Considerations for atmospheric correction of hyperspectral measurements: The FLEX perspective

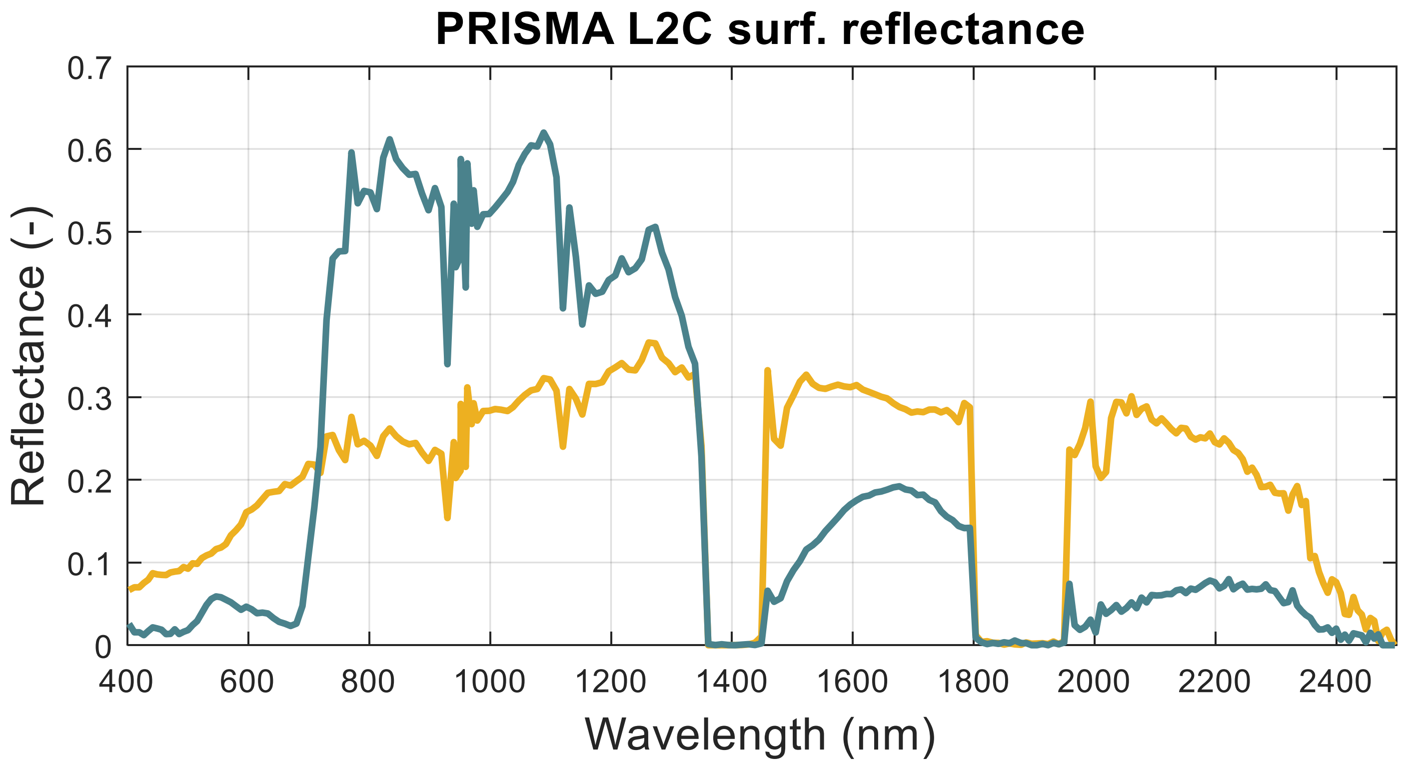
Jorge Vicent Servera, N. Sabater, P. Kolmonen, G. Matot, J. Verrelst, M. Drusch and J. Moreno

jorge.vicent-servera@magellium.fr earthobservation.magellium.com

CHALLENGES OF HYPERSPECTRAL ATMOSPHERIC CORRECTION

Introduction

- Hyperspectral high resolution measurements are affected by a continuous of gaseous features (H2O, O2, CO2) with coupled absorption and scattering effects
- An accurate modelling of the at-sensor signal is key for the inversion of reflectance
- Goal: sharing the FLEX perspective to the hyperspectral community



