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New scheme for the inter-band co-registration of the TROPOMI cloud parameters using VIIRS cloud information

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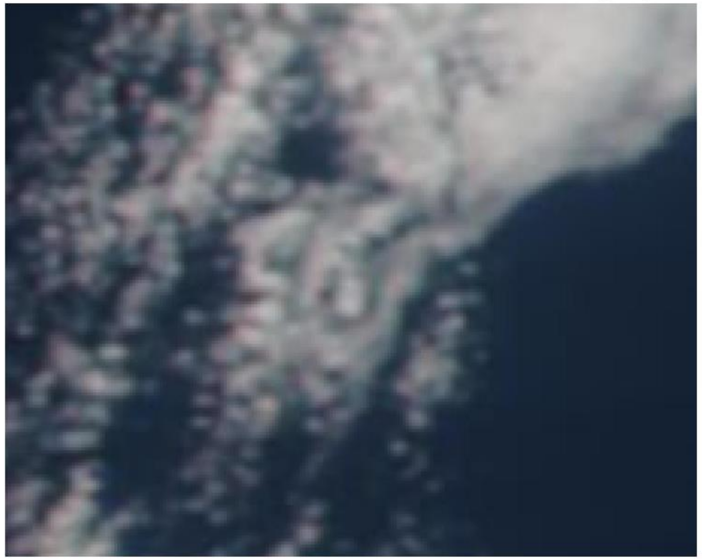
Inter-band mis-registration

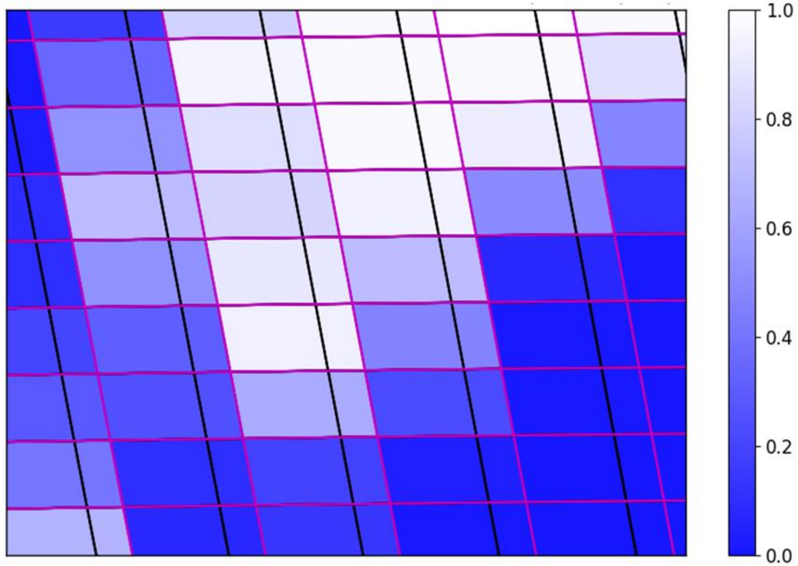
TROPOMI footprints for UV (BD3) and NIR (BD6) are not identical. Thus, the operational OCRA/ROCINN cloud parameters need to be co-registered from the original band.

Currently, the co-registration of S5P cloud parameters is performed using the static mapping tables provided by KNMI. Our goal was to improve the co-registration using VIIRS cloud information from the updated re-gridded NPP product developed by RAL.

VIIRS RGB (source: worldview.earthdata.nasa.gov)



VIIRS cloud fraction in BD3

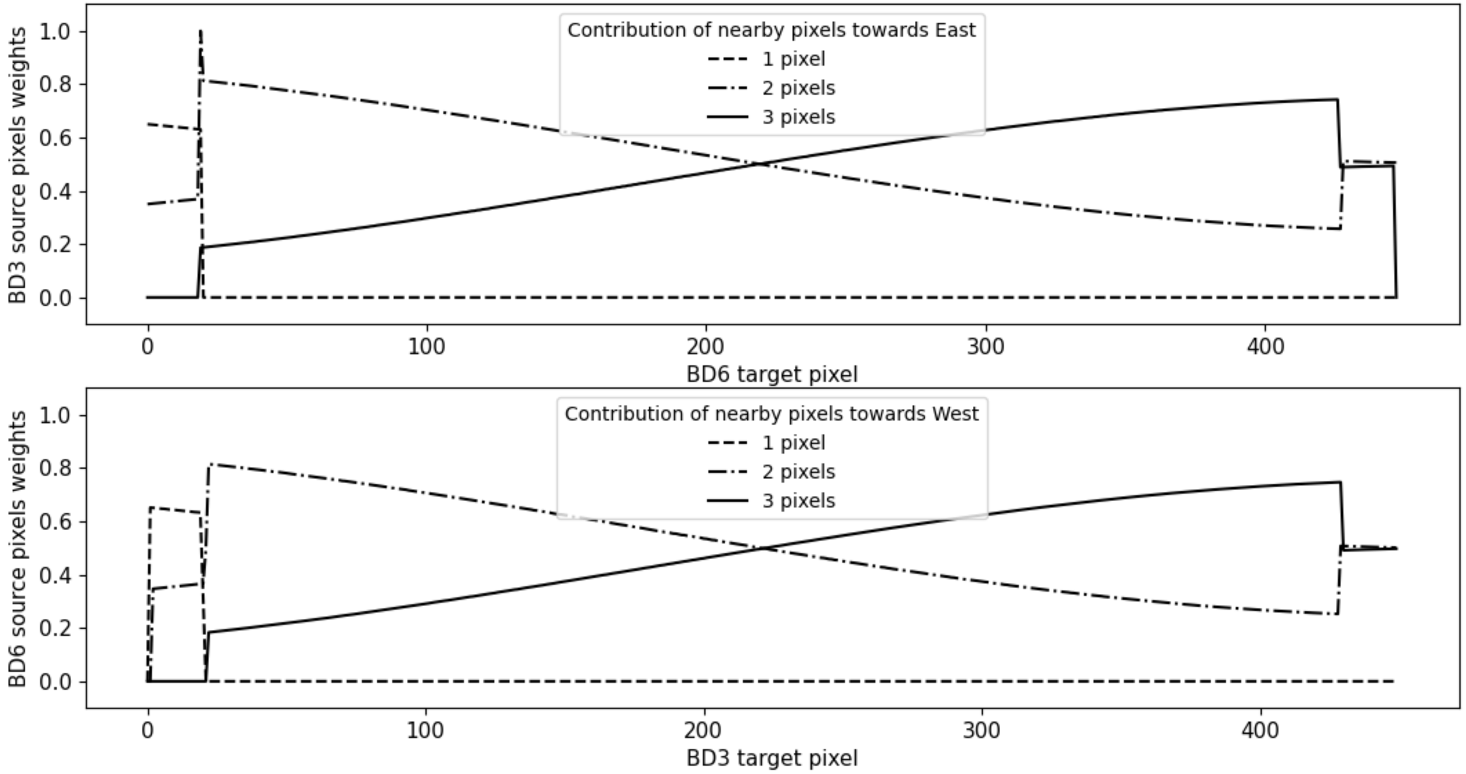


TROPOMI footprints in BD3 (magenta) and BD6 (black)

Current co-registration scheme

Current co-registration scheme at the operational CLD product is based on static mapping tables produced by KNMI (Sneep, 2015).

The pre-computed tables contain the weights when co-registering from BD3 (source band) to BD6 (target band) and vice versa.



Sneep, M.: Sentinel-5 precursor inter-band coregistration mapping tables, S5P-KNMI-L2-0129-TN, issue 4.0.0, 2015.

Co-registration of the OCRA cloud fraction

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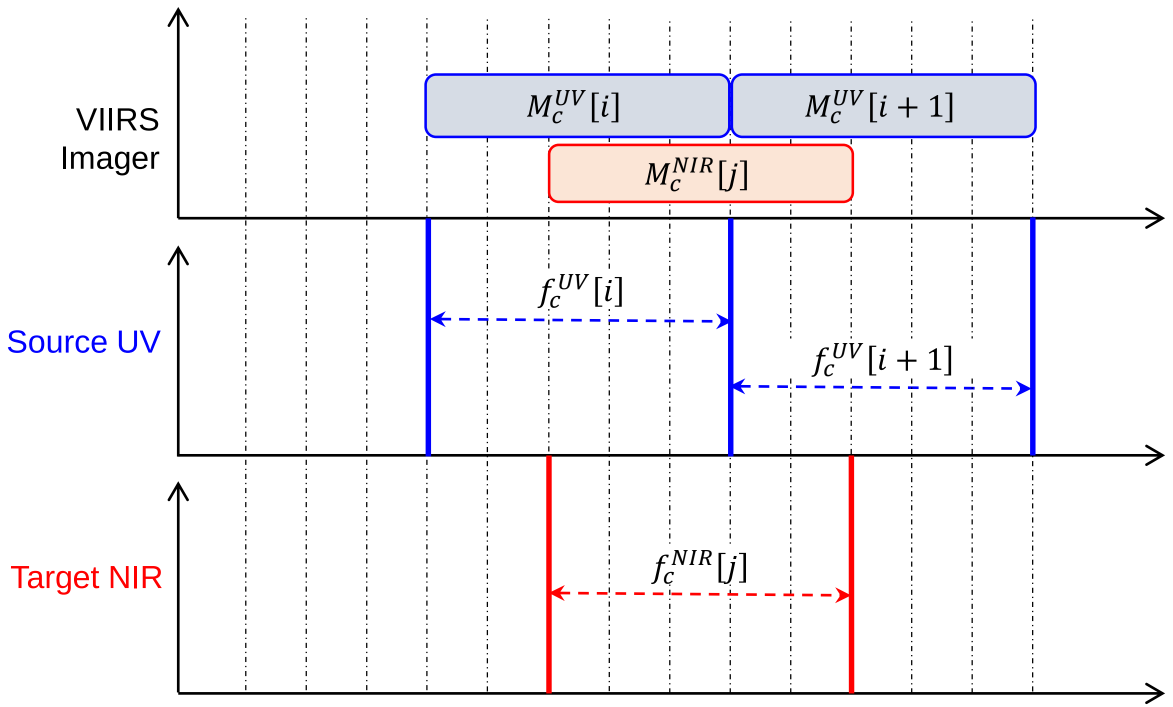
- OCRA retrieves the radiometric cloud fraction a priori in UV
- VIIRS ECM cloud fraction is defined as number of confidently cloudy devided by sum of all four categories (confidently cloudy, probably cloudy, confidently clear, probably clear)



<u>Weight calculation for the following scenarios:</u>

- 2 UV source pixels contribute to the target NIR pixel. VIIRS UV pixels have different cloud fraction values ($B_{VIIRS} \neq C_{VIIRS}$):

$$\gamma[j] = \frac{M_c^{NIR}[j] - M_c^{UV}[i+1]}{M_c^{UV}[i] - M_c^{UV}[i+1]}$$

$$f_c^{NIR}[j] = |\gamma[j]| f_c^{UV}[i] + (1 - |\gamma[j]|) f_c^{UV}[i+1]$$

- 2 UV source pixels contribute to the target NIR pixel. VIIRS UV pixels have equal cloud fraction values ($B_{VIIRS} = C_{VIIRS}$):

