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Institut für  
Umweltphysik

Fachbereich 01  
Physik/Elektrotechnik

# Applying the CO2M candidate algorithm FOCAL to OCO-2

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**IWGGMS 17**

THE 17TH INTERNATIONAL WORKSHOP ON  
GREENHOUSE GAS MEASUREMENTS FROM SPACE

**NASA**

14-17 JUNE 2021  
VIRTUAL MEETING

# Introduction


- The European Copernicus CO2M mission is envisaged to be launched in 2025.
- EUMETSAT is preparing to operate up to three retrieval algorithms in its ground segment.
- One of these algorithms is FOCAL (fast atmospheric trace gas retrieval).
- Retrieval studies with simulated data are essential. However, it turned out, that the retrieval algorithms usually require significant adaptations when applying them to the observations from instruments in orbit.
- This comprises, e.g., pre-processing steps, handling of systematic residuals, outlier detection, and bias correction.
- Thus, we are developing strategies to adapt FOCAL to satellite instruments already in orbit, from which hope to learn for a smooth transition to CO2M, eventually.
- The presentation of S. Noël et al. shows results for FOCAL GOSAT and GOSAT-II.



- Here we present the most recent developments for the FOCAL OCO-2 algorithm.
- Starting point: FOCAL v09 as described by Reuter et al. 2017a, b, and 2020
- v10 is work in progress.



moersch, Pixabay

|  |  |                                    |
|--|--|------------------------------------|
|  | ESA Climate Change Initiative "Plus" (CCI+)                              | Page 1                             |
|  | Algorithm Theoretical Basis Document<br>Version 2 (ATBDv2) - FOCAL OCO-2 | Version 2 – Final<br>24. Aug. 2020 |
|  | for the Essential Climate Variable (ECV)<br>Greenhouse Gases (GHG)       |                                    |

ESA Climate Change Initiative "Plus" (CCI+)

**Algorithm Theoretical Basis Document Version 2 (ATBDv2)**

**Retrieval of XCO<sub>2</sub> from the OCO-2 satellite using the Fast Atmospheric Trace Gas Retrieval (FOCAL)**

for the Essential Climate Variable (ECV)  
Greenhouse Gases (GHG)

[climate.esa.int/en/projects/ghgs](http://climate.esa.int/en/projects/ghgs)

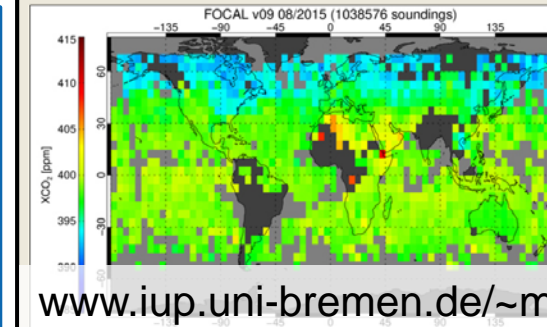
Written by:  
GHG-CCI group at IUP  
Lead author: M. Reuter, IUP, Univ. Bremen, Germany

## FOCAL-OCO2 Fast atmospheric trace gas retrieval for OCO2

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### Overview

The fast atmospheric trace gas retrieval for OCO<sub>2</sub> (FOCAL-OCO2) has been setup to retrieve XCO<sub>2</sub> (the column-average dry-air mole fraction of atmospheric CO<sub>2</sub>) by analyzing hyper spectral solar backscattered radiance measurements of NASA's OCO<sub>2</sub> satellite. FOCAL includes a radiative transfer model which has been developed to approximate light scattering effects by multiple scattering at an optically thin scattering layer. This reduces the computational costs by several orders of magnitude. FOCAL's radiative transfer model is utilized to simulate the radiance in all three OCO-2 spectral bands allowing the simultaneous retrieval of CO<sub>2</sub>, H<sub>2</sub>O, and solar induced chlorophyll fluorescence.



[www.iup.uni-bremen.de/~mreuter/focal.php](http://www.iup.uni-bremen.de/~mreuter/focal.php)



remote sensing



[www.mdpi.com/2072-4292/9/11/1159](http://www.mdpi.com/2072-4292/9/11/1159)

Article

**A Fast Atmospheric Trace Gas Retrieval for Hyperspectral Instruments Approximating Multiple Scattering—Part 1: Radiative Transfer and a Potential OCO-2 XCO<sub>2</sub> Retrieval Setup**

Maximilian Reuter <sup>\*</sup>, Michael Buchwitz, Oliver Schneising, Stefan Noël, Vladimir Rozanov, Heinrich Bovensmann and John P. Burrows



remote sensing



[www.mdpi.com/2072-4292/9/11/1102](http://www.mdpi.com/2072-4292/9/11/1102)