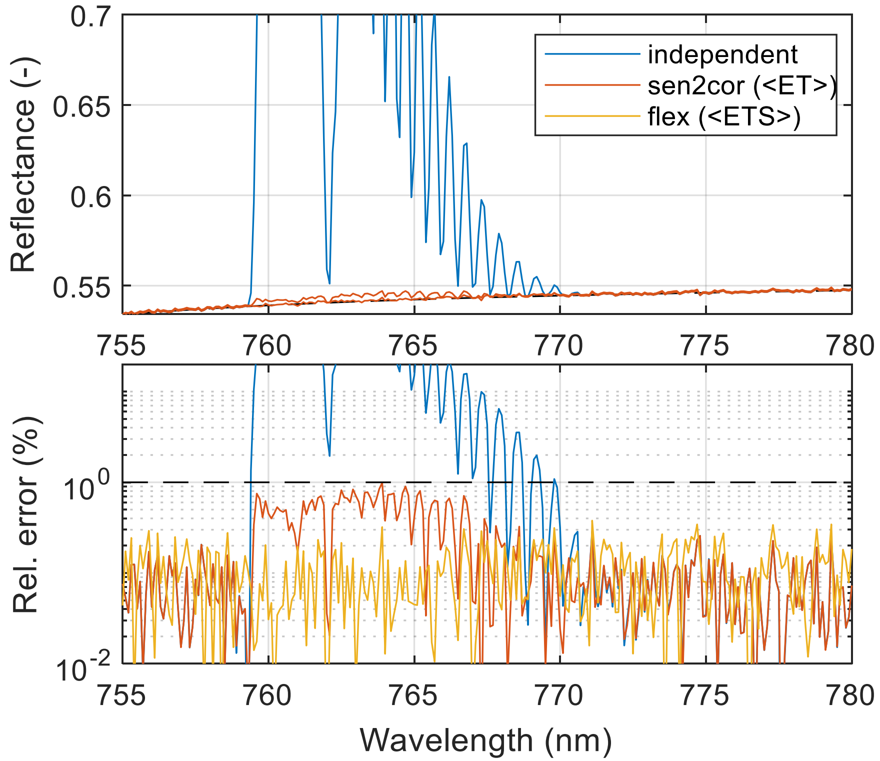
Some issues to account for

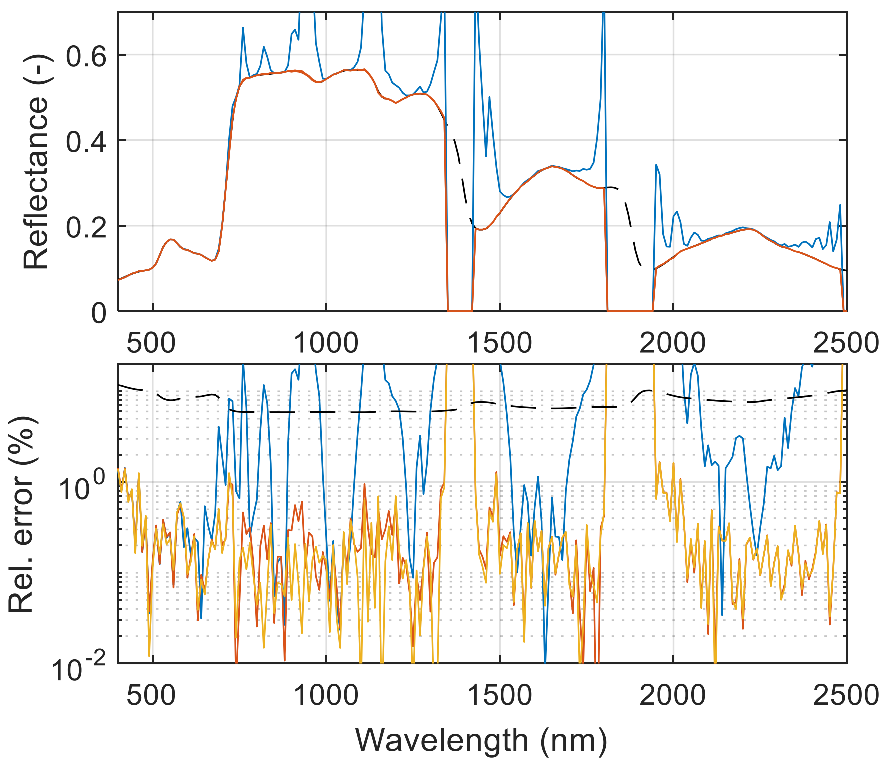
- Spectral: calibration errors, smile, instrument response, convolution…
- Atmospheric profile
- Aerosol model (opt. properties)
- LUT size and interpolation

SPECTRAL EFFECTS: CONVOLUTION, SPECTRAL CALIBRATION & ISRF

- Integration of continuous energy weighted by the spectral response (ISRF)
    - Multispectral: typically convolve each transfer function with the nominal spectral response
    - Hyperspectral: this does not takes into account the effect caused by the high frequency in absorption regions