$$\gamma[j] = \frac{M_c^{NIR}[j]}{M_c^{UV}[i]}$$

$$f_c^{NIR}[j] = |\gamma[j]| f_c^{UV}[i] + (1 - |\gamma[j]|) f_c^{UV}[i+1]$$

Co-registration of the OCRA cloud fraction

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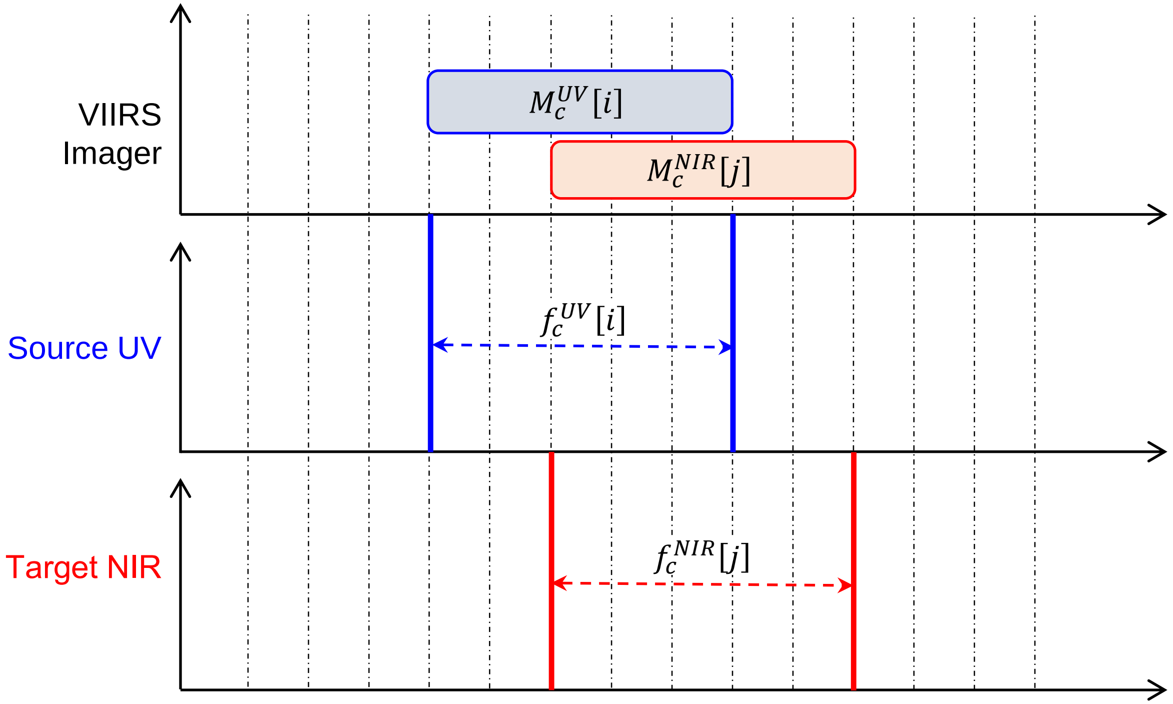
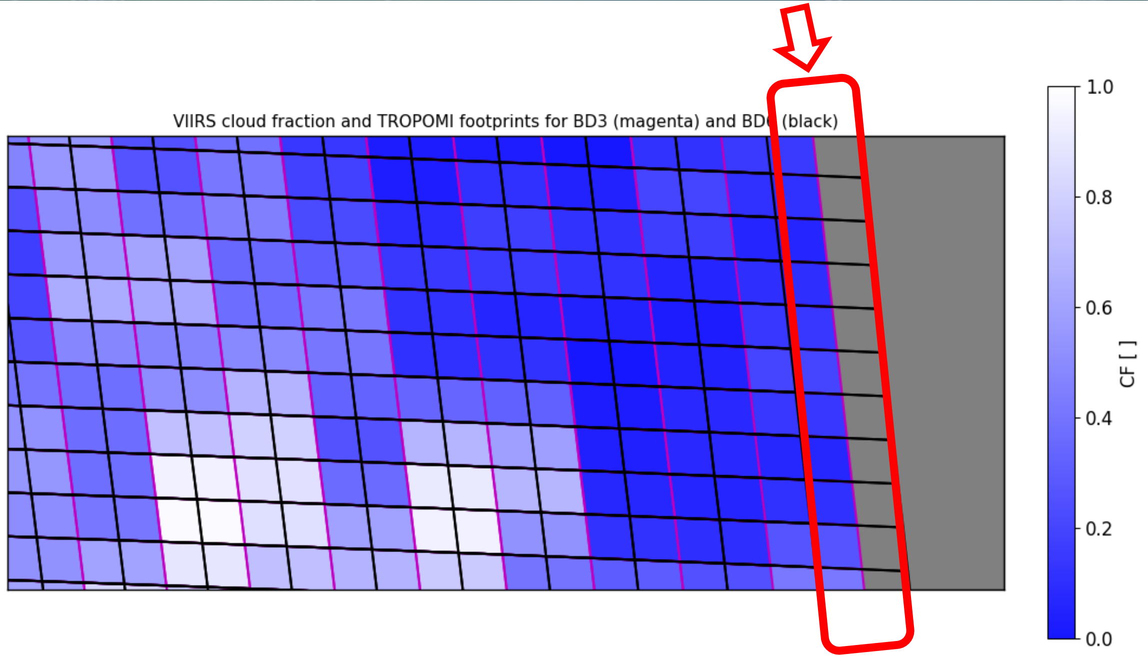
- At the east edge of the swath, there is incomplete overlap between the last UV and NIR footprints.





Weight calculation for the following scenario:

1 UV source pixel contributes to the target NIR pixel:

$$\gamma[j] = \frac{M_c^{NIR}[j]}{M_c^{UV}[i]}$$

$$f_c^{NIR}[j] = |\gamma[j]| f_c^{UV}[i]$$

Note: At the moment incomplete overlap is not taken into account !

Co-registration of the OCRA cloud fraction

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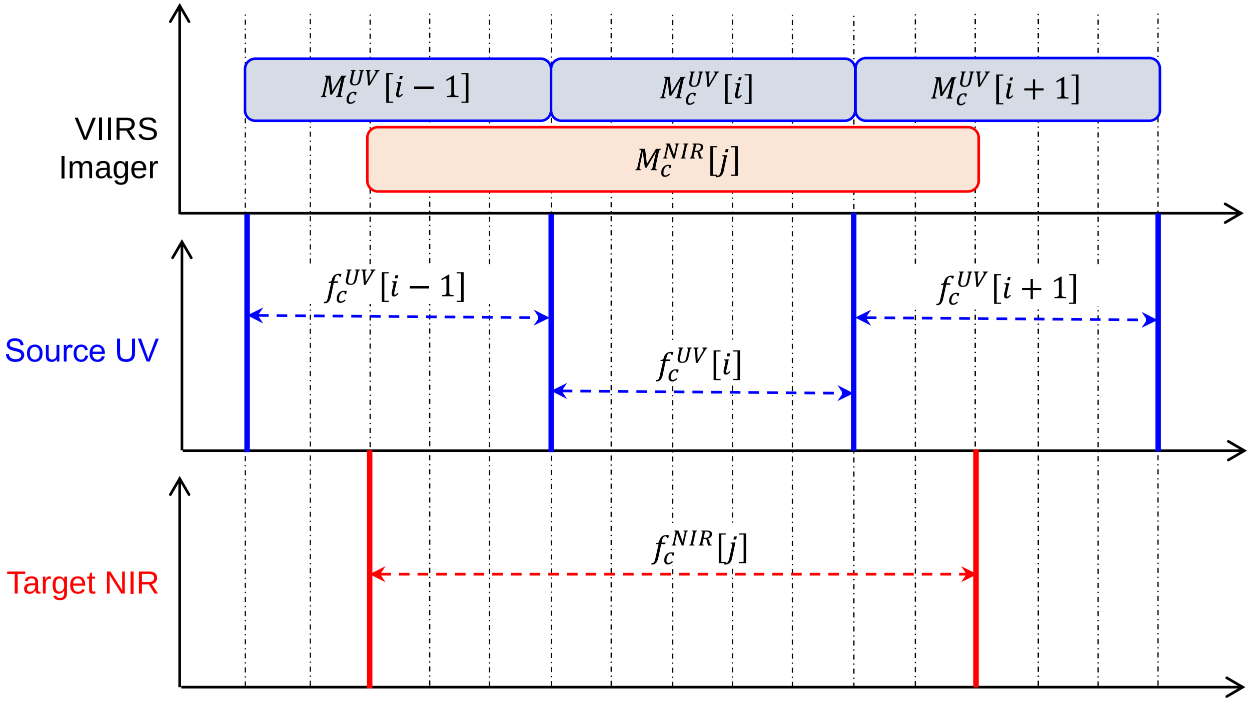
- At the location where the binning changes (NIR target pixel #19), there is a special case with 3 UV source pixels contributing to the target NIR pixel.



Weight calculation for the following scenario:

The usual case is when VIIRS UV pixels have different cloud fraction values ($B_{VIIRS} \neq C_{VIIRS} \neq D_{VIIRS}$):

$$\gamma_1[j] = \frac{M_c^{NIR}[j] - M_c^{UV}[i]}{M_c^{UV}[i-1] - M_c^{UV}[i]}$$

$$\gamma_2[j] = \frac{M_c^{NIR}[j] - M_c^{UV}[i+1]}{M_c^{UV}[i] - M_c^{UV}[i+1]}$$

$$f_c^{NIR}[j] = \frac{1}{2}|\gamma_1[j]| f_c^{UV}[i-1] + (1 - |\gamma_1[j]| + |\gamma_2[j]|) f_c^{UV}[i] + (1 - |\gamma_2[j]|) f_c^{UV}[i+1]$$

Co-registration of ROCINN cloud parameters

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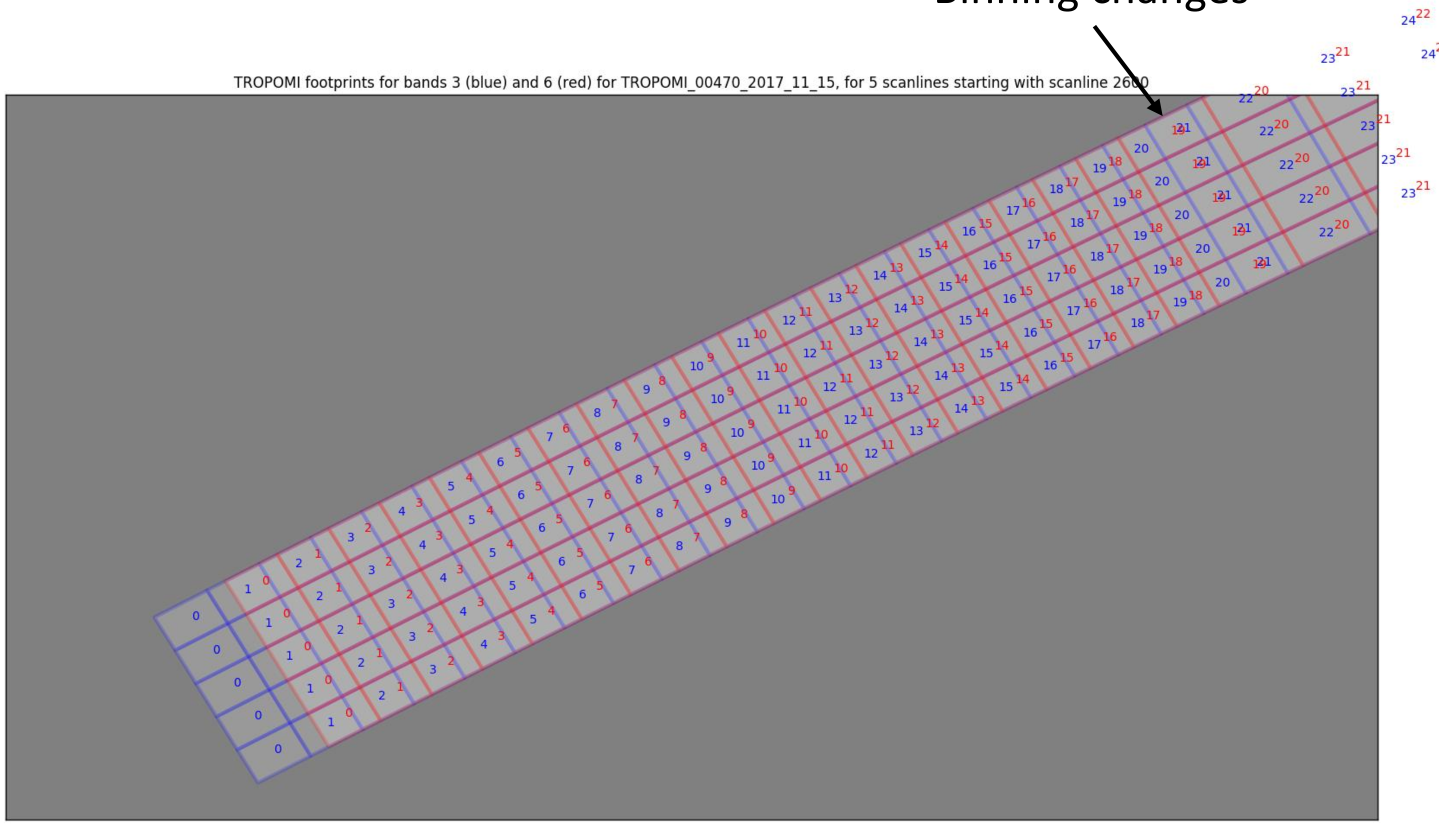
UV pixel #0 has no overlap with NIR.

UV pixel #1 has partial overlap with a single NIR pixel.

From UV pixel #2 to pixel #449, two NIR source pixels contribute to the target UV pixel with the exception of UV pixel #21. For UV pixel #21, NIR pixel #19 contributes only. This is where the binning scheme changes.

Binning changes



Co-registration of cloud top height

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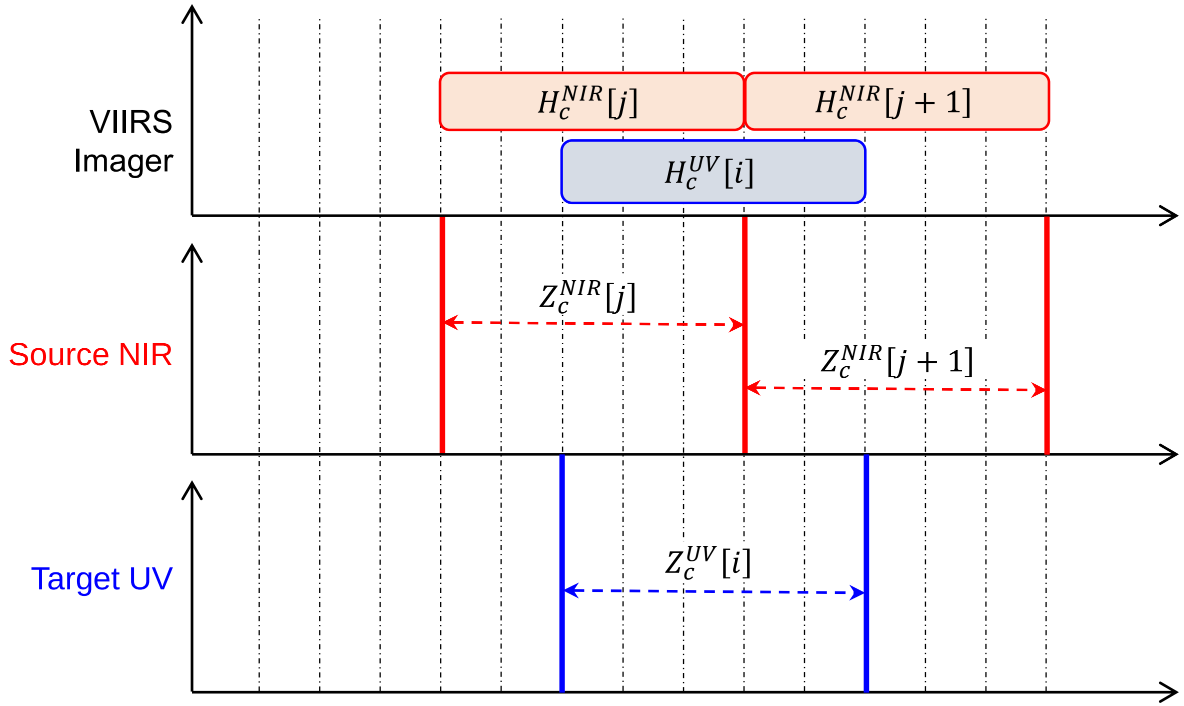

Weight calculation for the following scenario:

2 NIR source pixels contribute to the target UV pixel ($B_{VIIRS} \neq C_{VIIRS}$).:

$$\gamma[i] = \frac{H_c^{UV}[i] - H_c^{NIR}[j+1]}{H_c^{NIR}[j] - H_c^{NIR}[j+1]}$$

$$Z_c^{UV}[i] = |\gamma[i]| Z_c^{NIR}[j] + (1 - |\gamma[i]|) Z_c^{NIR}[j+1]$$

This is the case for all NIR pixels with exception to:

- UV pixel #0 with no overlap with NIR pixels
- UV pixel #1 and #21 where only one NIR pixel contributes.

