

# CO2M CLIM & MAP synthetic test data RfQ

Final Review – July 29<sup>th</sup> 2025

Mathieu Compiègne (HYGEOS) on behalf the team

HYGEOS, Lille

ICARE data center, Lille

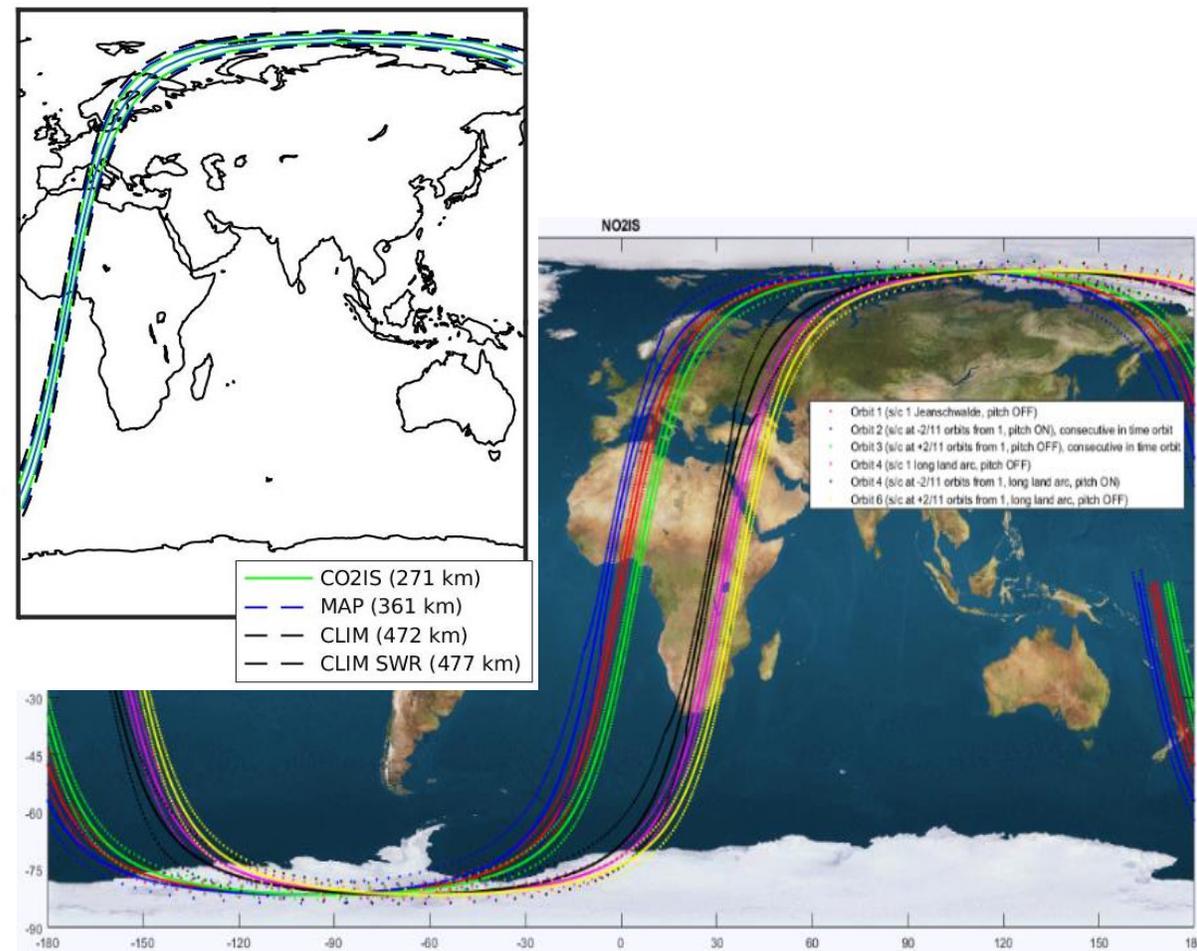
# Context of the study

- Follow on study on production of MAP and CLIM to support preparation of CO2M ground segment
  - *Update MAP and CLIM instrument design*
  - *Modification in scene description*
    - *correction of errors in previous dataset*
    - *improvement of scene description*
- Main constraints for the test data production
  - Being consistent with the design and purpose of the CO2M mission
  - Being consistent with CO2IS synthetic test data produced through a separate study (conducted by Rutherford Appelton Laboratory)