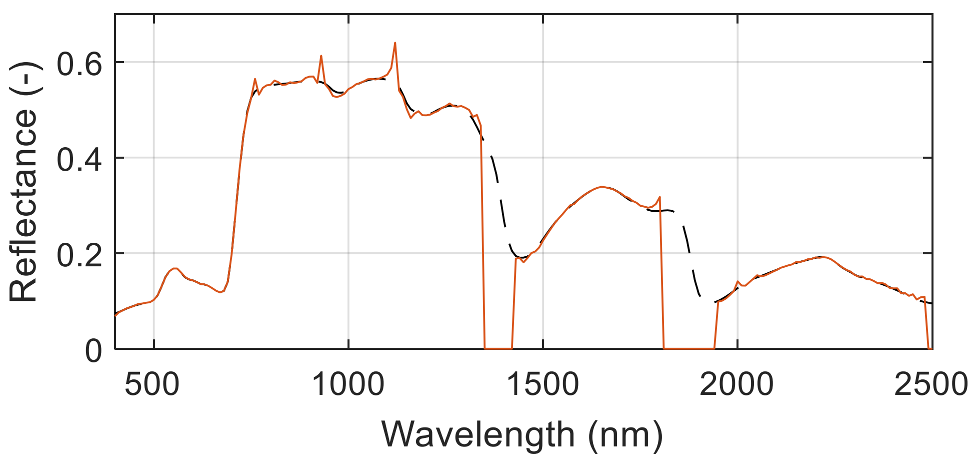
$$L = \langle L_0 \rangle + \left\langle \frac{ET\rho}{\pi(1 - S\rho)} \right\rangle \neq \langle L_0 \rangle + \frac{\langle E \rangle \langle T \rangle \rho}{\pi(1 - \langle S \rangle \rho)}$$

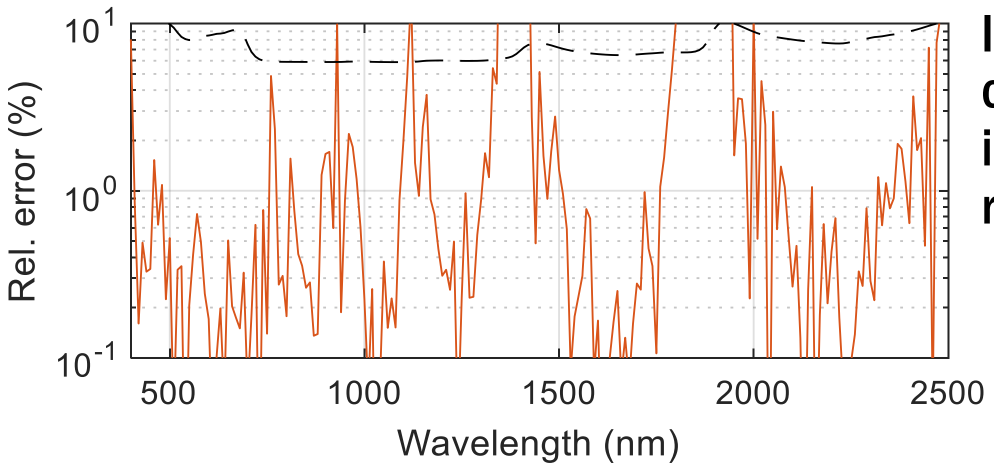




SPECTRAL EFFECTS: CONVOLUTION, SPECTRAL CALIBRATION & ISRF

- **Spectral calibration errors** and ISRF knowledge on atmospheric correction
  - Transfer functions convolved at the nominal ISRF, i.e. fixing barycenter and shape of ISRF
  - Effects of smile, L1B spectral calibration errors and ISRF characterization amplified in hyperspectral data if not taken into account





Impact of spectral cal. error (0.05 SSI) in inverted surface reflectance

- FLEX L2 performs a vicarious spectral adjustment to reduce errors in atm. correction
  - Smile explicitly taken into account by convolution of hires transfer functions on the loop

➔ L2 atmospheric correction in **focal plane geometry** instead of orthorectified product