Co-registration of cloud top height

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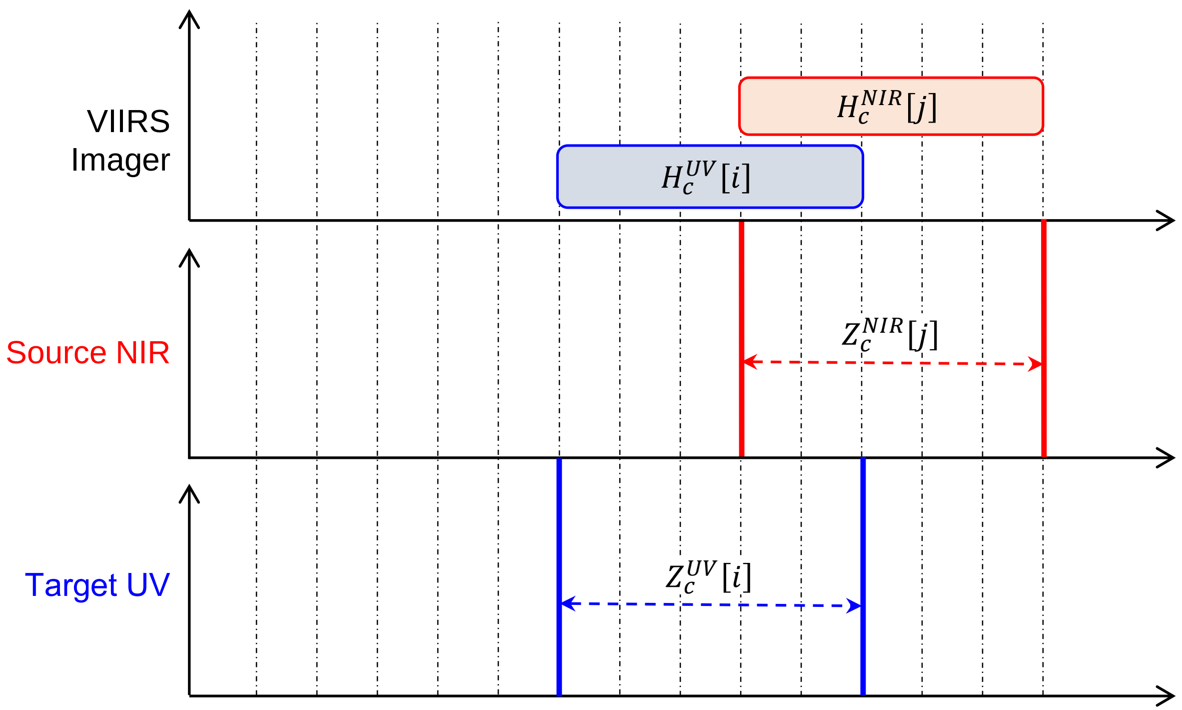
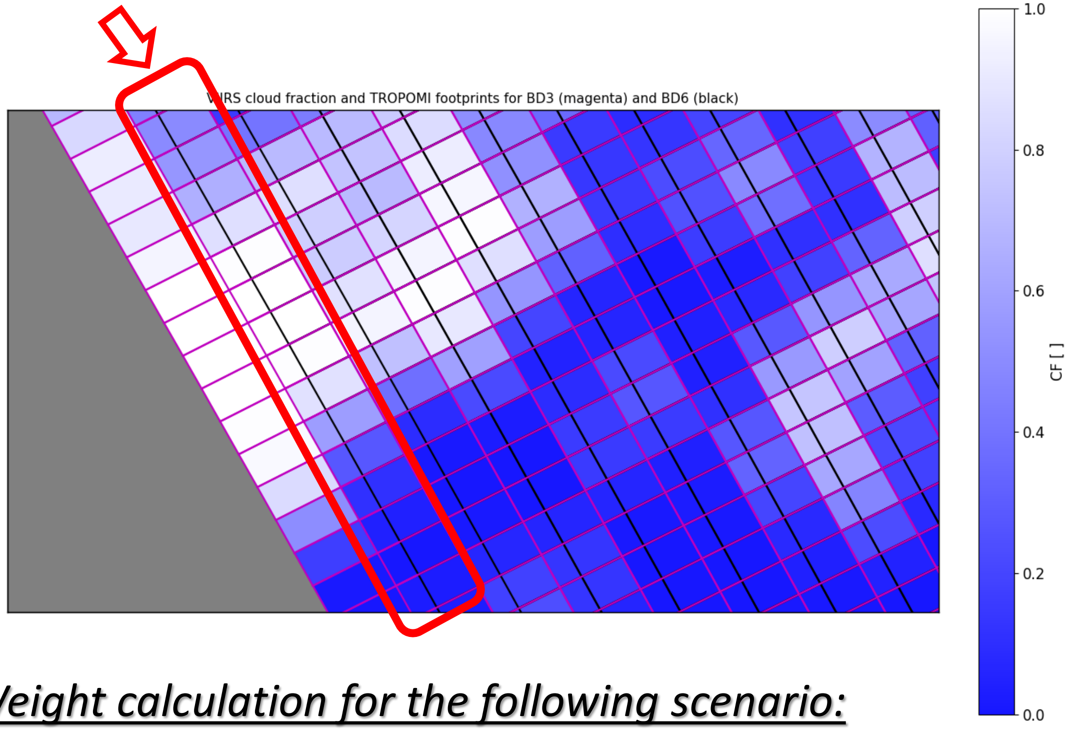
- At the west edge of the swath, the second UV pixel has partial overlap with the first NIR pixel.





Weight calculation for the following scenario:

1 NIR source pixels contribute to the UV target pixel ($B_{VIIRS} \neq C_{VIIRS}$). This is the case for UV pixel #1 with partial overlap and UV pixel #21 with complete overlap:

$$\gamma[i] = \frac{H_c^{UV}[i]}{H_c^{NIR}[j]}$$

$$Z_c^{UV}[i] = |\gamma[i]| Z_c^{NIR}[j]$$

Co-registration of cloud top height

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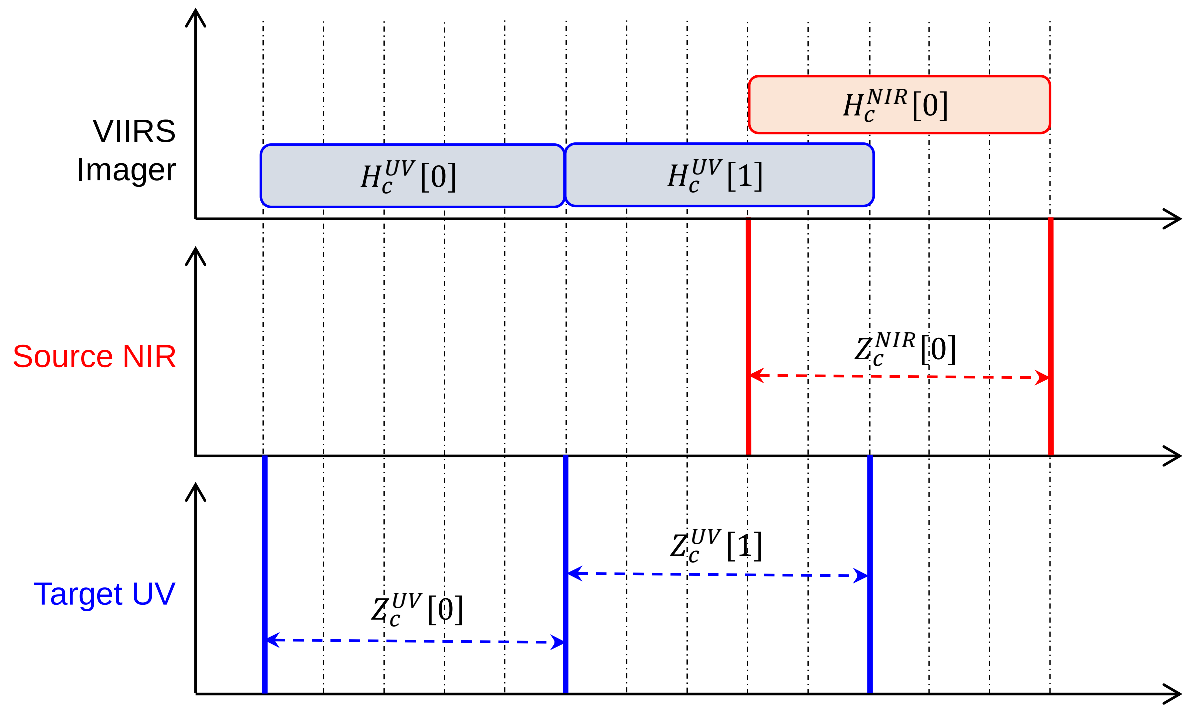
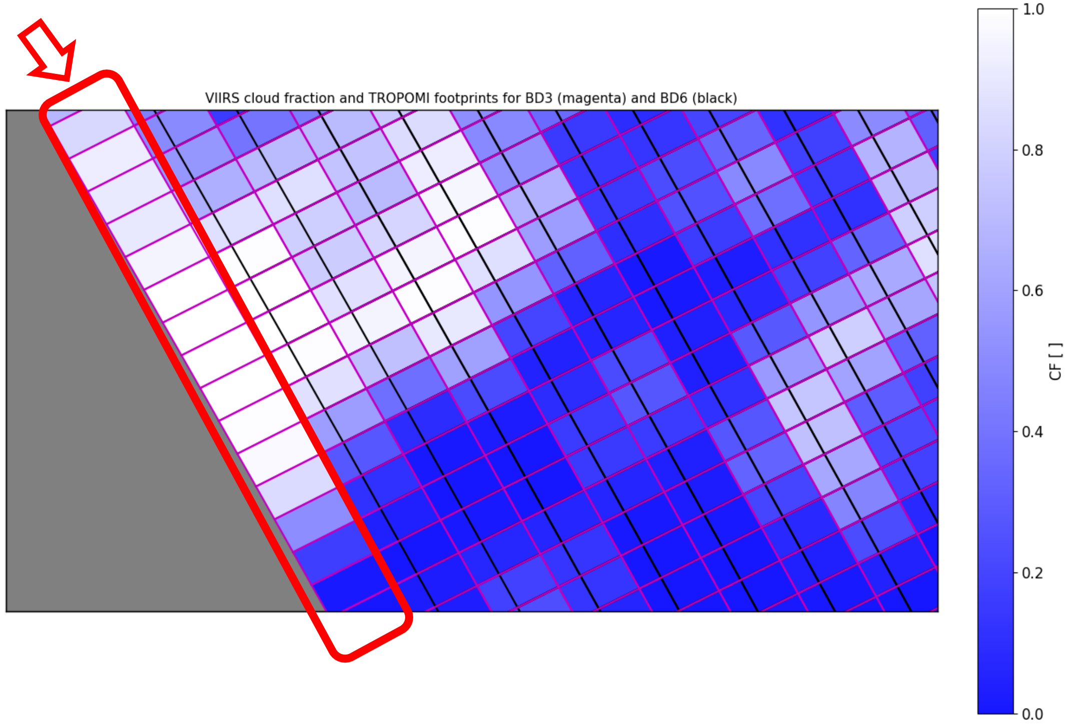
- At the west edge of the swath, the first UV pixel has no overlap with any NIR pixel.





Offset calculation using the VIIRS UV cloud information:

