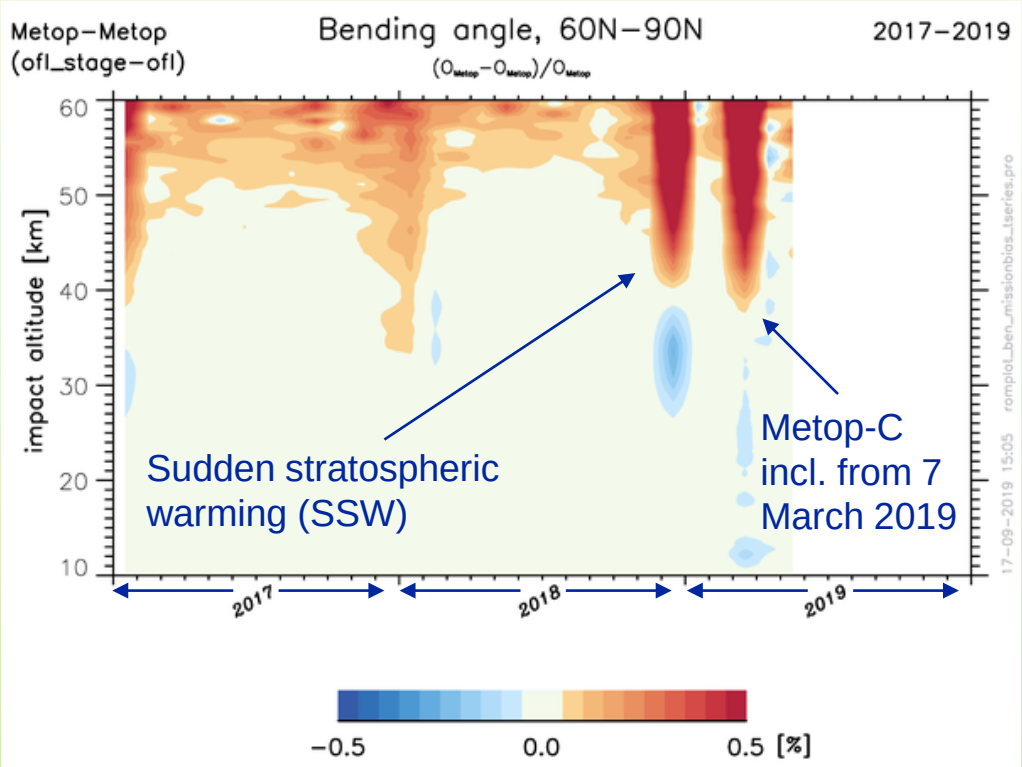


Some effects of sampling errors



OFL v1.1-beta – OFL v1.0

Jan 2017 – May 2019

- OFL v1.1: QC partly based on ERA5
- OFL v1.0: QC partly based on ERA-I

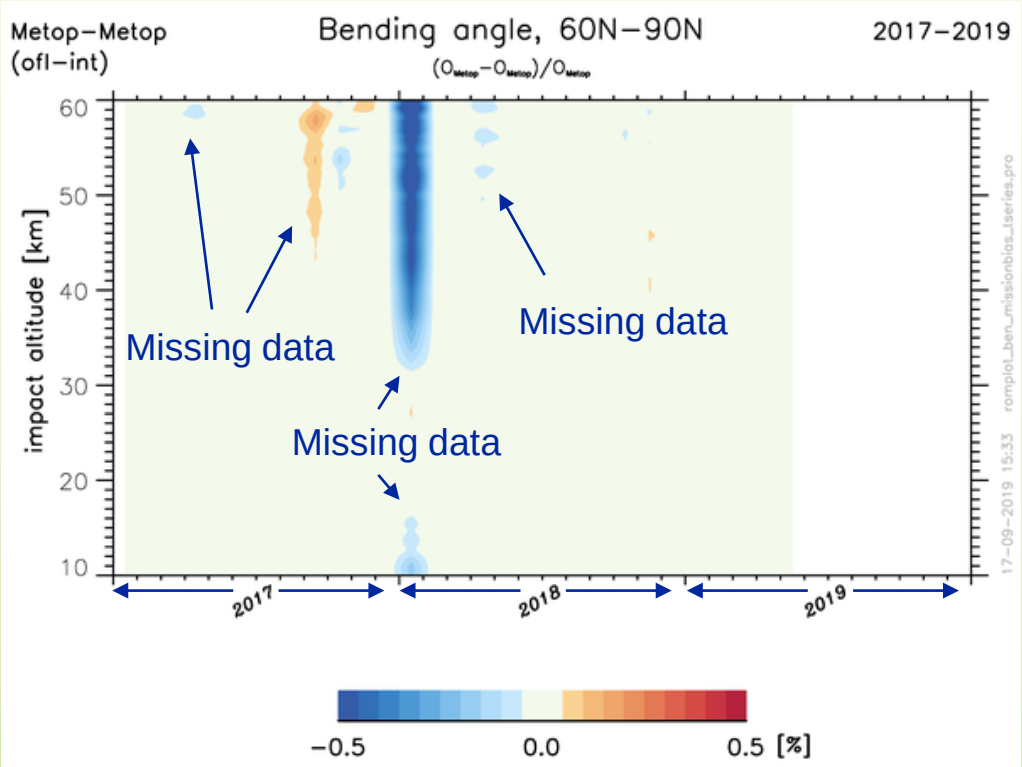
Result: Not exactly the same occultation events enter the statistics (profound effect during SSWs)