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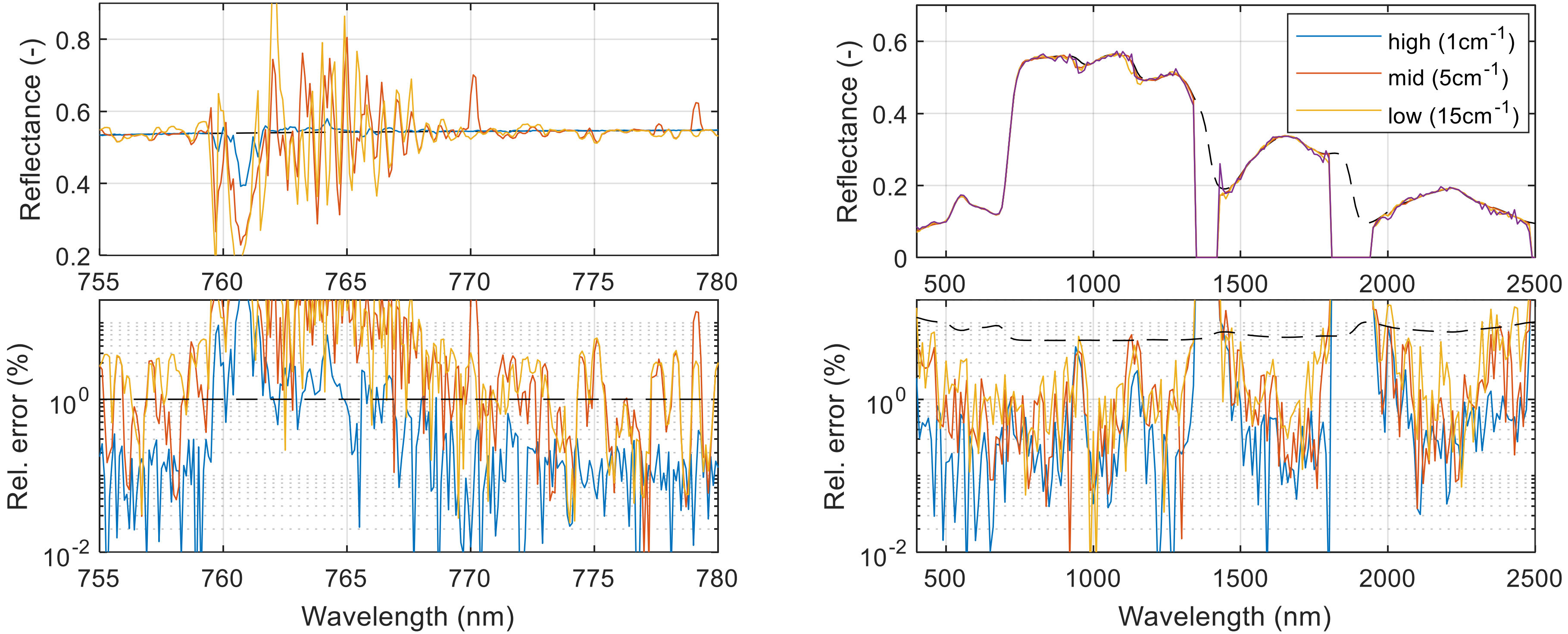
SPECTRAL EFFECTS: CONVOLUTION, SPECTRAL CALIBRATION & ISRF

- **Spectral sampling** of RTM simulations (for atmospheric LUTs)
  - Spectrally-resolved simulations at pseudo-bands of integrated energy (correlated-k, reptran…)
  - Lower sampling ➔ missing spectral information ➔ errors in surface reflectance