$$\delta = H_c^{UV}[1] - H_c^{UV}[0]$$

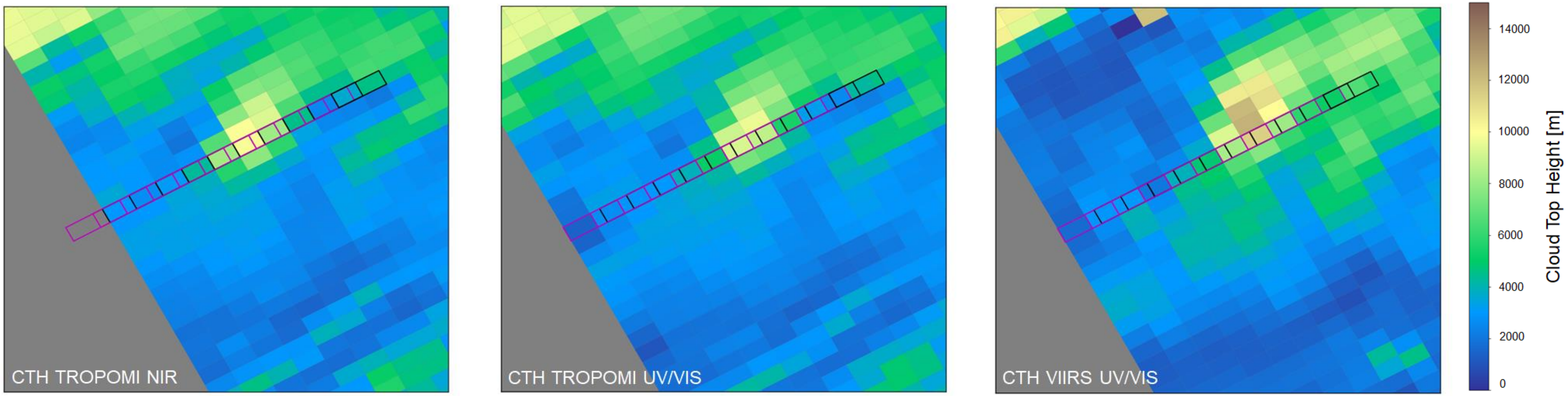
$$Z_c^{UV}[0] = Z_c^{UV}[1] + \delta$$

Co-registration of cloud top height

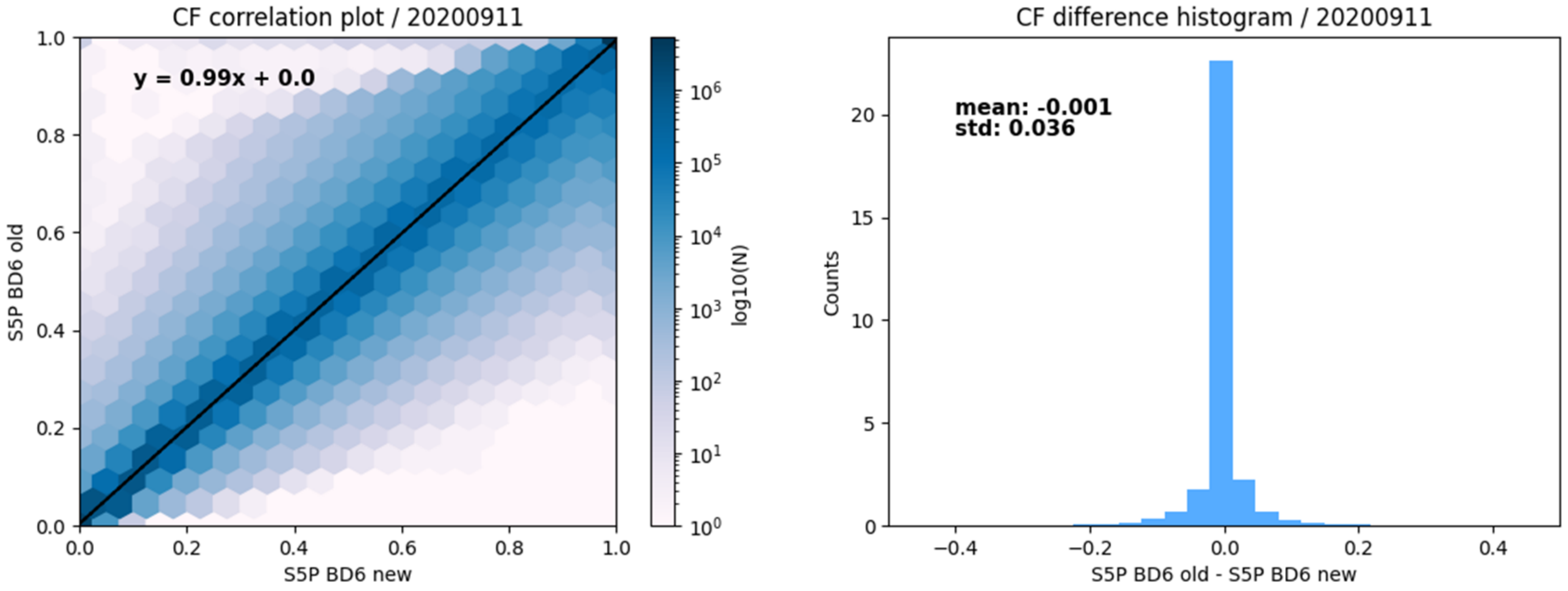
Original parameter in NIR

Co-registered parameter in UV

VIIRS parameter in UV



Old Versus New comparison - CF



> 70% of the pixels have the new co-registration

Old Versus New comparison – CTH CAL

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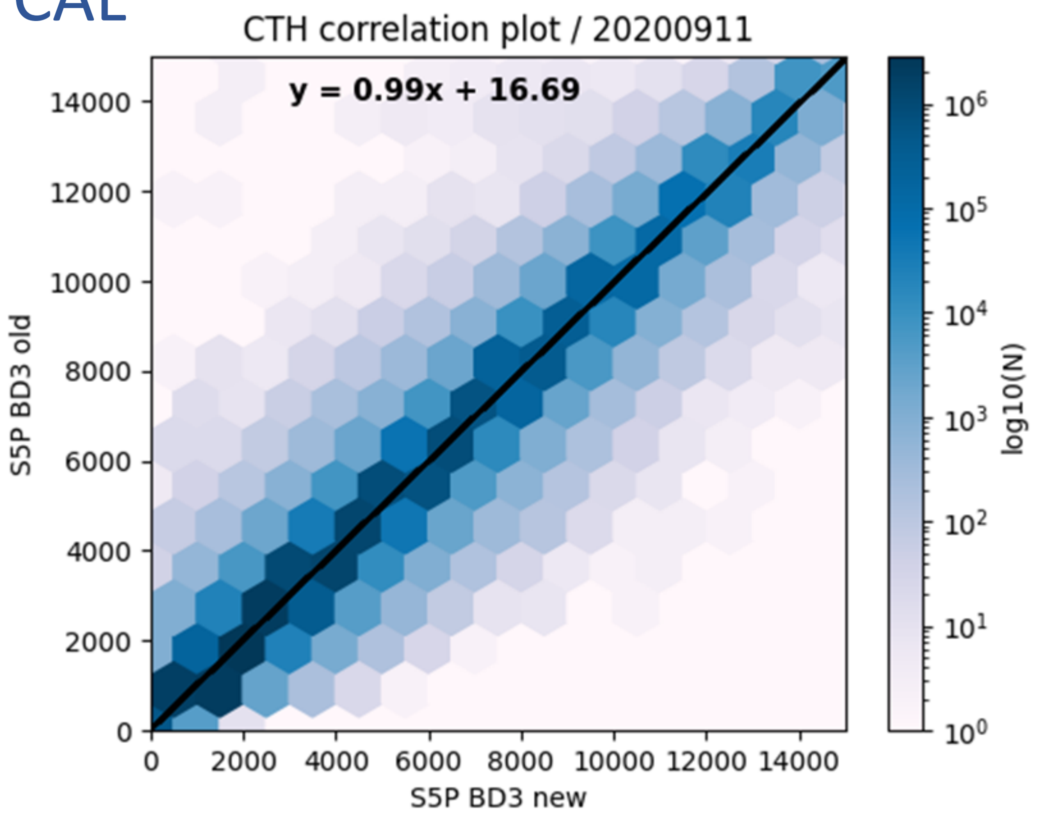
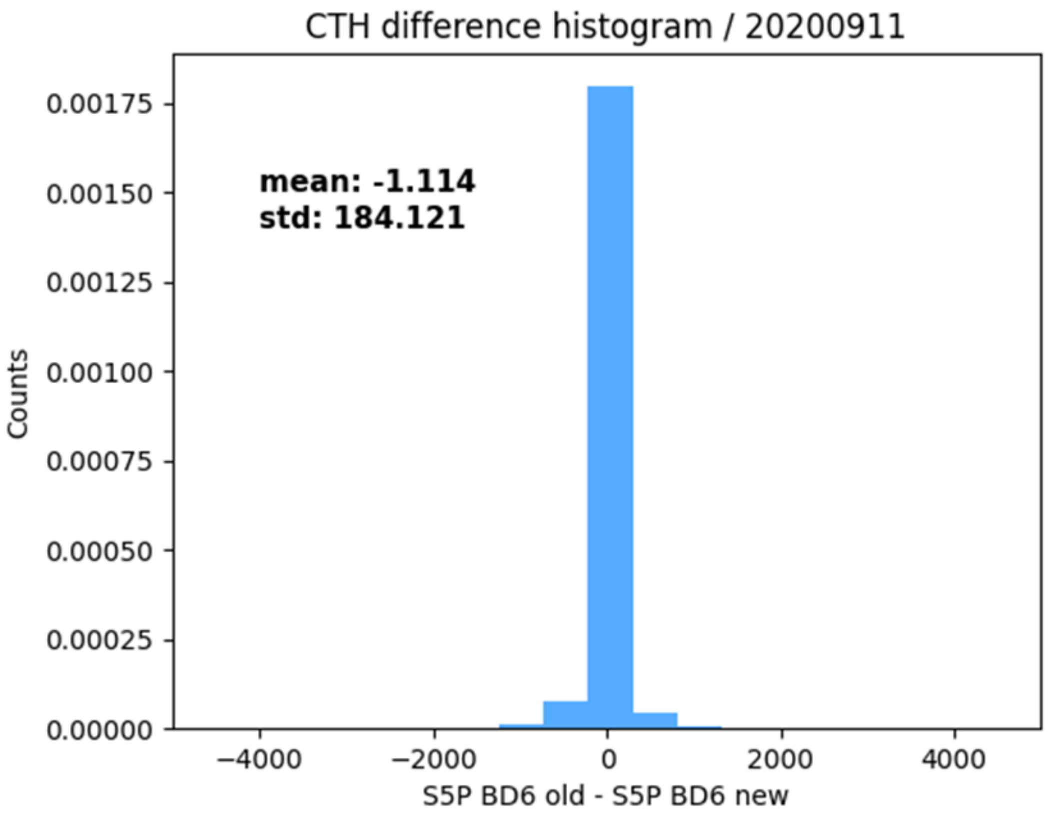
CTH CAL