Article

**A Fast Atmospheric Trace Gas Retrieval for Hyperspectral Instruments Approximating Multiple Scattering—Part 2: Application to XCO<sub>2</sub> Retrievals from OCO-2**

Maximilian Reuter <sup>\*</sup>, Michael Buchwitz, Oliver Schneising, Stefan Noël, Heinrich Bovensmann <sup>†</sup> and John P. Burrows <sup>†</sup>



# Cloud detection

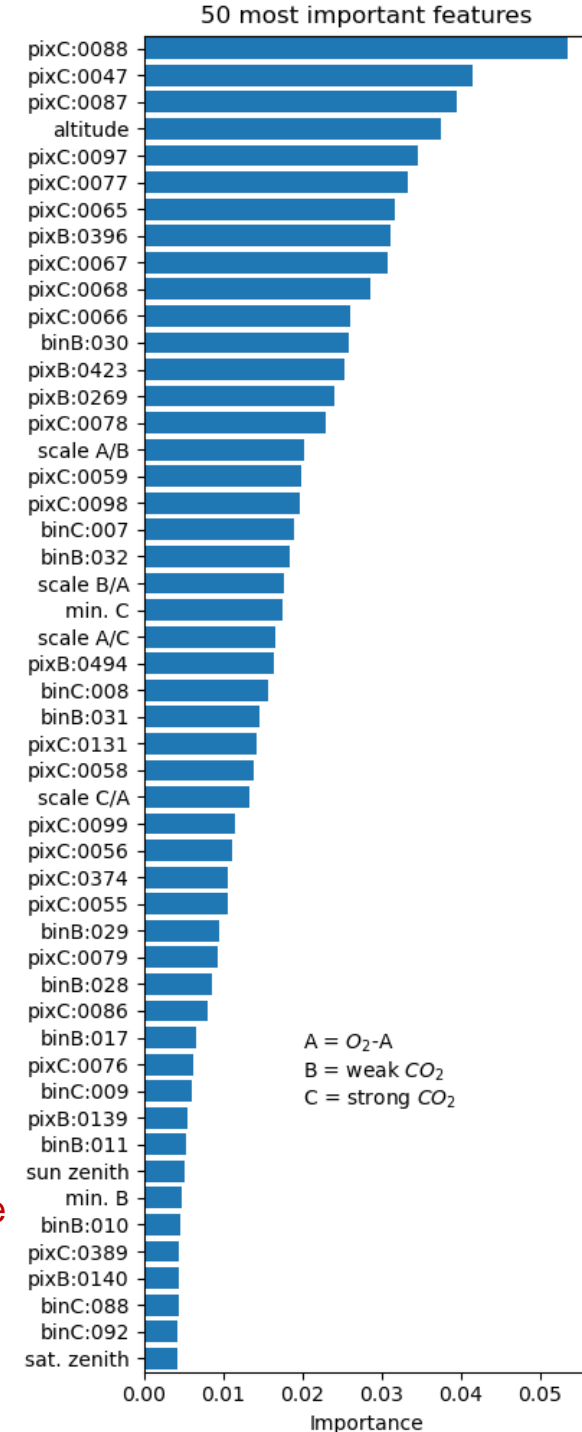
- v09: based on NASA MODIS AQUA cloud mask  
⇒ poor throughput (<11%)
- v10: random forest classifier analyzing OCO-2 v10 L1b
  - Training / control truth: MODIS AQUA
  - Candidate features: OCO-2 v10 L1b all colors normalized by continuum radiance, colors binned by 8, observation geometry, etc.
  - Features selected for training: 50 most important
  - High performance in training and control

| Training  |        | Actual |       |
|-----------|--------|--------|-------|
|           |        | cloudy | free  |
| Predicted | cloudy | 49575  | 449   |
|           | free   | 425    | 49551 |

| Control   |        | Actual |       |
|-----------|--------|--------|-------|
|           |        | cloudy | free  |
| Predicted | cloudy | 80819  | 201   |
|           | free   | 897    | 18083 |