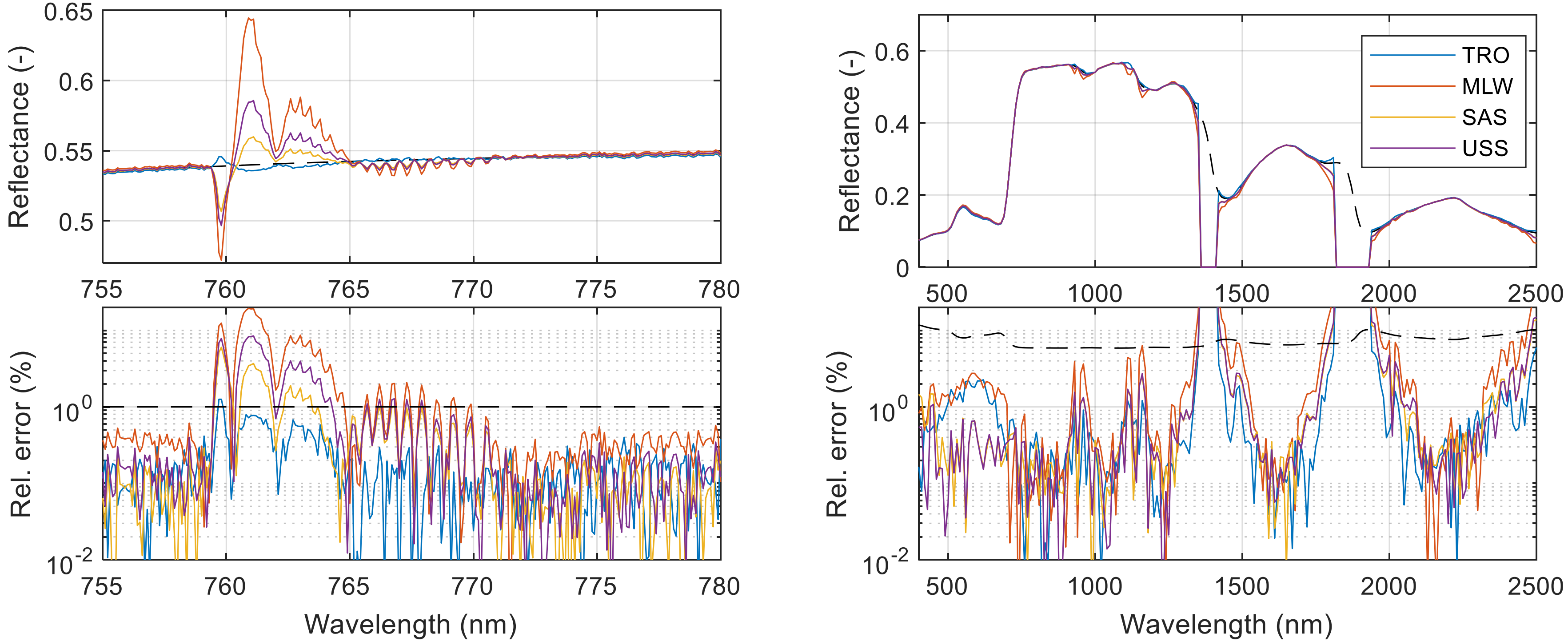


Forward simulation at 0.1 cm-1 and inversion with coarser resolutions

- **FLEX: sensitivity analysis to identify the optimal sampling in RTM simulations balancing accuracy vs data volume**

ATMOSPHERIC EFFECTS: ATM. PROFILE, AEROSOL TYPE

- **Atmospheric vertical profile**
  - Vertical pressure profile affects depth of absorption and molecular scattering
  - E.g. in Sentinel-2 Level-2A processor only MLS and MLW are used



Forward simulation w/ MLS and inversion with other standard profiles

- In FLEX surface pressure is critical for accurate simulation of the O2 band
- For broadband instruments, probably N>2 profiles would be sufficient (TBC)

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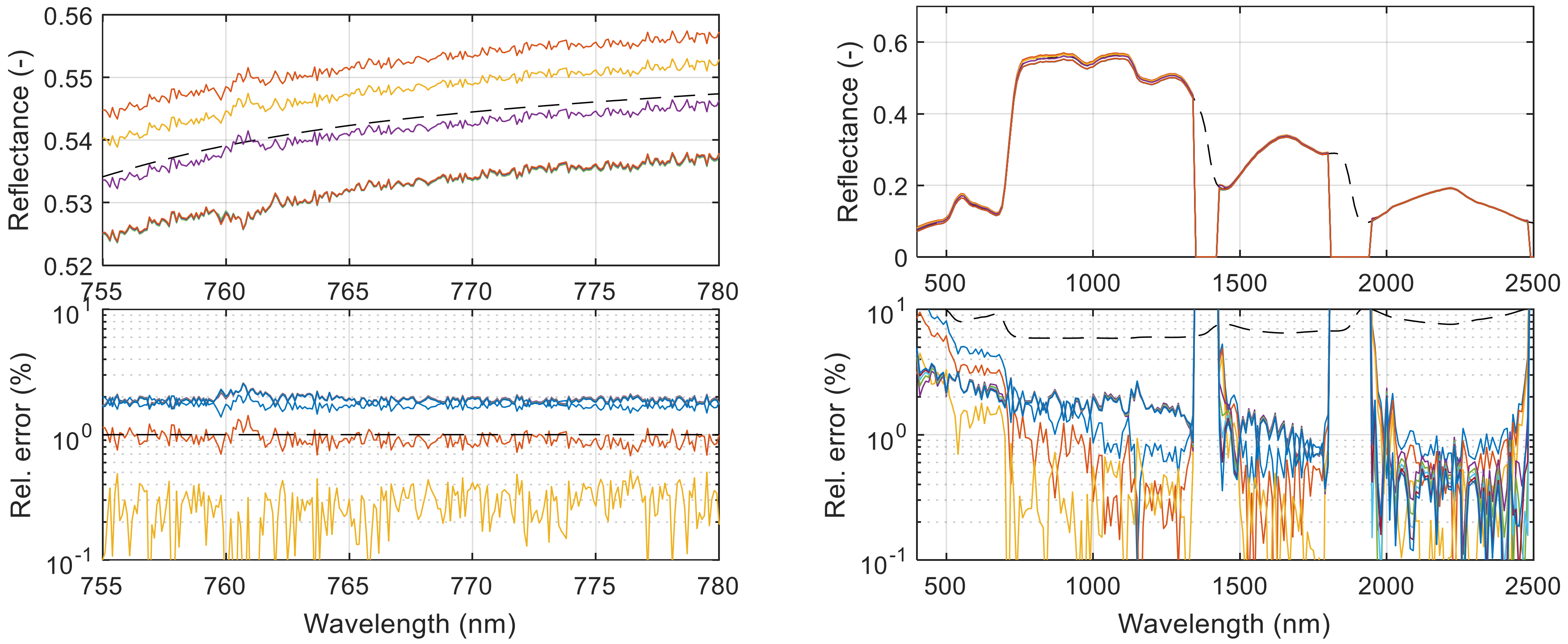
- Modelling aerosol scattering and absorption
  - Aerosol *type* typically considered a variable to define aerosol scattering and absorption
  - Interpolation between types is commonly not implemented to add higher aerosol variability