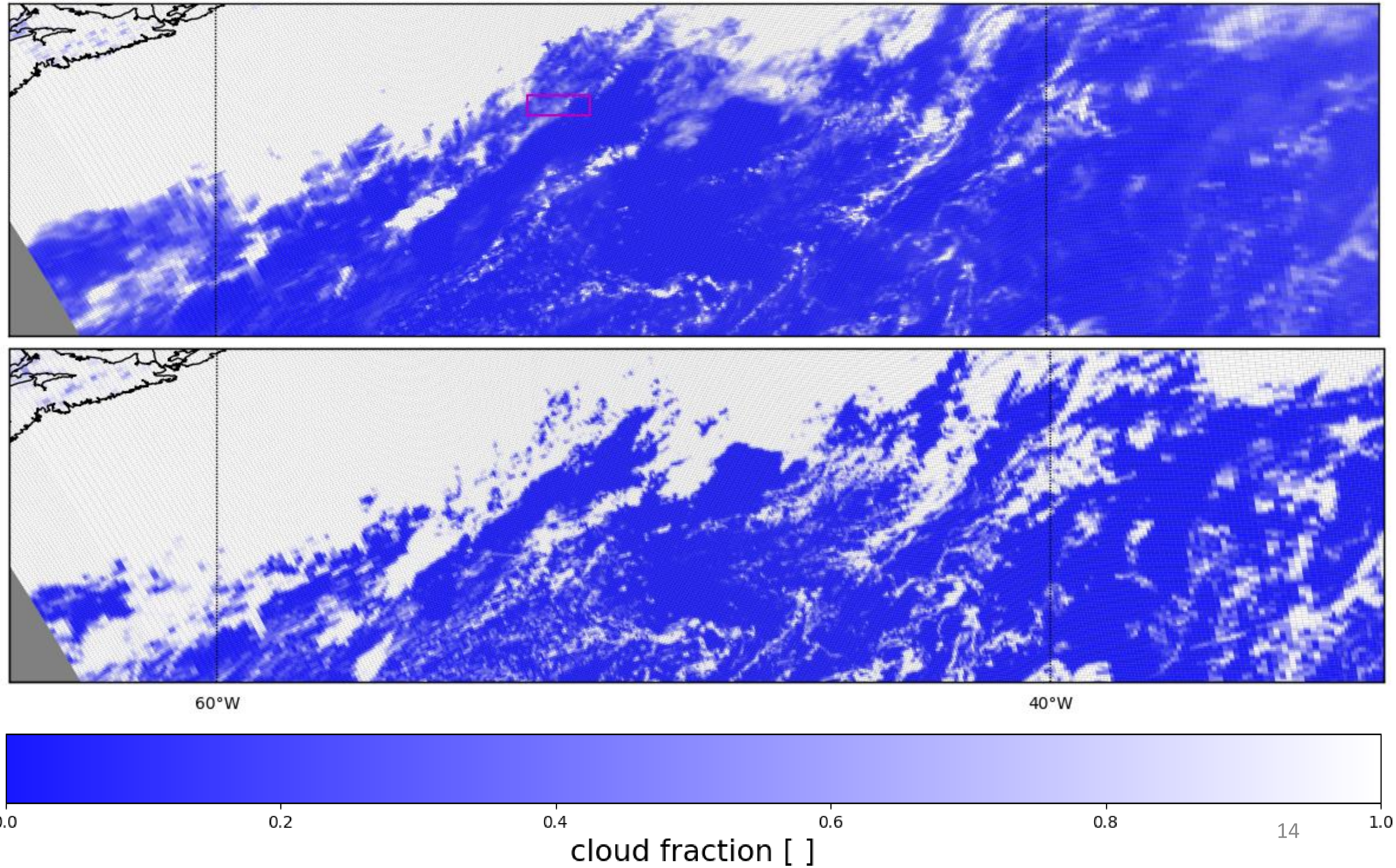




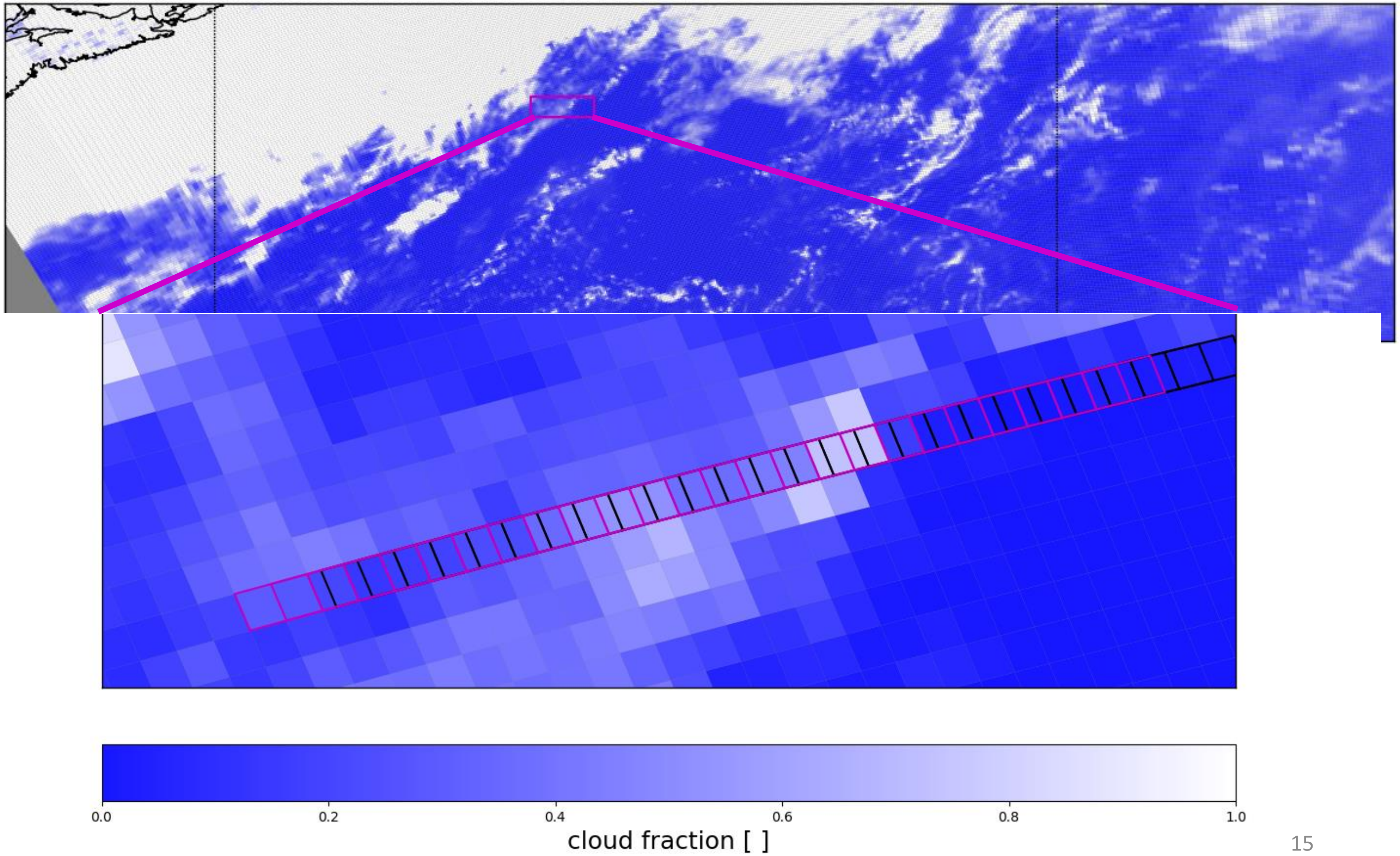
> 50% of the pixels have the new co-registration

OCRA CF - UV

VIIRS CF - UV



OCRA CF - UV



Inhomogeneous scenes - CF

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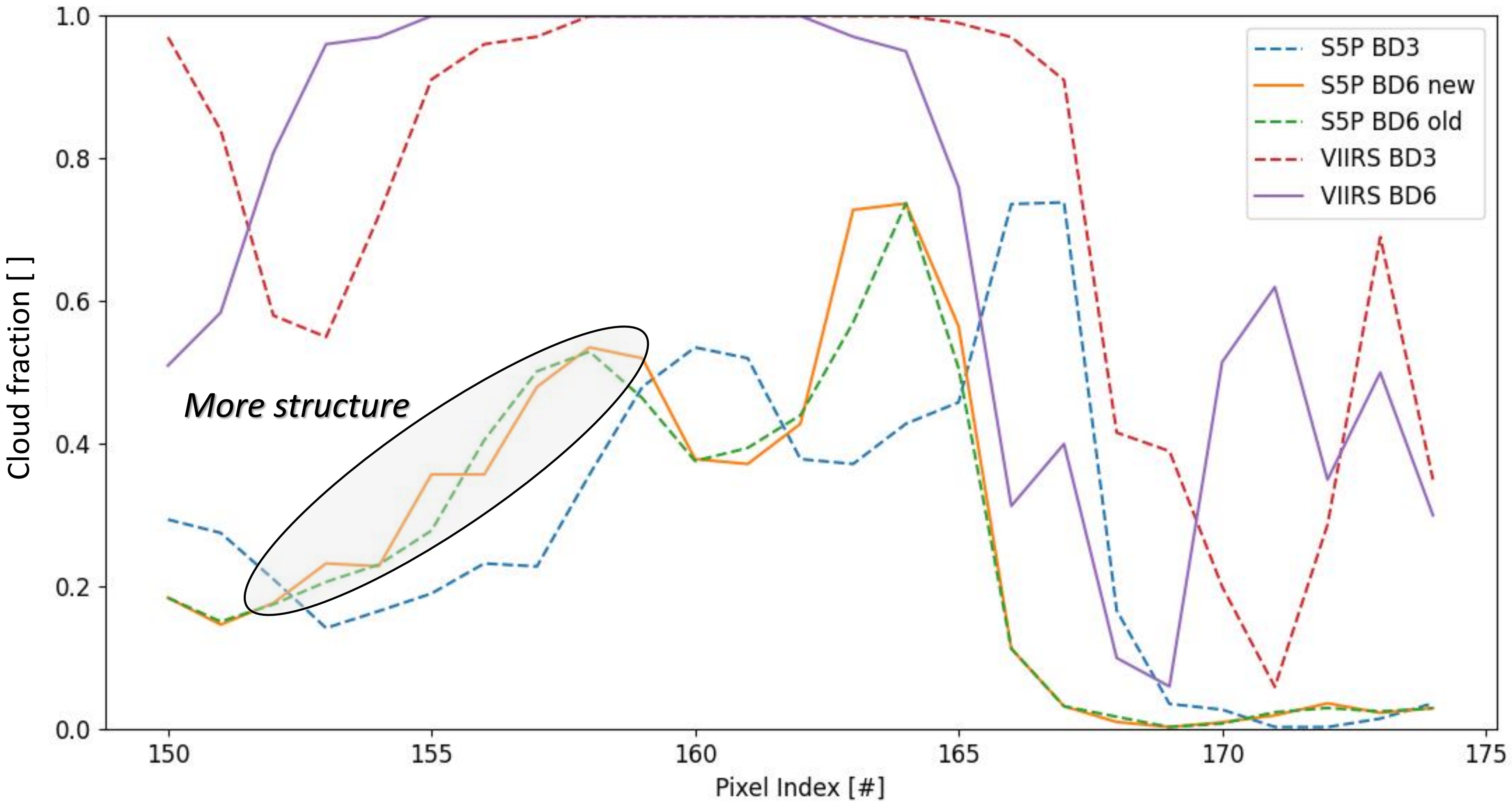
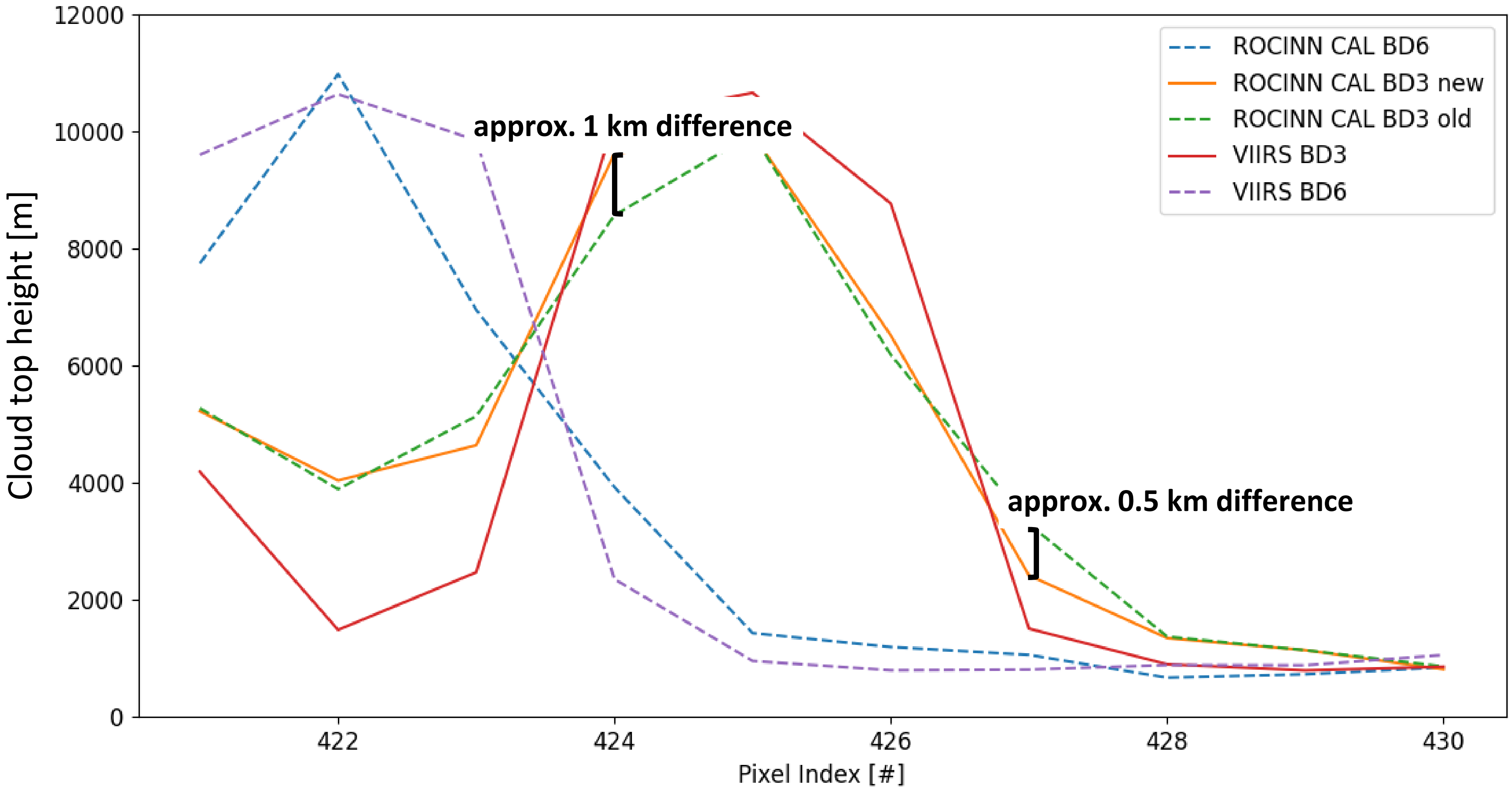


S5P_OFFL_L2__CLOUD__20200911T151027_20200911T165157_15099_01_020103_20200913T073154.nc : scanline 2820

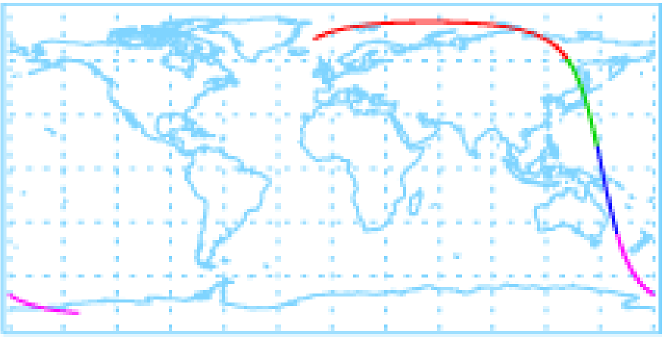
Single cloud scene – CTH CAL



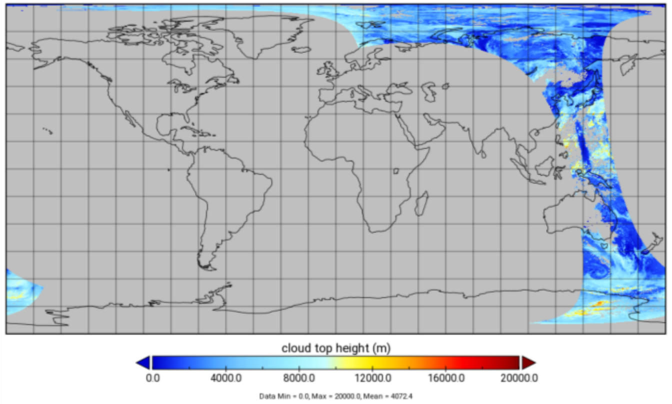
S5P_OFFL_L2__CLOUD__20200911T151027_20200911T165157_15099_01_020103_20200913T073154.nc : scanline 2710

