Correction of instrument ageing in TROPOMI L01b processing

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Processor evolution

The TROPOMI L01b processor was developed well prior to the start of the Sentinel-5 Precursor mission on the 13th of October 2017. Rather than using prototype code, the L01b processor was already employed during the on-ground calibration campaign which started in December 2014.
The processor was then used to derive self consistently all necessary calibration key data. The key data serves as an input for the processor to convert the raw input data into calibrated spectral radiances and irradiances.

- Version 2.0.0. is operational since 1-7-2021 (orbit 19258)
- New version includes important new algorithms to address instrument ageing, code cleanup and some minor bugfixes.
- Updates to CKD to address ageing of the instrument.
- Updates to CKD to improve radiometric calibration.
- Version 3.0.0 expected for 2022
- Version 3.0.0 will include instrument degradation correction in radiance
- Version 3.0.0 will include further improvements to transient pixel detection

Algorithm development

Most relevant updates in version 2:

- CCD blooming detection and flagging
- Transient signal detection and flagging
- Diffuser degradation correction
- Electronic gain drift correction
- UV radiometric ageing correction
- Monitoring algorithms for wavelength and degradation
- Instrument thermal instability warning and flagging
- See: https://amt.copernicus.org/articles/13/3561/2020/

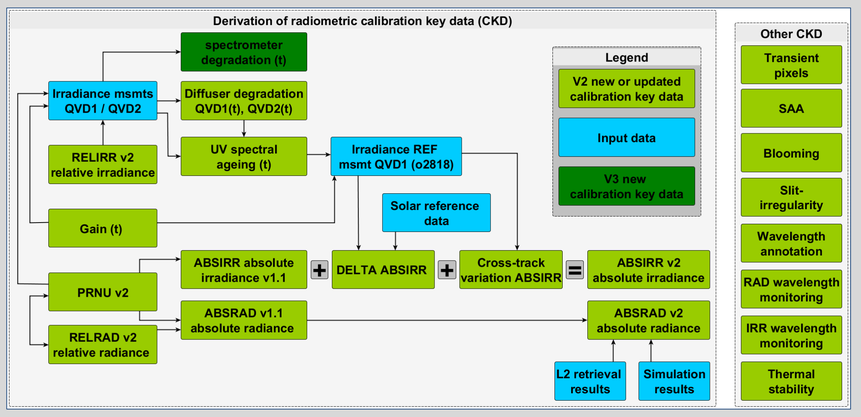
Calibration key data analysis

Most relevant updates version 2:

- Time dependent electronic gain drift
- Time dependent diffuser degradation
- Time dependent UV radiometric ageing
- Improved on-ground PRNU / RELRAD to cover more CCD pixels
- Absolute radiometry irradiance bands 1 to 4 (not for 5 to 8)
- Cross-track radiometry irradiance
- Relative angular radiometry irradiance
- UV slit irregularity anomaly
- Wavelength annotation improvement (UV, UVIS & SWIR)

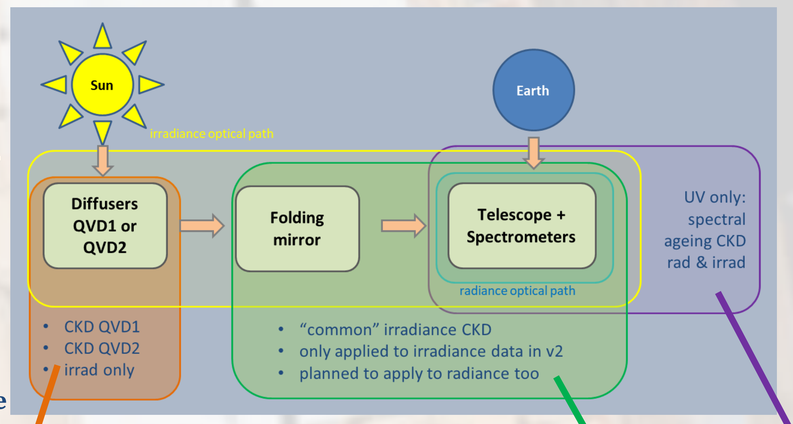
CKD derivation

- New /updated calibration key data to reflect in-flight behaviour of degradation
- Derived with L01b pre-processing
- Sequential derivation
- Self consistent
- Keydata for radiance degradation from v3 on