~5% of  
predicted free

~1% of  
actually free



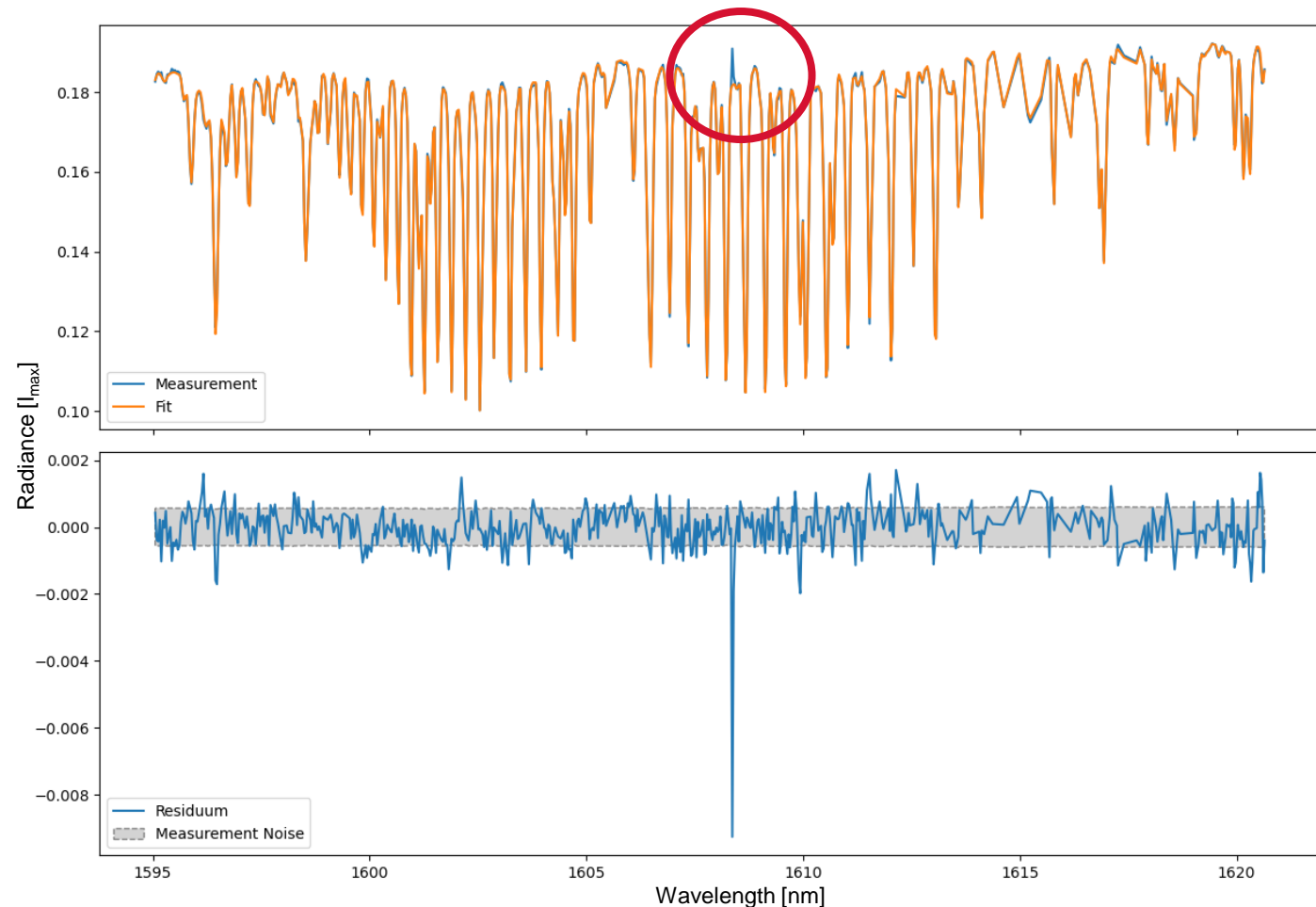
# Handling of spectral spikes

## v09

- Allows <60 “bad colors” in the O2 band, no “bad colors” in the SWIR bands.
- Throughput: ~90% but rejected basically all soundings in the SAA.
- Static bad pixel mask.