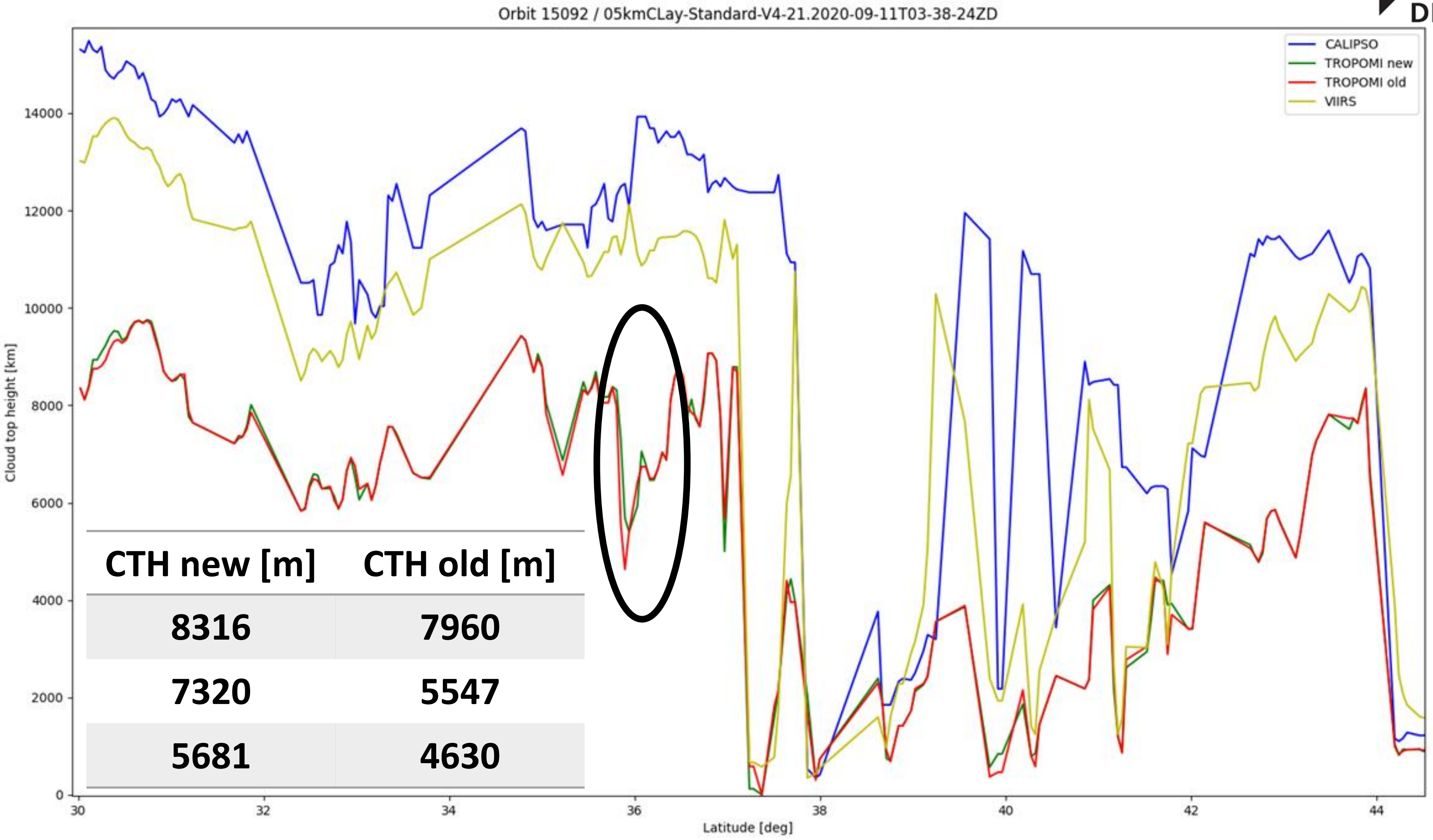
Across-track CTH comparisons against CALIPSO

CALIPSO ascending DAYTIME 03.38.22



TROPOMI orbit 15092





CTH new [m]	CTH old [m]
8316	7960
7320	5547
5681	4630

Summary & Conclusions

- We developed an improved UV-NIR (BD3-BD6) co-registration scheme based on VIIRS data. The old approach using static mapping tables is used as a fallback.
- The new approach fully exploits the cloud information from VIIRS and improves significantly the co-registration results.
- Comparisons in the along-track direction have been performed against VIIRS and in the across-track direction with collocated CALIPSO cloud data.
- **The major improvement is found at inhomogeneous scenes and at cloud edges.**
- Furthermore, the new method allows to provide cloud information for the first UV detector pixel (where there is no overlap with NIR) by extrapolating the OCRA/ROCINN results using the VIIRS cloud information. **UV trace gas products can now be provided for the first UV detector that up to now were skipped.**

Acknowledgments

- The updated re-gridded NPP product and the new TROPOMI co-registration scheme were developed in the framework of the ESA MPC project (CCN#5 & CCN#6) complemented with national funding.
- This work is well-supported by NOAA for the provision of VIIRS data.

- It is planned to update the operational CLOUD product with the improved co-registration in 2023.

Support slides

Regridded VIIRS data from RAL

The VIIRS data contain the following cloud-related EDRs *[Variables used for the new co-registration scheme]*:

- **CloudBase**: *cldbasehght, cldbasepres, cldtophght_adj, cldtoppres_adj*
- **CloudDCOMP**: *cloudmicrovisod, cloudmicrovisodmd6*
- **CloudHeight**: *cldoptdpth, cldtophght, cldtoppres, cldtopemss*
- **CloudMask+AF**: *cloudprobability, cloudmaskbinary, cloudmask_*, dust_mask_*, smoke_mask_**
- **CloudPhase**: *cloudphase_clear, cloudphase_ice, cloudphase_liquid_water, cloudphase_mixed_phase*

Co-registration of the CA and COT

The co-registration of both optical cloud parameters CA from ROCINN CRB and COT from ROCINN CAL is performed similarly to the CAL CTH.

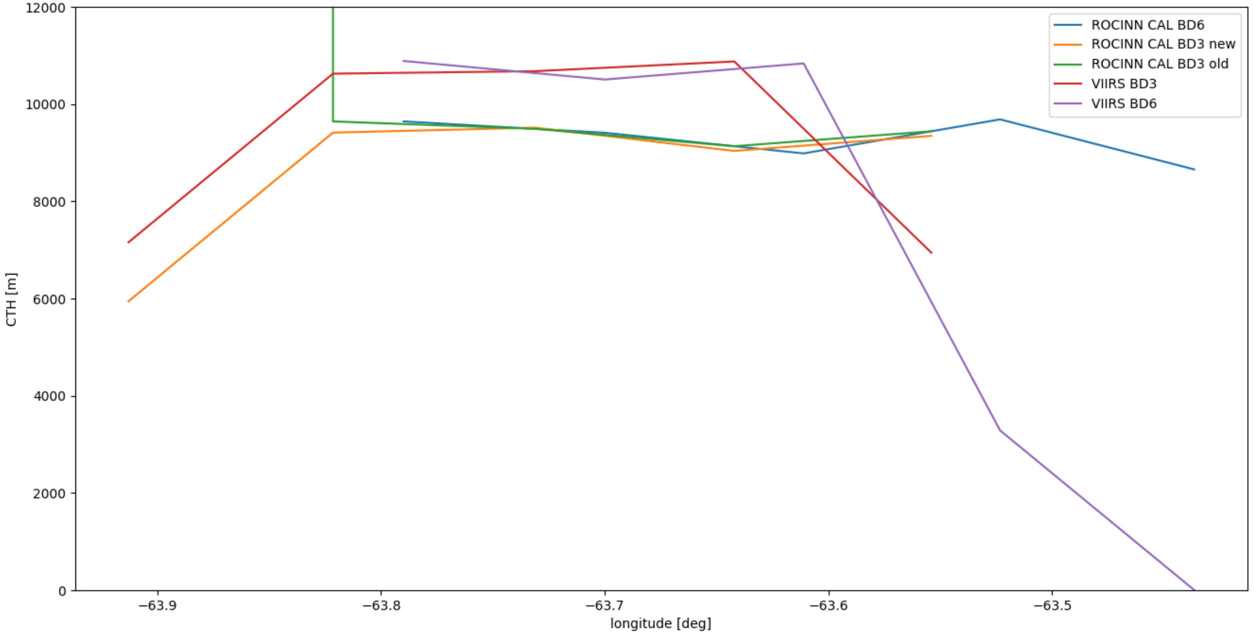
The cloud albedo is not included in the VIIRS data. Therefore, it is necessary to convert the cloud optical thickness to a cloud albedo. Then, the co-registration takes place in the cloud albedo domain.

Inapplicability of the new scheme

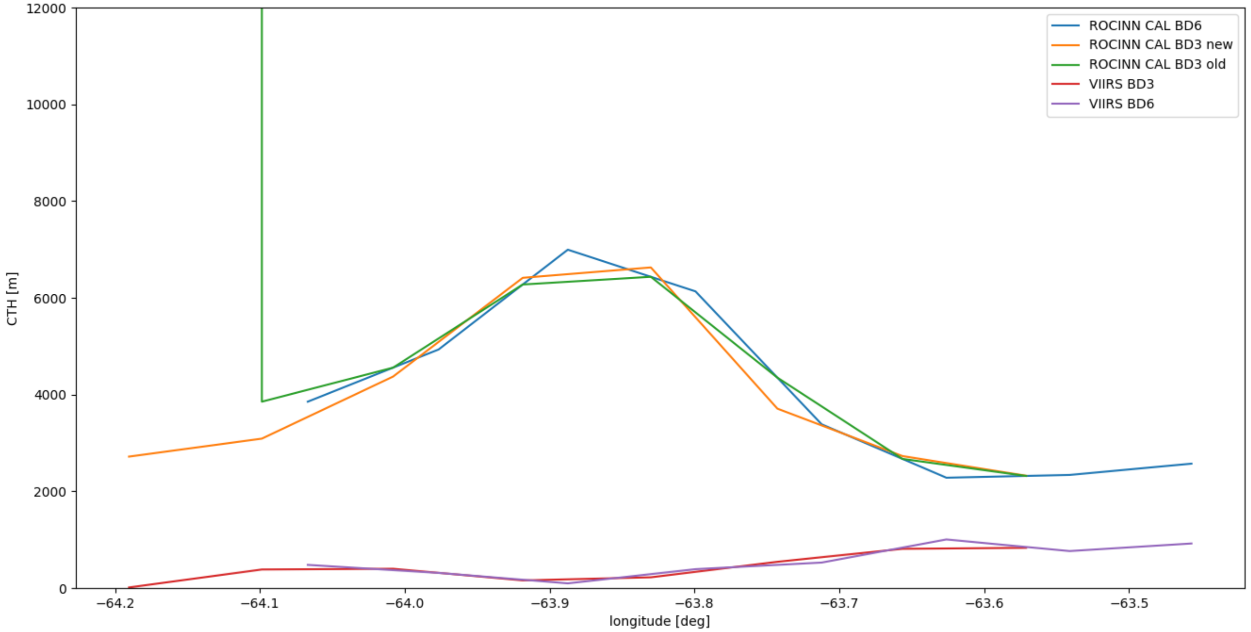
The co-registration is done only based on the static mapping tables (old scheme) in the following cases:

- when S5P or VIIRS pixels contain a fill value. It affects all cloud parameters.
- when neighboring VIIRS pixels contain zeros because of the numerical errors at the weight calculations. It affects all cloud parameters.
- when the weight calculation results to values outside the expected range [0,1]. It affects all cloud parameters.
- when all 3 VIIRS UV pixels are equal ($B_{VIIRS} = C_{VIIRS} = D_{VIIRS}$) while S5P UV pixels are different ($B_{OCRA} \neq C_{OCRA} \neq D_{OCRA}$). It affects only the CF.