Degradation

- Determined from irradiance measurements
- 3 parts: diffuser (QVD1 & 2) degradation, common degradation, spectral ageing (UV only)
- Strongest for the shortest wavelengths (UV + UVIS)
- For SWIR no effect visible
- Orbit (time) dependent correction
- L01b processor can extrapolate correction
- Common degradation: in irradiance and radiance measurements
- Common degradation corrected from v2 for irradiance, for radiance from v3 on
- Diffuser degradation & spectral ageing corrected in v2
- Degradation slowing down

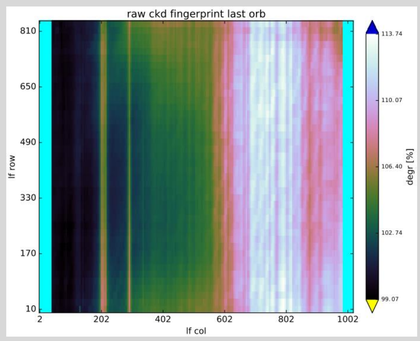


Status orbit 20819	QVD1 + common [%]	common only [%]	spectral ageing [%]
Band 1	13.27	5.50	-2.45
Band 2	10.07	3.93	-9.23
Band 3	7.06	2.63	–
Band 4	3.13	1.25	
Band 5	0.49	0.25	–
Band 6	0.40	0.22	–
Band2:317 nm	9.80	3.81	-12.48
Band3:317nm	9.73	3.85	–

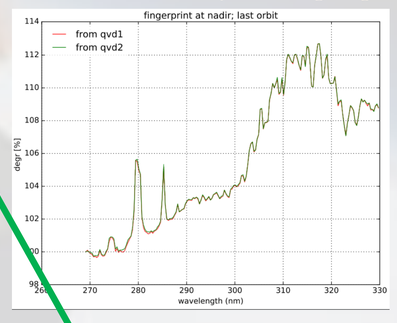
degradation status, orbit 20819

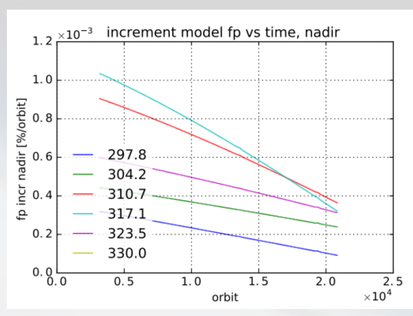
UV spectral ageing

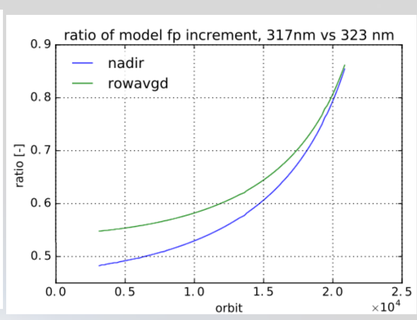
- Emerging spectral features in UV (bands 1 & 2)
- Signal increases with time
- Correlation with Solar spectrum
- Suspect bleaching close to or on/within the detector
- Degradation rate is slowing down
- Highest rate @317nm decreasing the fastest
- Rates get more similar across the rows
- Correction applied in V2 L1b