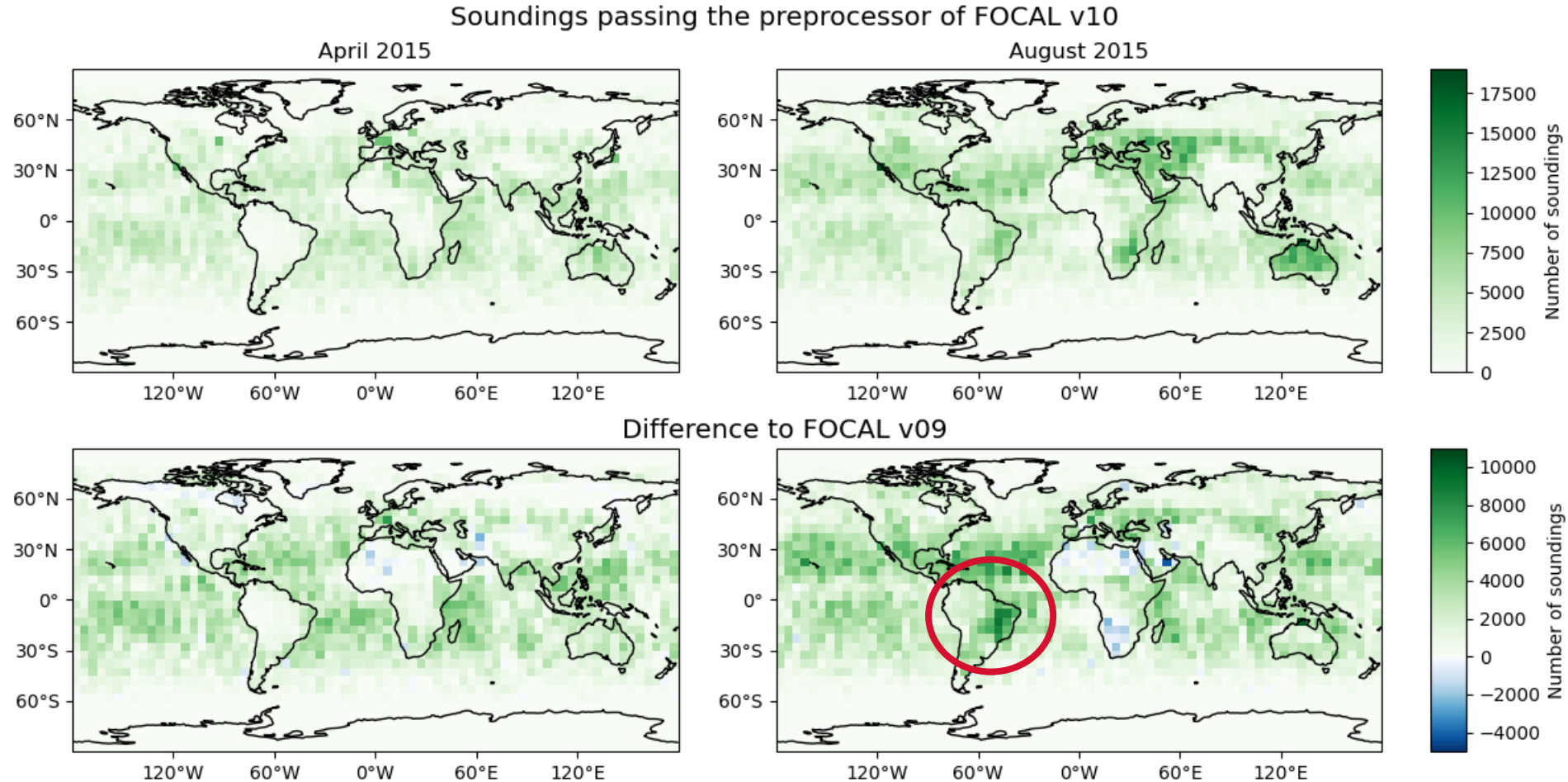
## v10

- No pre filtering by bad colors.
- Dynamic bad pixel mask, i.e., only those parts of the spectra are used which are not affected by, e.g., cosmic rays.
- Improved throughput especially in the SAA.



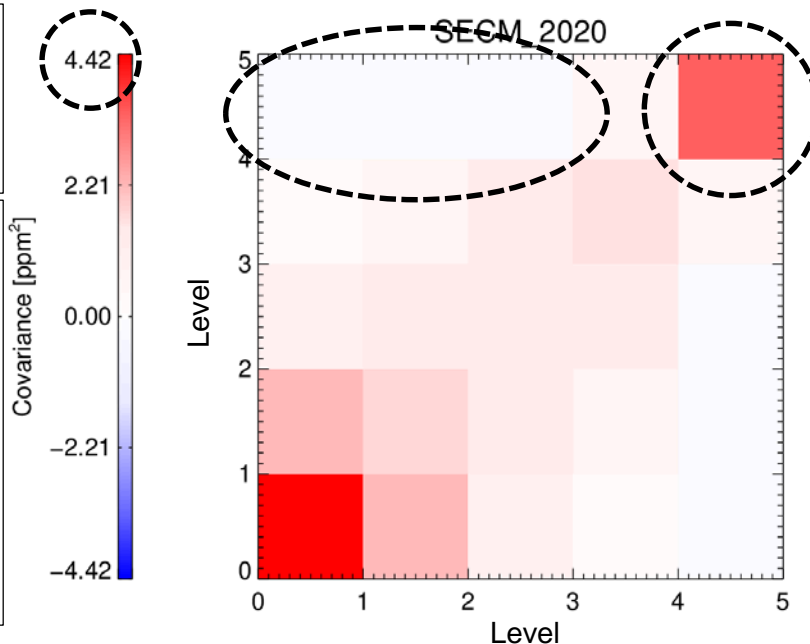
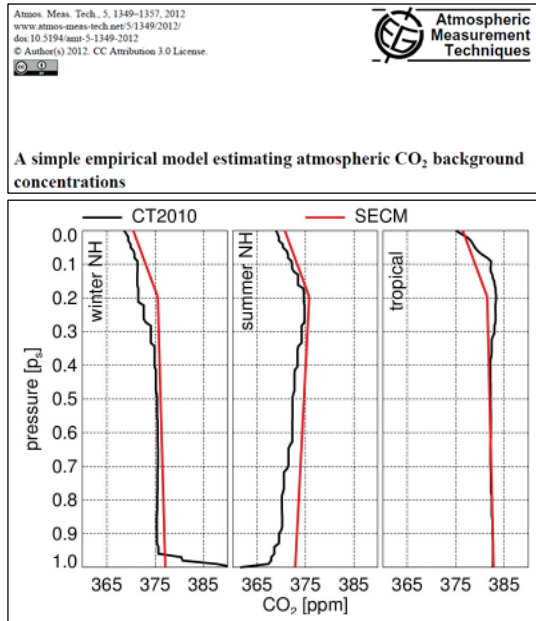
# Pre-processor throughput