The first BD3 pixel extrapolated using VIIRS



Extrapolation at the first UV pixel with partial VIIRS/TROPOMI agreement



Extrapolation at the first UV pixel with VIIRS/TROPOMI disagreement

Old Versus New comparison – CH CRB

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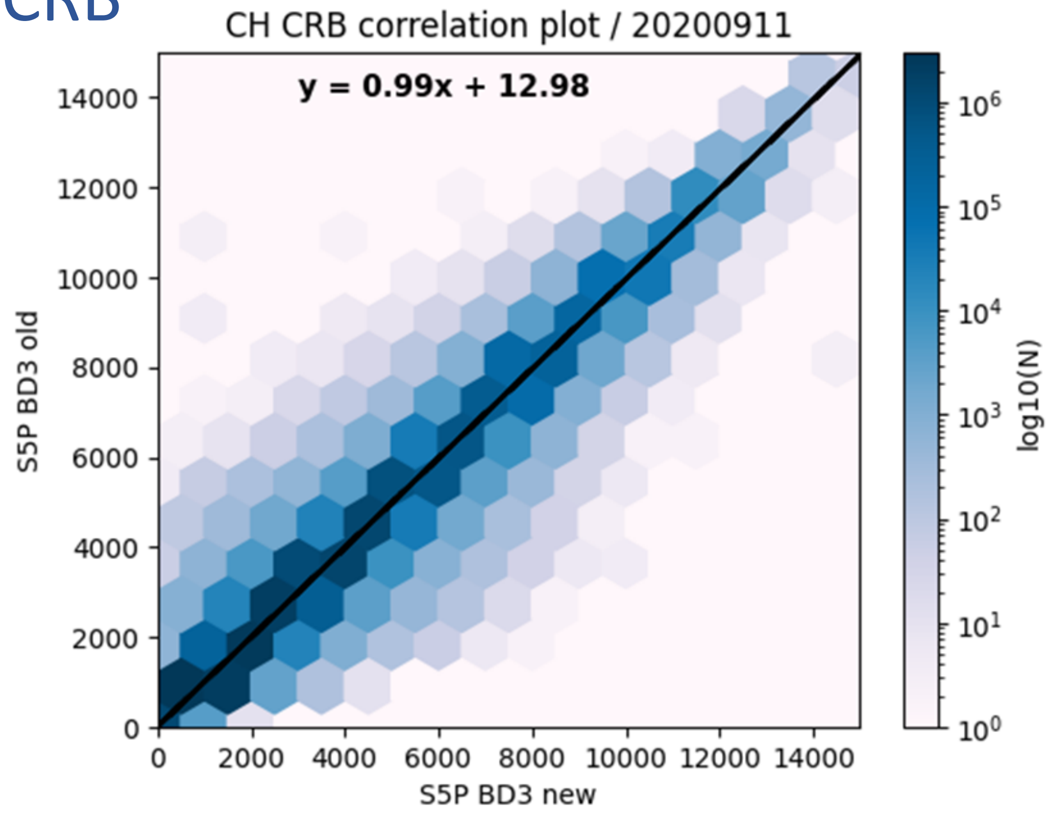
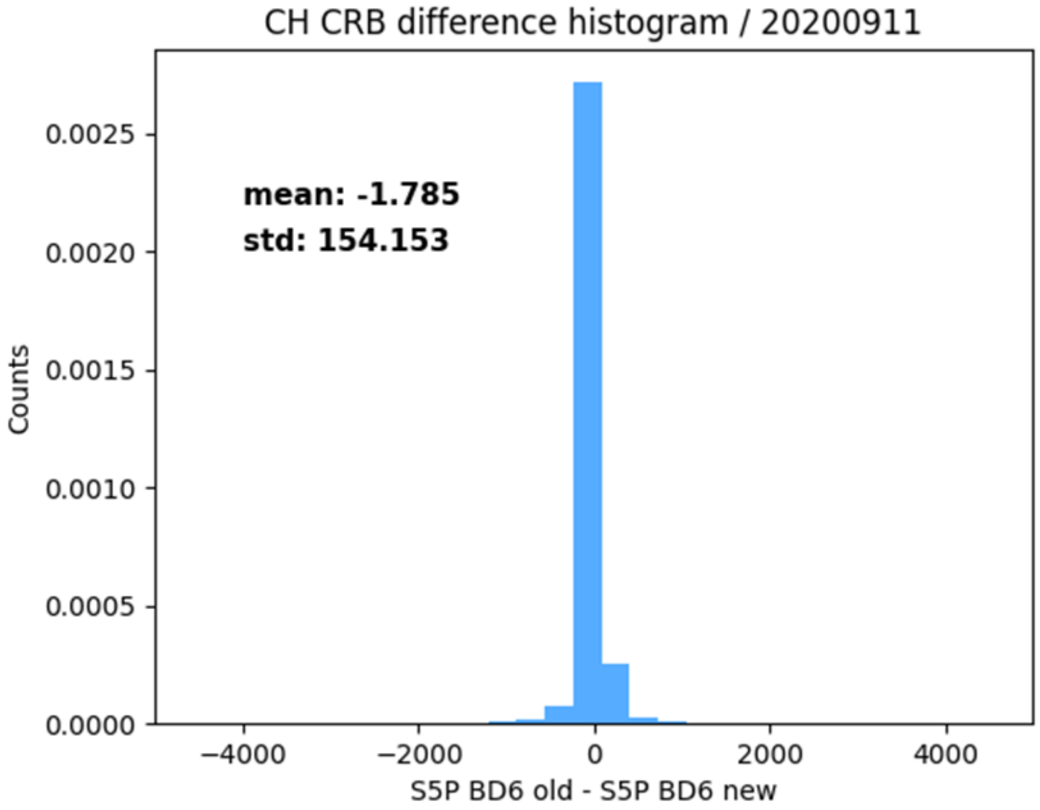
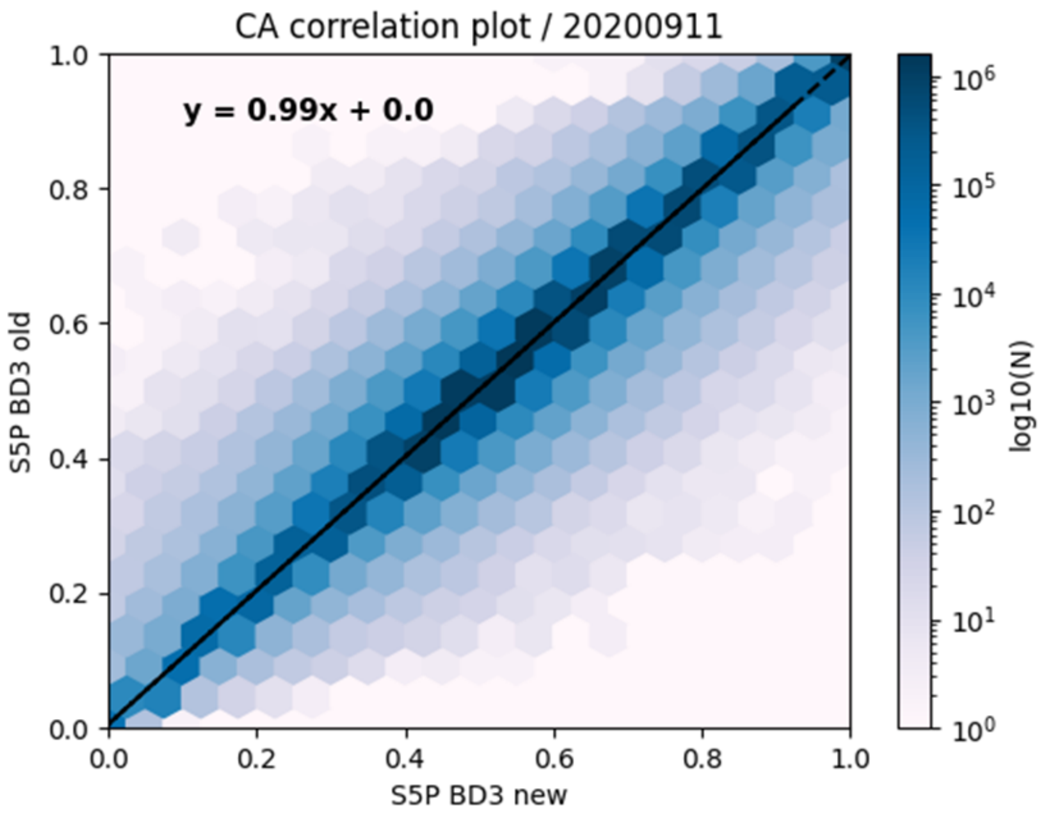
CH CRB