- OFL v1.1: Metop-C included
- OFL v1.0: Metop-C not included

Result: March 2019 monthly mean in v1.1-beta run is ‘skewed’ by the inclusion of Metop-C only part of the month

- Sampling error correction is essential (in gridded Level 3 products) – sampling errors may be much larger than residual ionospheric errors
- Our sampling error correction using ERA5 is under development

Some effects of sampling errors



OFL v1.0 – ICDR v1.0

Jan 2017 – May 2019

OFL and ICDR processed with identical algorithms (both using ERA-I in QC – no kappa correction)

- OFL v1.0: Data gaps on certain days
- ICDR v1.0: Gaps were filled in

Result: Not exactly the same occultation events enters the statistics (big gap in OFL in Jan 2018)

- Sampling error correction is essential (in gridded Level 3 products) – sampling errors may be much larger than residual ionospheric errors
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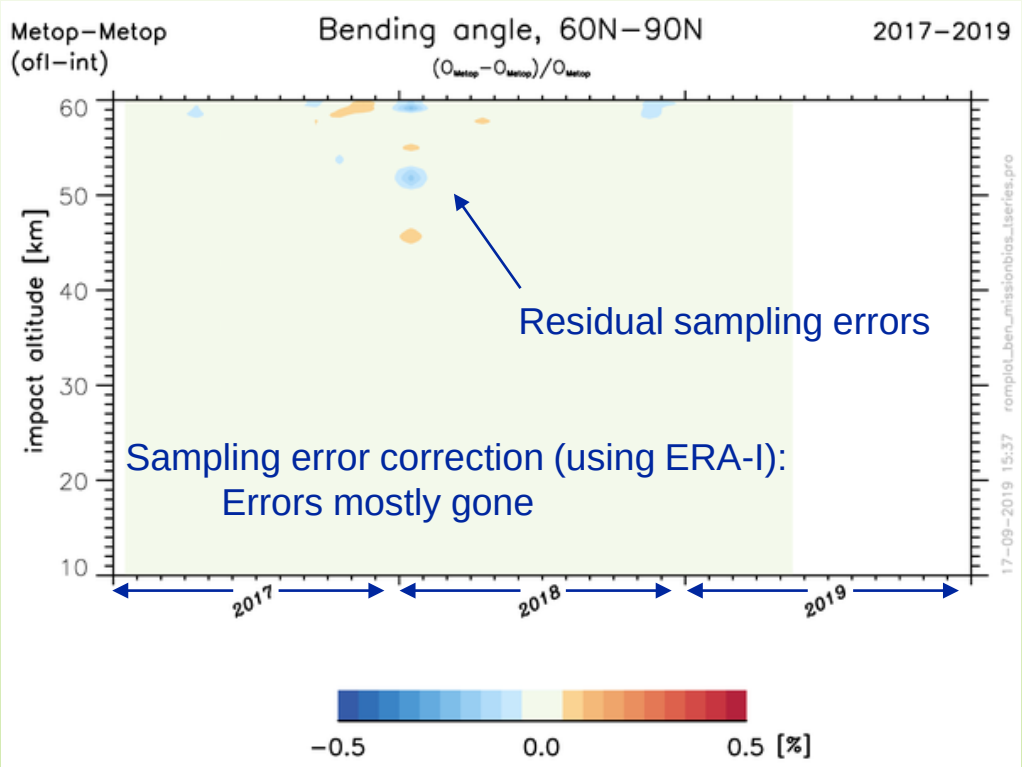
Some effects of sampling errors



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Result: Not exactly the same occultation events enters the statistics (big gap in OFL in Jan 2018)

- Sampling error correction is essential (in gridded Level 3 products) – sampling errors may be much larger than residual ionospheric errors
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Summary of size of kappa-correction

Based on ROM SAF processing (and for Oct 2016)

Bending angle:	Refractivity:	Dry temperature:
@ 60 km: up to ~0.4%	@ 60 km: up to ~0.7%	@ 60 km: up to ~1 K
@ 50 km: up to ~0.15%	@ 50 km: up to ~0.25%	@ 50 km: up to ~1 K
@ 40 km: < 0.02%	@ 40 km: up to ~0.08%	@ 40 km: up to ~0.5 K
@ 30 km: insignificant	@ 30 km: < 0.02%	@ 30 km: up to ~0.15 K

A little larger residuals to be expected at solar maximum

(last solar max was in 2014)

Putting things in perspective

- Maximum residual ionospheric errors are on the order of 0.1μrad
  - For Metop we have mean bending angle differences between rising and setting occultations of similar size, presumably caused by periodic orbit biases (under investigation at EUMETSAT)
  - Statistical optimization (relevant for refractivity and dry temperature) may introduce errors overshadowing residual ionospheric errors – depends on the approach
  - Sampling errors can be much larger (relevant for gridded climatologies) – residual sampling errors are likely smaller, though we haven't yet seen results using ERA5
  - Horizontal ionospheric gradients limit the accuracy of residual ionospheric corrections (see poster P23)
- We have here shown only differences between correcting and not correcting residual ionospheric errors – nothing to verify if the corrections are indeed correct
  - Models aren't accurate enough as reference
  - SABER and MIPAS data are being investigated, but likely not accurate enough either
  - We believe we are in the right ballpark and with the right sign (at least in the mean)
  - But it would be nice with a real experimental verification – any ideas?

Thank you!