The overall pre-processor filtering throughput of v10 is  $\sim 3.7$  times larger than for v09.



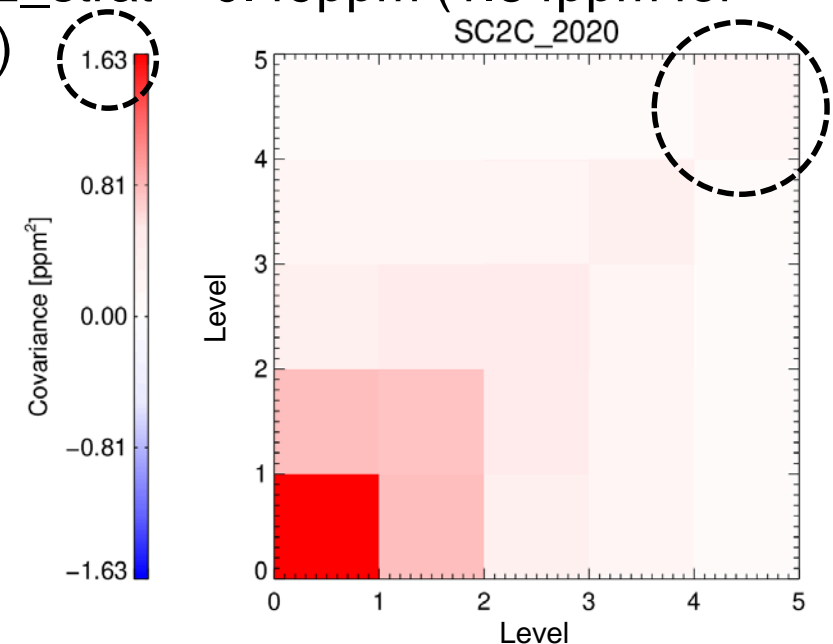
## v09

- SECM 2020 has been used as a priori for CO<sub>2</sub>.
- SECM is an empirical function fitting NOAA's CarbonTracker (CT) model.
- SECM parameterizes profiles linearly in the troposphere and stratosphere.