spectral ageing UV, orbit 20819

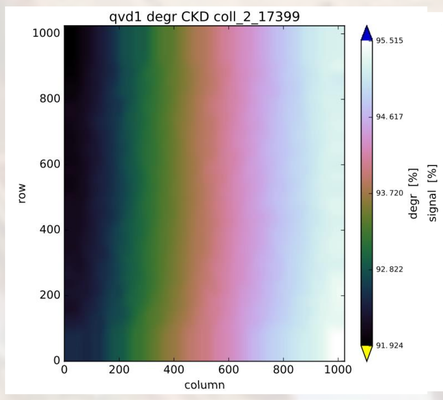




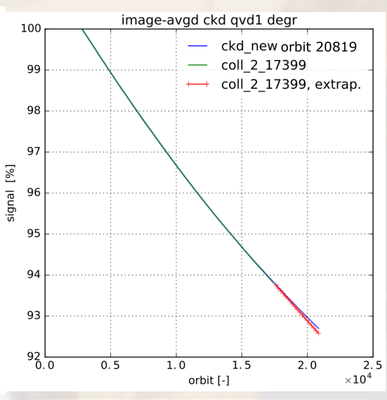


Diffuser degradation

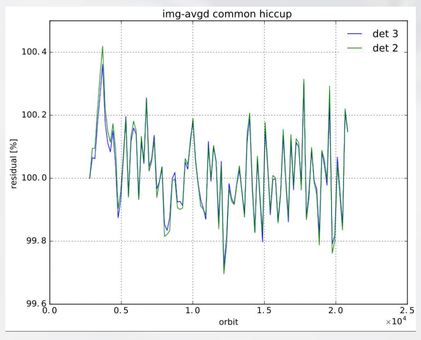
- Degradation shows only spectral variation
- NIR degradation < 0.25%
- No degradation so far for SWIR
- Extrapolation in L01b processor works well
- Erratic additional solar variation for all detectors: smallest in UV and remains uncorrected
- Variation in UV+SWIR and UVIS+NIR correlated



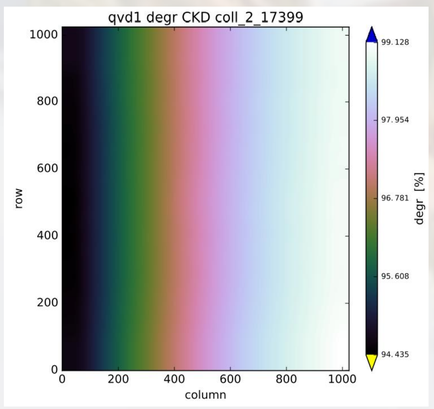
Diffuser degradation CKD UV



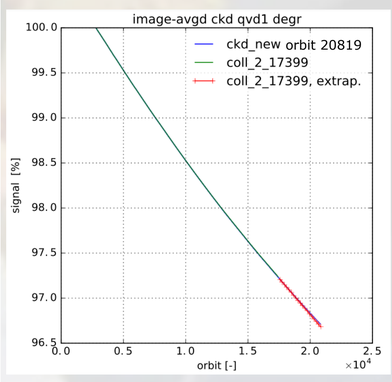
Extrapolation vs new CKD UV



Non-deterministic residual UVIS and NIR



Diffuser degradation CKD UVIS

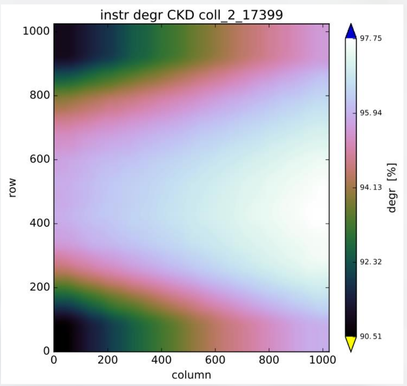


Extrapolation vs new CKD UVIS

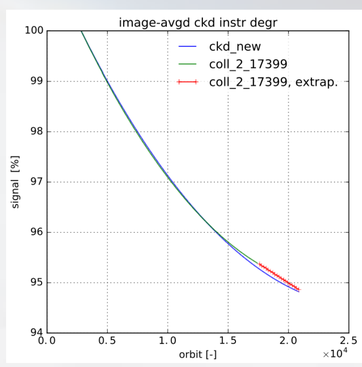
Common degradation

- Determined from irradiance measurements
- Shows spatial and spectral dependence
- Occurs in spectrometers
- NIR degradation <0.25%
- No degradation so far for SWIR
- Extrapolation in L01b processor works well
- Only applied to irradiance in v2
- Applied also to radiance from v3 on
- In UVIS also other features (scratches) corrected
- For UV also spectral ageing (already in v2)
- Degradation is slowing down