Forward simulation w/ 8 "continental" aerosol types and inversion with standard "rural" aerosol

- FLEX: we directly use aerosol opt. properties as free parameters instead of fixed aerosol types

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CURRENT CHALLENGES IN FLEX PROCESSING

- FLORIS spectral response ➔ impact in surface reflectance and SIF retrieval
- Aerosol asymmetry ➔ use of climatology to constrain aerosol retrieval
- Compensation of radiometric effects due to vertical profile (real vs "standard" profiles)
- Sensitivity of SIF retrieval to errors in atmospheric correction
- Atmospheric LUT size: computation time, handling data volume

FLORIS				
	Variable	N grid points	Values	Units
ATM	MODEL	5	MLS, MLW, SAS, SAW, Tropical	-
AER	AOD	7	0.03, 0.05, 0.15, 0.25, 0.36, 0.48, 0.60	-
	α	2	0.02, 2	-
	SSA	2	0.8, 1	-
	ASY(g)	2	0.55, 0.8	-
GAS	H_2O	6	0.50, 1.12, 1.90, 2.83, 3.91, and 5.00	g/cm^2
	O_3	2	0.17, 0.38	atm-cm
GEO	Elevation	5	0, 0.72, 1.55, 2.38, 3.00	Km
	VZA	2	0,6	deg
	SZA	12	20.00 , 29.47, 38.95, 51.58, 57.90, 61.05, 64.21, 67.37, 70.53, 73.68, 76.84, and 80.00	deg
	RAA	4	0, 40, 140, 180	deg

Reduced LUT (L2RM v3.3)

- 60'500 points (out of 3.6 million)
- 3 min/simu. (12 cores) ➔ Total time: 2 weeks
- File size (single precision) ➔ 70 Gb

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DISCUSSION

Analysis of the results

- FLEX: various strategies are being implemented to achieve the stringent mission requirements (1% error in reflectance) in the O2 bands (for SIF retrieval)
- For broadband instruments these effects are likely less critical but considering them might improve accuracy

Error source	Impact in refl. (CHIME)
Convolution	~0.1%
Spectral calibration	Up to 5-10%
RTM sampling	Up to 1% (w/ 1cm-1)
Atmospheric profile	Up to 1-5%
Aerosol type	10% (at 400nm)