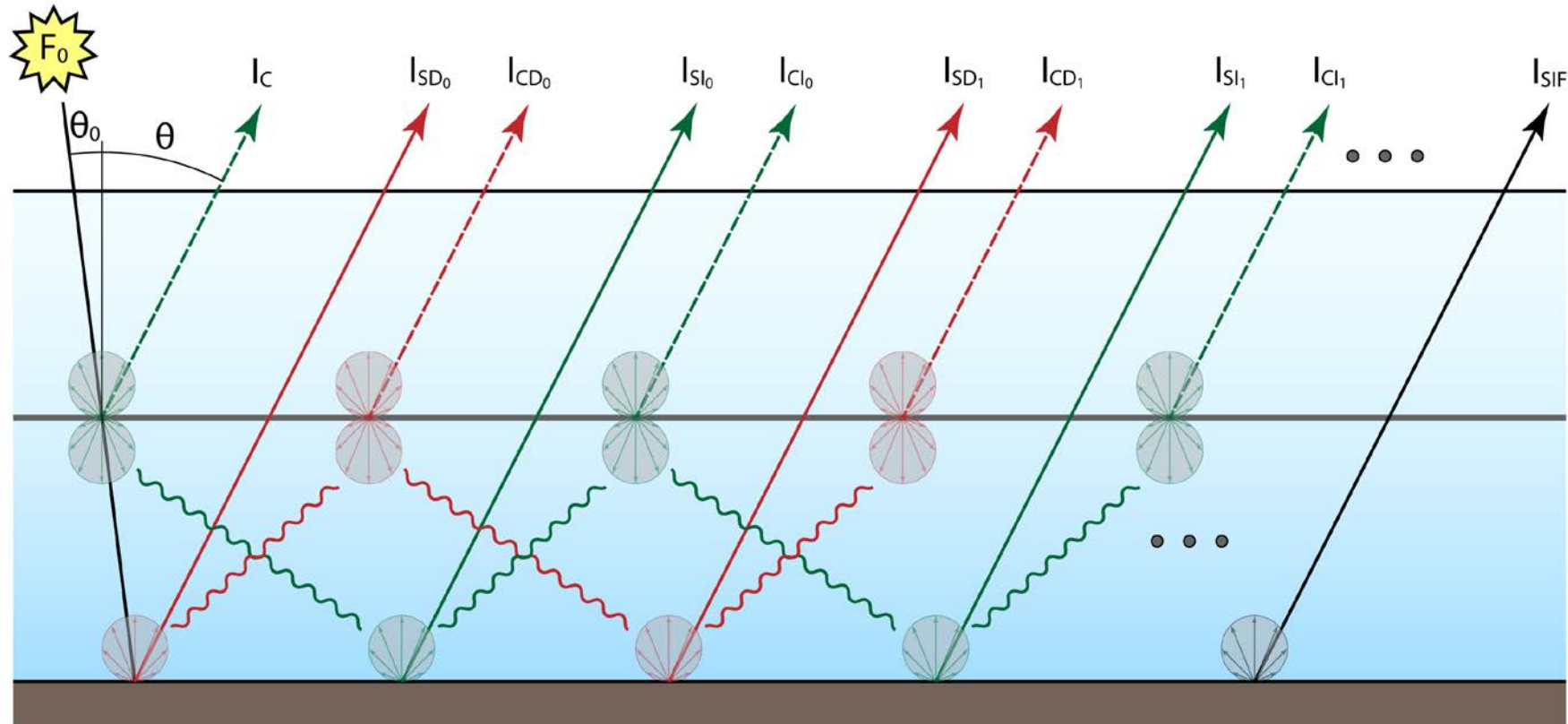
## v10

- The v10 a priori bases on a 16-year CT climatology corrected for the annual growth.
- More realistic XCO<sub>2</sub> and profile shape (especially in the stratosphere).
- No negative correlations.
- $\sigma\Delta XCO_2 = 0.58\text{ppm}$  (1.00ppm for SECM)
- $\sigma\Delta CO_2_{\text{strat}} = 0.49\text{ppm}$  (1.84ppm for SECM)



# Radiative transfer v09

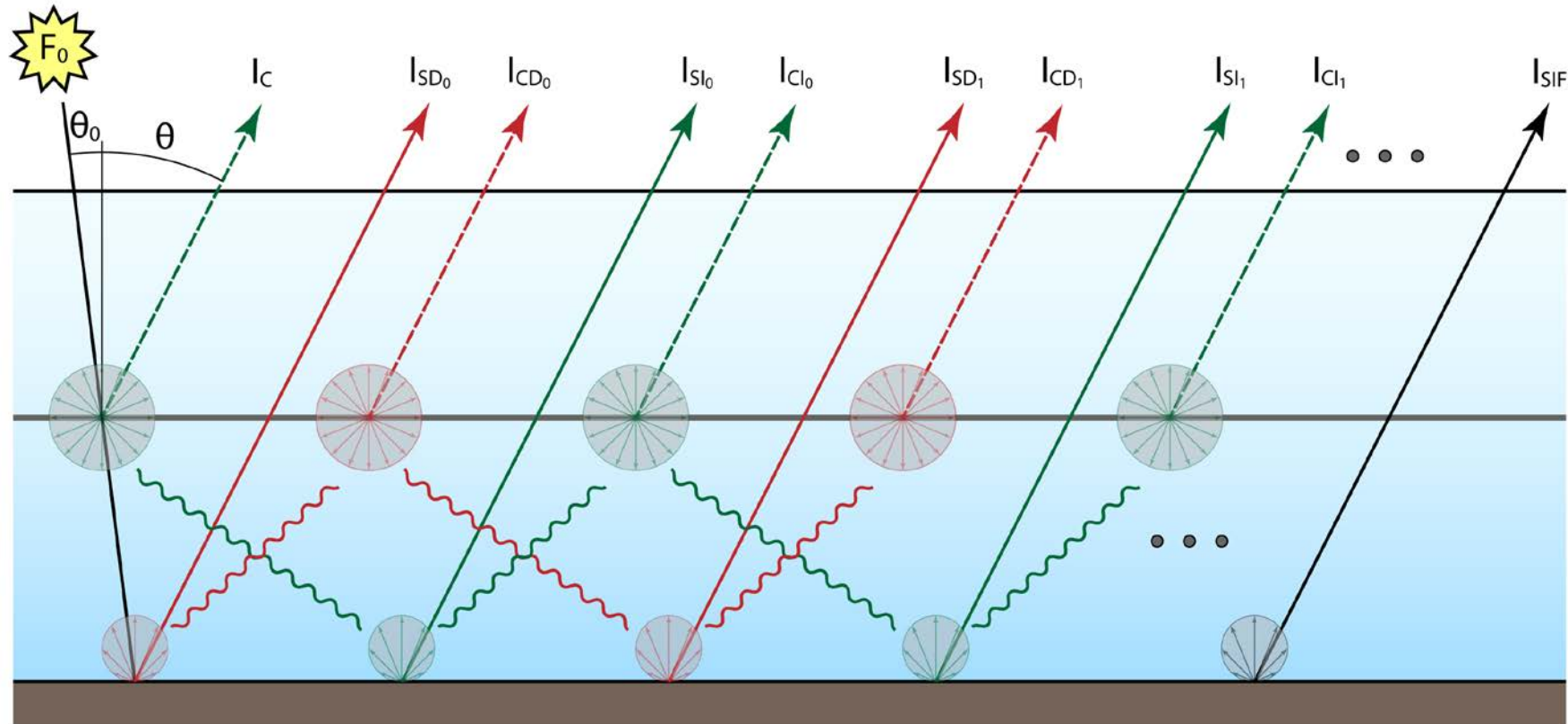
- FOCAL v09 approximates scattering to occur only at one optically thin scattering layer.
- Scattering at the surface and the scattering layer is assumed to be Lambertian.
- The observed radiance is split into direct and diffuse parts.
- The transmission of the diffuse flux can be computed by  $2E3(\tau)$ .
- Multiple scattering of the diffuse flux can be expressed by a geometric series.