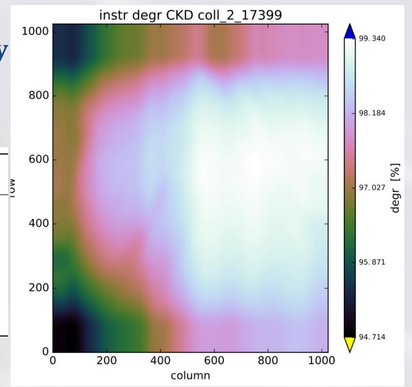
Per 1000 orbits @orbit	QVD1 + common [%] 18299	QVD1 + common [%] 20819	common only [%] 18299	common only [%] 20819
Band 1	0.776	0.737	0.326	0.305
Band 2	0.588	0.560	0.234	0.218
Band 3	0.411	0.392	0.158	0.146
Band 4	0.182	0.174	0.076	0.070
Band 5	0.032	0.027	0.018	0.014
Band 6	0.027	0.022	0.016	0.012
Band2:317 nm	0.572	0.544	0.227	0.211
Band3:317nm	0.568	0.540	0.230	0.214



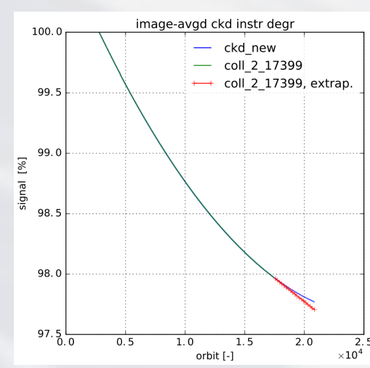
Instrument degradation CKD UV



Extrapolation vs new CKD UV



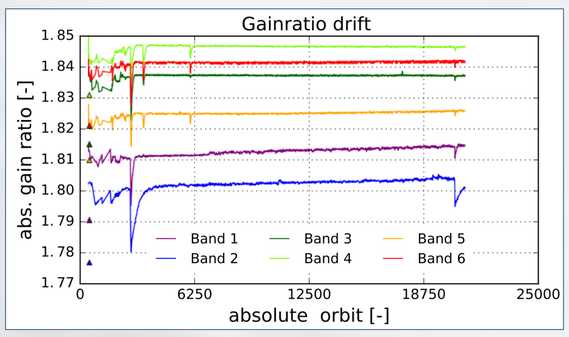
Instrument degradation CKD UVIS



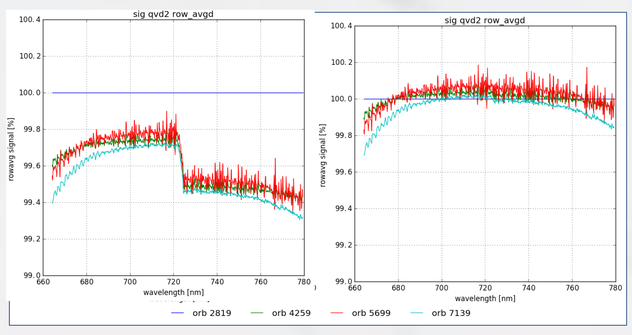
Extrapolation vs new CKD UVIS

Electronic gain drift UVN

- Instabilities in the CCD output node cause changes/ jumps in absolute electronic gain per band.
- These drifts cause signal jumps across the center column of each detector, and drifts in absolute radiometry.
- Timescale varies per band from hours to days and strong jumps in gain occur during instrument shut-down (orbit 2769) or during orbital control manoeuvres (orbit 20435).
- Daily monitoring of the CCD output node gain ratio is used to correct for the drift.
- This correction has been introduced in the L01b processor.



Gain drift over time



Before correction

After correction

CCD blooming detection

- High saturation causes charge blooming
- Results in unrealistic low reflectance
- Occurs mostly in bands 3-6 (UVIS & NIR)
- Occurs mainly over bright clouds in the tropics
- Bloomed pixels are now flagged as saturated
- Algorithm tuned with input from L2