Some considerations

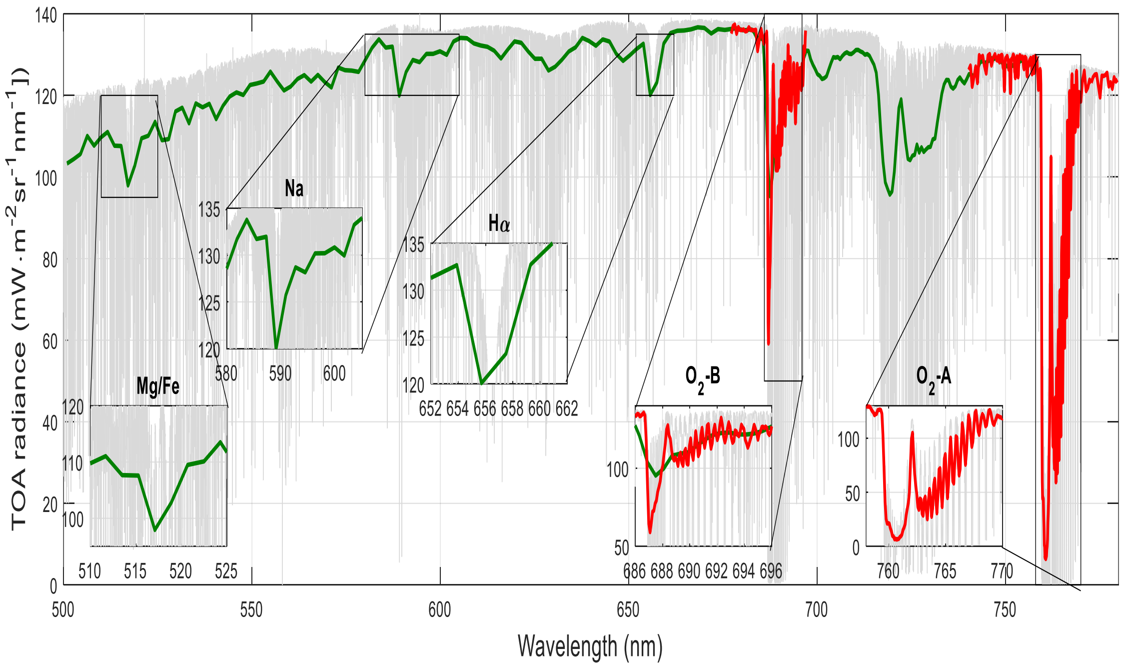
- Atmospheric correction in focal plane
  - For vicarious spectral adjustment
  - Smooth surf. Reflectance → orthorect.
- LUTs in native RTM resolution
  - Explicitly accounting for spectral calibration
- RTM sampling & LUT data volume
- Check impact of atm. profile
- Aerosol type vs opt. properties
- LUT size: consider emulation as alternative!

BACK-UP SLIDES

Overview of ESA's FLEX Earth Explorer mission

- **Mission objective:** to estimate actual photosynthesis rate and early stress indicators from measuring vegetation SIF from space
- **Processing chain:** merging FLEX and S3 data in FLORIS focal plane geometry, atmospheric correction, decoupling of SIF from reflected signal, biophysical parameters retrieval and photosynthesis

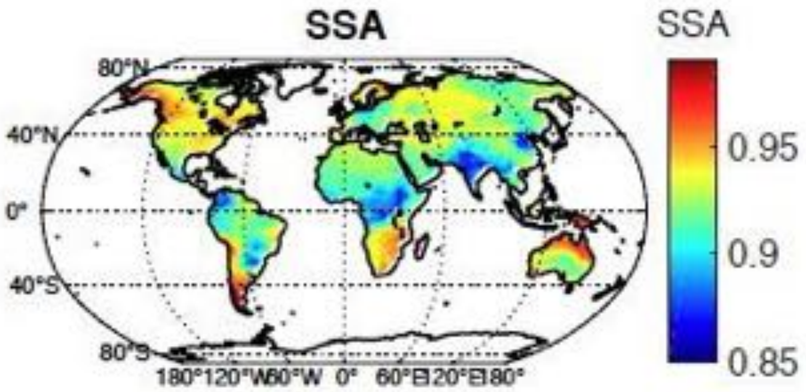
Feature	FLEX	CHIME
Spectral range	500-780 nm	400-2500 nm
Spectral res. and sampling	• ≤3 nm (0.3 nm in O2) • ≤2 nm (0.1 nm in O2)	≤10 nm
SNR	115 (NIR) up to 1015 (in O2A)	250-500 (up to 2200 for water)
Spatial res.	300 m	≤30 m
Orbit	Sun-synchronous (10:30-11:30h LTDN)	