# Radiative transfer v10

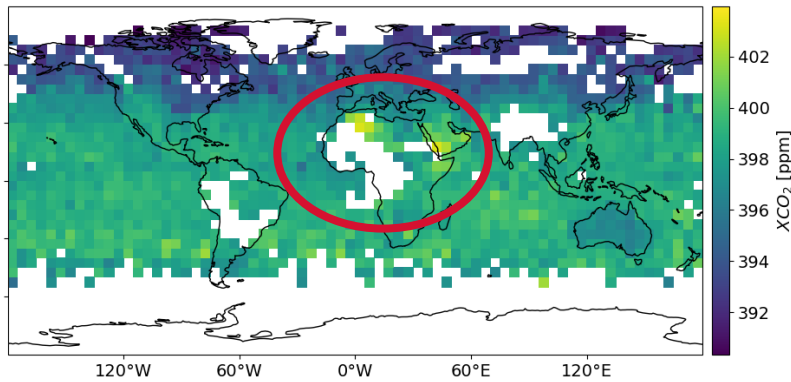
- FOCAL v10 assumes isotropic scattering at the scattering layer which is more realistic for an optically thin layer.
- The transmission of the downward flux becomes  $E_2(\tau)$  and the geometric series change accordingly.



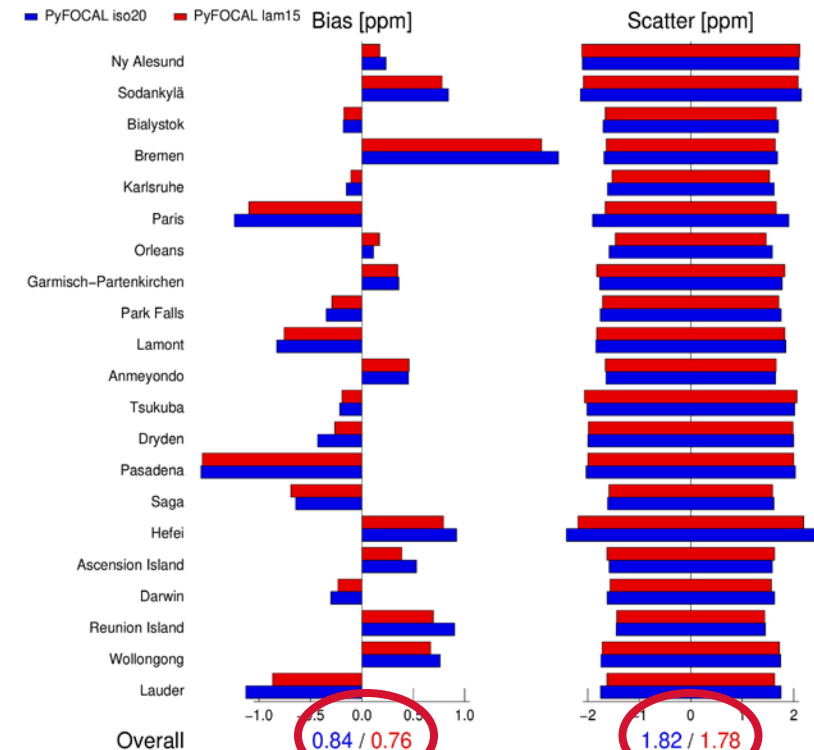
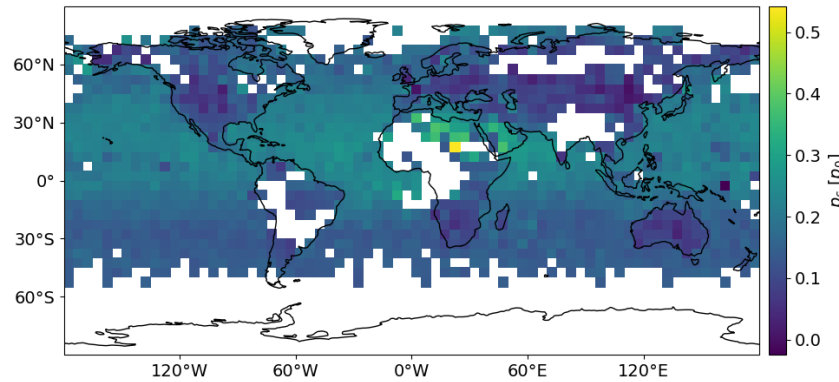
# Radiative transfer v10 vs. v09