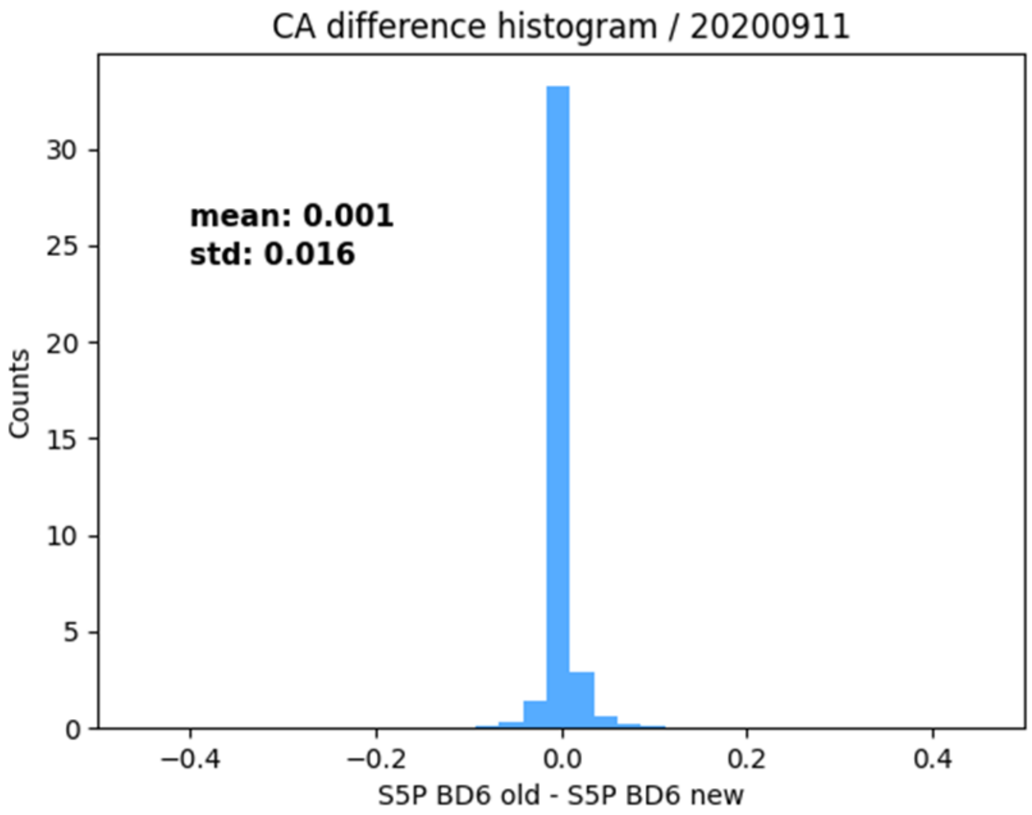




> 50% of the pixels have the new co-registration

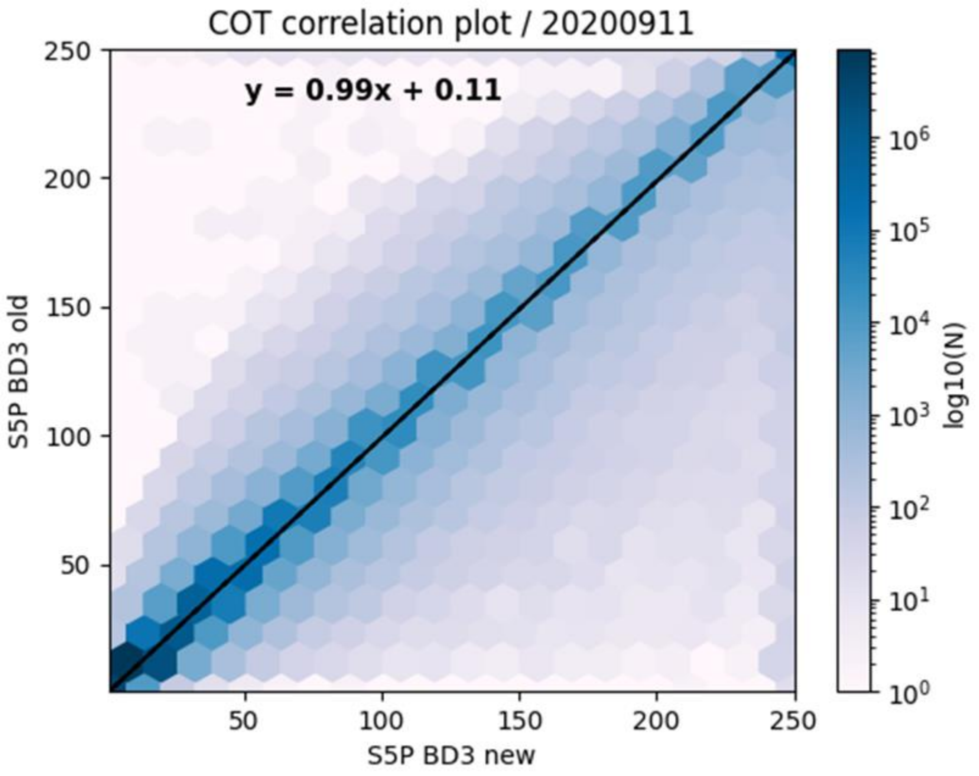
Old Versus New comparison – CA CRB

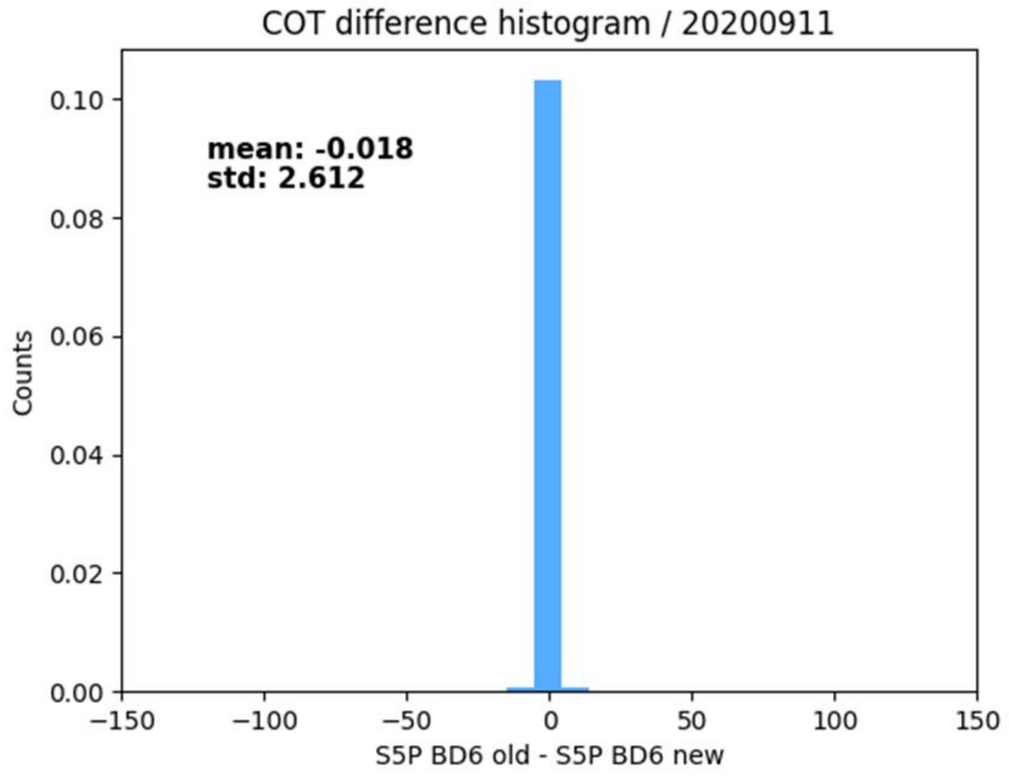




> 40% of the pixels have the new co-registration

Old Versus New comparison – COT CAL





> 40% of the pixels have the new co-registration

Inhomogeneous scenes - CF

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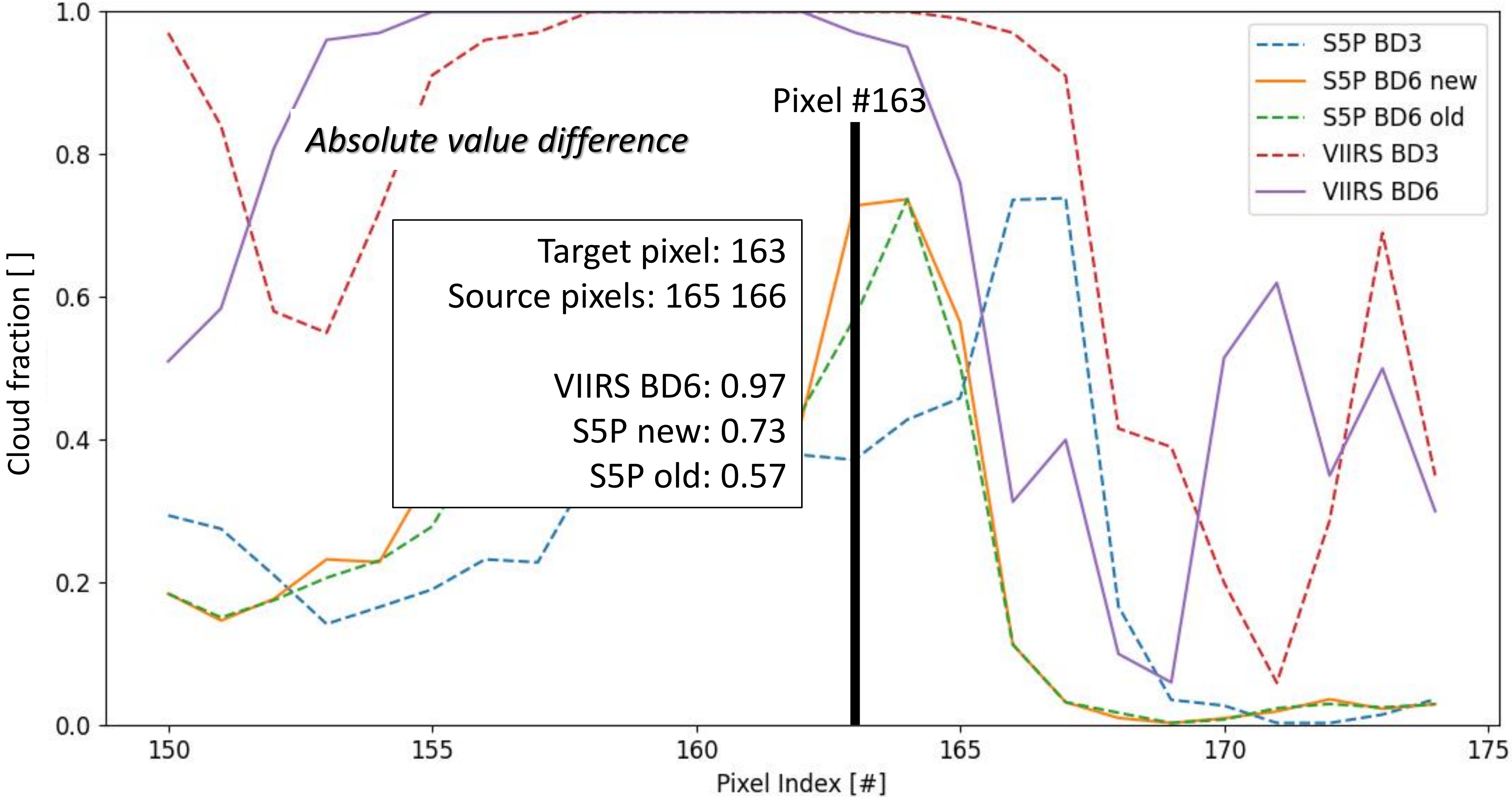

S5P_OFFL_L2__CLOUD__20200911T151027_20200911T165157_15099_01_020103_20200913T073154.nc : scanline 2820

Inhomogeneous scenes - CF

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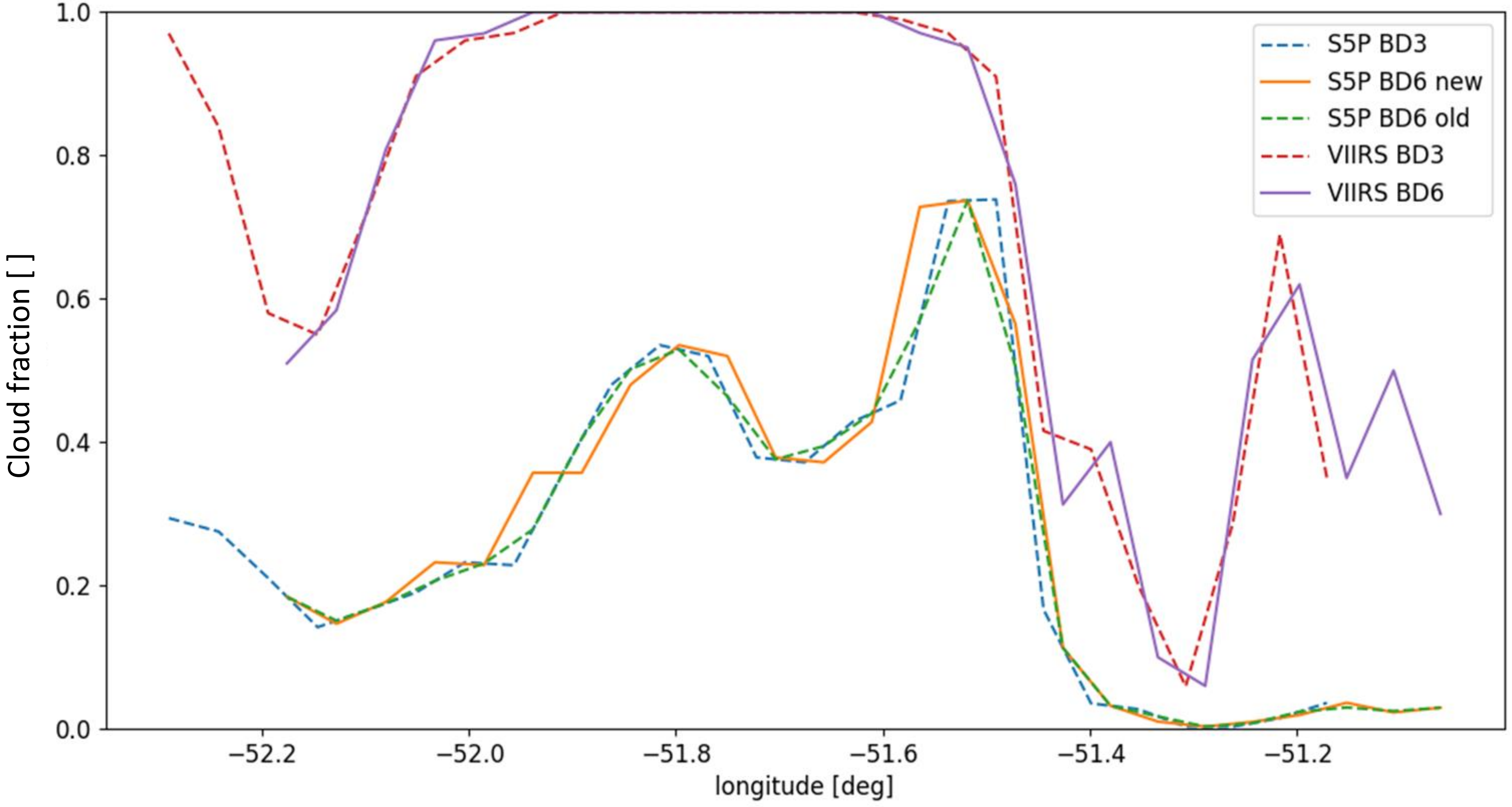
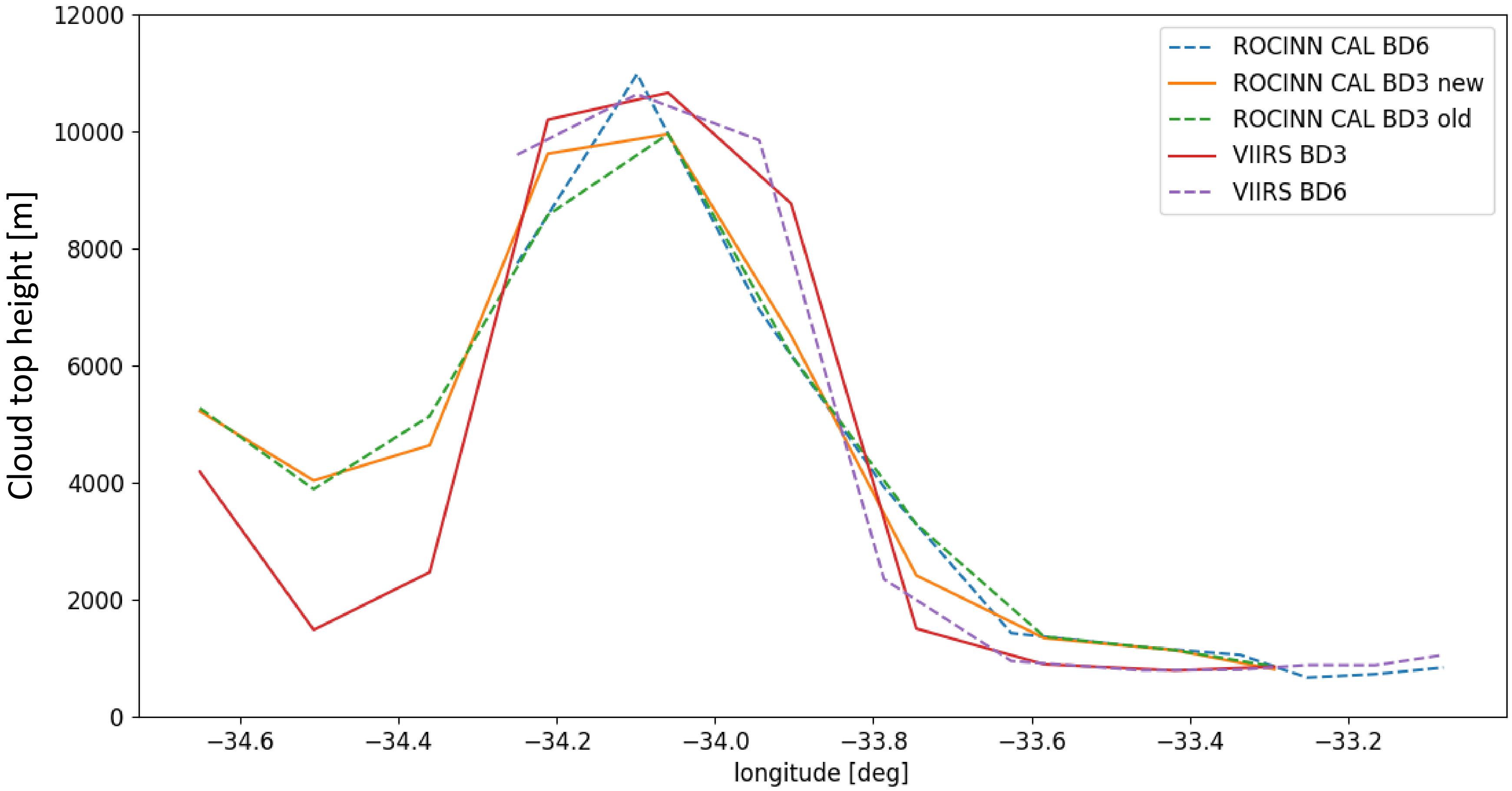


S5P_OFFL_L2__CLOUD__20200911T151027_20200911T165157_15099_01_020103_20200913T073154.nc : scanline 2820

Single cloud scene – CTH CAL



S5P_OFFL_L2__CLOUD__20200911T151027_20200911T165157_15099_01_020103_20200913T073154.nc : scanline 2710

Collocation of TROPOMI and CALIPSO

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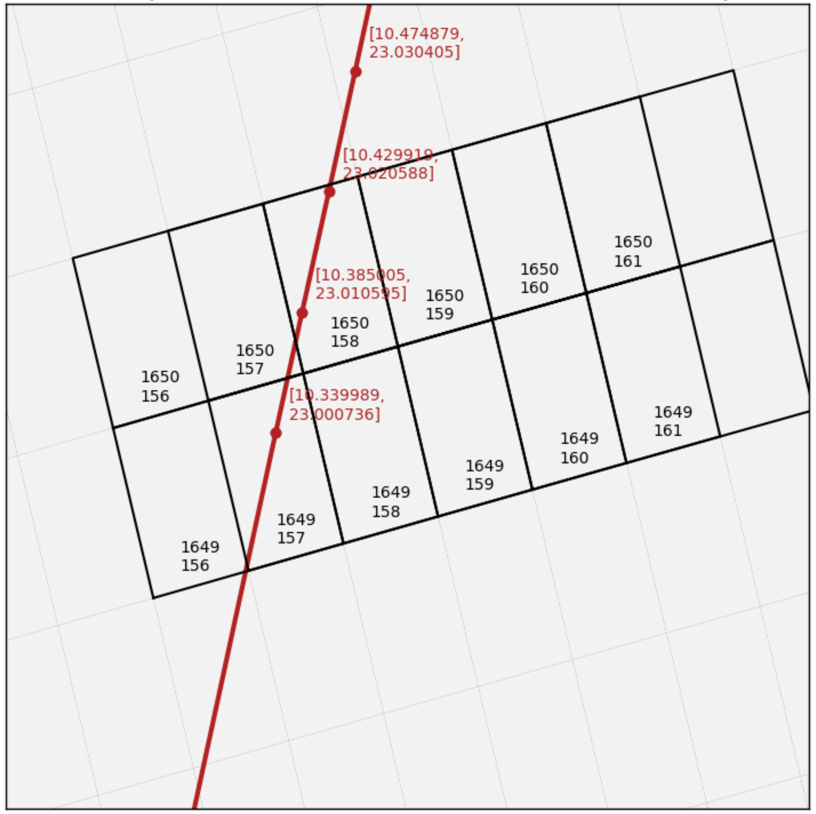
TROPOMI footprints for BD6 (black) and CALIPSO overpass (red)



- Calculate the distance between the CALIPSO coordinates and the mid-pixel TROPOMI coordinates:

$$\Delta\varphi = rad(\varphi_2 - \varphi_1),\ \Delta\lambda = rad(\lambda_2 - \lambda_1)$$

$$a = \left(\sin\frac{\Delta\varphi}{2}\right)^2 + \left(\sin\frac{\Delta\lambda}{2}\right)^2 \cos(rad\varphi_1)\cos(rad\varphi_2)$$

$$c = 2\ atan2(\sqrt{a}, \sqrt{1-a})$$

$$d = R\ \ c,\ with\ R = 6378137\ m$$

- Define the TROPOMI pixel within the CALIPSO point is co-located using a search window for latitude [ϕ-0.1, ϕ+0.1] and longitude [λ-0.05, λ+0.05].

** CALIPSO L2 data used for the collocation: CAL_LID_L2_05kmCLay-Standard-V4-20 is the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) Lidar Level 2 5 km Cloud Layer, Version 4-20 data product. Data for this product was collected using the CALIPSO Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument.*