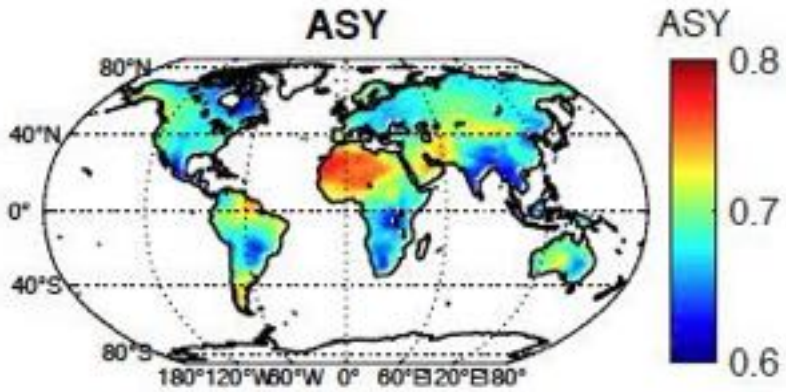


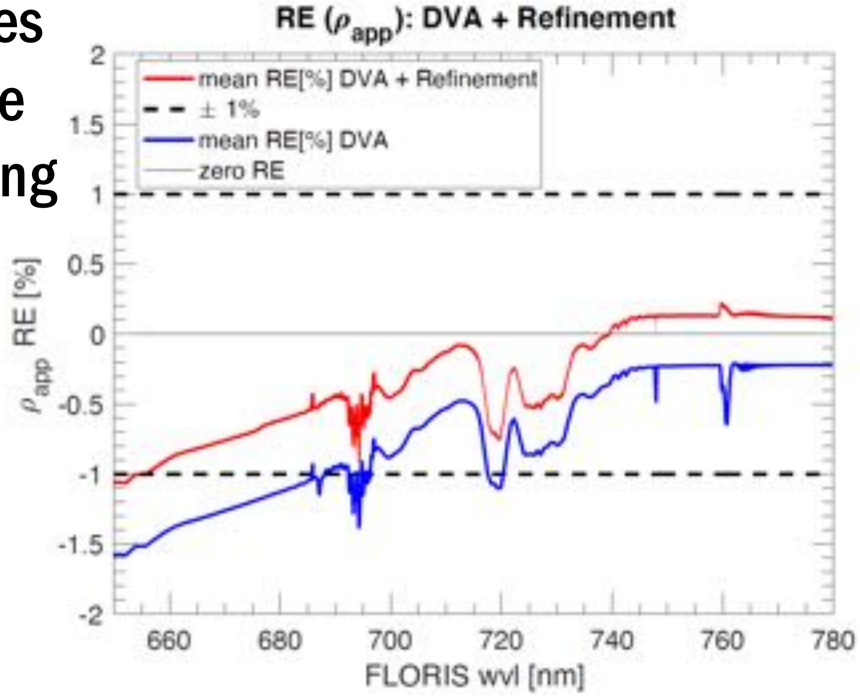
BACKGROUND: THE FLEX MISSION

Overview of FLEX atmospheric correction

- Water vapor: based on APDA differential absorption on OLCI radiance data
- Aerosol optical properties
  1. SLSTR dual-viewing algorithm (DVA):
     - $\rho_{(Ob)} = k\rho_{(N)}$ where k is assumed spectrally constant and retrieved from SWIR channels
  2. Refinement using FLORIS data at O2A band
     - Shape of O2A absorption sensitive to aerosol opt. properties
     - Difference measured and simulated (w/ DVA results) radiance allows disentangling SIF contribution from aerosol scattering
     - Use of climatology to constrain retrieval



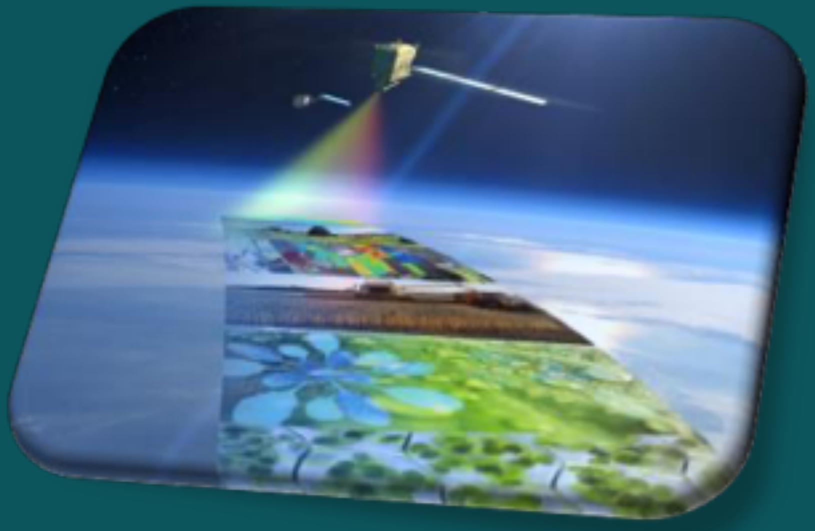




ATMOSPHERIC LUT SIZE & INTERPOLATION

- LUT size (in 10^6 points): 0.6 (sen2cor), 1.3 (S3 SYN), 3.6 (FLEX)
  - Full resolution: 180 Gb for $1.8 \cdot 10^6$ points (float)
  - CHIME resolution (~200 bands): 8 Gb
- Run time (400-2500 nm @5cm^{-1}): ~1.5 min/simulation
  - Total run time: 120 days ($1.8 \cdot 10^6$ points in 16 cores)
- Total LUT
- Atmospheric LUT size: computation time, handling data volume

Thank you for your attention.



earthobservation.magellium.com

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