- Overall similar XCO<sub>2</sub> results.
- More realistic XCO<sub>2</sub> values above the Saharan desert in some months due to changes in the retrieved scattering properties (especially, pressure of the scattering layer).
- 5-10% more converging soundings; fewer iterations needed.
- Slightly degraded agreement of rudimentary bias corrected XCO<sub>2</sub> with TCCON (likely not significant).

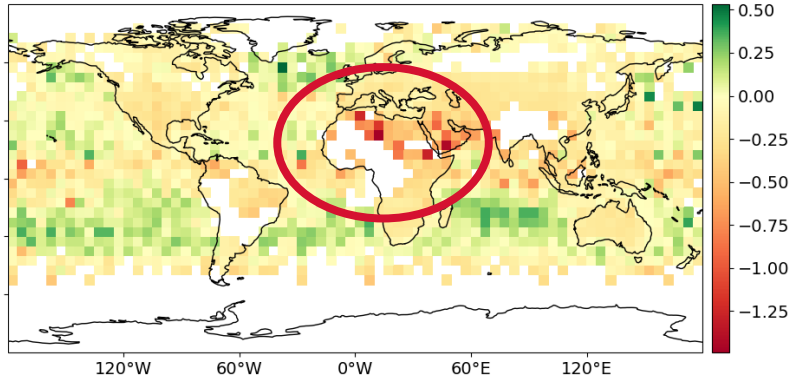
XCO<sub>2</sub> – Isotropic scattering



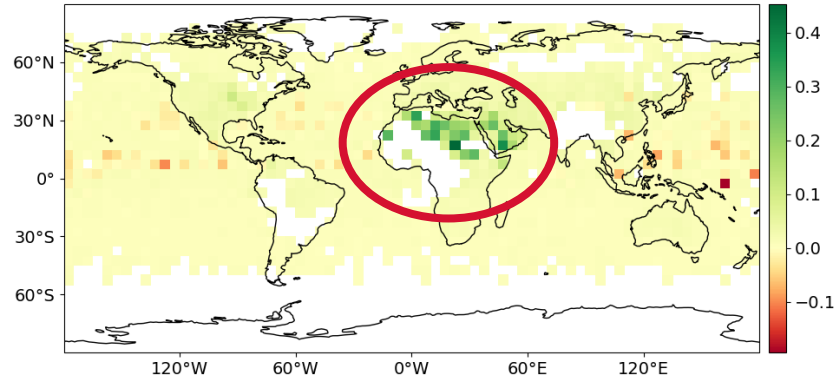
Pressure of scattering layer – Isotropic scattering



XCO<sub>2</sub> – Difference to Lambertian scattering



Pressure of scattering layer – Difference to Lambertian scattering





# Summary

- New pre-processor has about 3.7 times larger filtering throughput.
- Improved handling of spectral spikes.
- More realistic CO<sub>2</sub> a priori.
- Modified RT resulting in better convergence behavior and more realistic values above Sahara.
- Applying the filtering strategy of v09, v10 has about 2.7 time more soundings.

## Next steps

- L2 Processing.
- Adaptation of filtering and bias correction according to Noël et al.
- Validation, documentation, and release of v10 data set.



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# Acknowledgements

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