# Study overview

- Production of 6 half orbits (day side only)
  - 2 orbits in sunglint mode (pitched) and 4 orbits in nominal mode (nadir)
- L1 MAP and CLIM files provided by EUMETSAT
  - Including pixel footprint/geolocation, geometries, LSM and DEM
  - Starting point to set scene scenario for each pixel (no spatial distribution function)
  - To be populated with computed radiance
- Ancillary data mostly provided by RAL
  - Consistency with CO2IS synthetic test data
  - Atmosphere / surface global state to set the pixel scene scenario



#	Orbit name	Date	Location	Acquisition Mode
1	EUwest	3 <sup>rd</sup> July 2015	Western Europe	Sunglint (pitch)
2	EUcent	3 <sup>rd</sup> July 2015	Central Europ	Nominal (nadir)
3	EUeast	3 <sup>rd</sup> July 2015	Eastern Europe	Nominal (nadir)
4	SAcent	23 <sup>rd</sup> Sep 2015	South Africa	Nominal (nadir)
5	SAwest	23 <sup>rd</sup> Sep 2015	Western Asia	Sunglint (pitch)
6	SAeast	23 <sup>rd</sup> Sep 2015	Eastern Asia	Nominal (nadir)

# Study overview (II)

- TOA radiance for the 6 half-orbits
  - I, Q and U Stokes parameters for MAP and CLIM (Polder convention for the polarization)
  - around 15 L1B files (granule) per orbit per instrument
  - around 15 MAP L1C files per orbit
- All produced with 2 assumptions
  - “natural” scene
  - “clear sky hypothesis” scene

#	Channel centre Wavelength (nm)	Channel Spectral Width (nm)	DoLP
MAP-1	410	20	Y
MAP-2	443	20	Y
MAP-3	490	20	Y
MAP-4	555	20	Y
MAP-5	670	20	Y
MAP-6	753	9	N
MAP-7	865	40	Y

#	Channel centre Wavelength (nm)	Channel Spectral Width (nm)
CLIM-1	670	20
CLIM-2	753	9
CLIM-3	1370	15

# Team

- An industry / academic consortium based in Lille, France
- Already associated for multiple EUMETSAT studies
  - Synthetic radiance production : 3MI, METimage, MTG-FCI, MTG-IRS, MAP & CLIM
- Responsibilities
  - HYGEOs is responsible for all aspects of the project (subcontracting ...)
  - Mathieu Compiègne lead/manage the overall technical project
- **HYGEOs** (Mathieu Compiègne, Bruno Monsteerlet)
  - Administrative tasks (Sylvia Jacob)
  - Simulator development and running
  - Radiance post-processing and delivery
  - Reporting
  - Project outreach
- **ICARE** (Sylvain Neut)
  - CPU resources (including expertise in HPC)
  - Simulator running
  - Product feedback

# Work Package & schedule

- Task 0 : Management
- Task 1 : Setup of the radiative transfer model and input data
- Task 2 : Production of the MAP and CLIM test data
- Task 3 : Project outreach

	Effort (Hrs)			Total
	Mathieu C (Senior Scientist)	Bruno M (Software engineer)	Sylvain Neut (Software Engineer)	
<b>Management (WP0)</b>	7	0	0	7
<b>Task 1 (WP1)</b>	26	26	0	52
<b>Task 2 (WP2)</b>	93	99	108	300
<b>Task 3 (WP3)</b>	14	0	0	14
<b>TOTAL</b>	140	125	108	373
workloadover project	15,27 %	13,63 %	11,78 %	

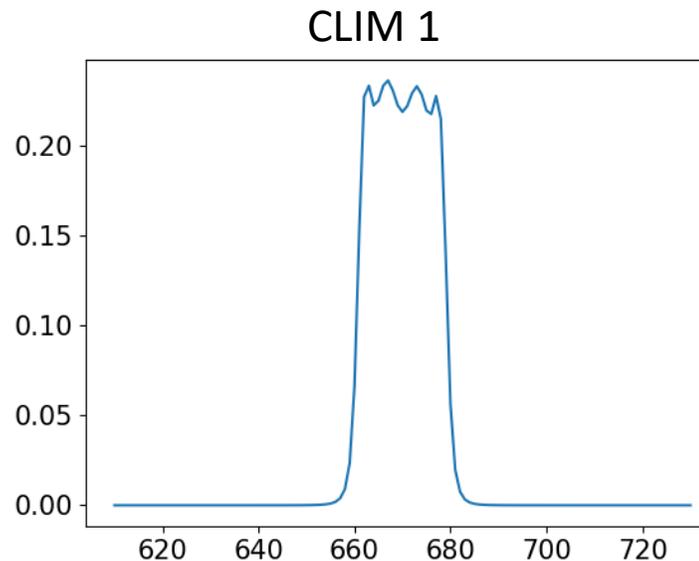
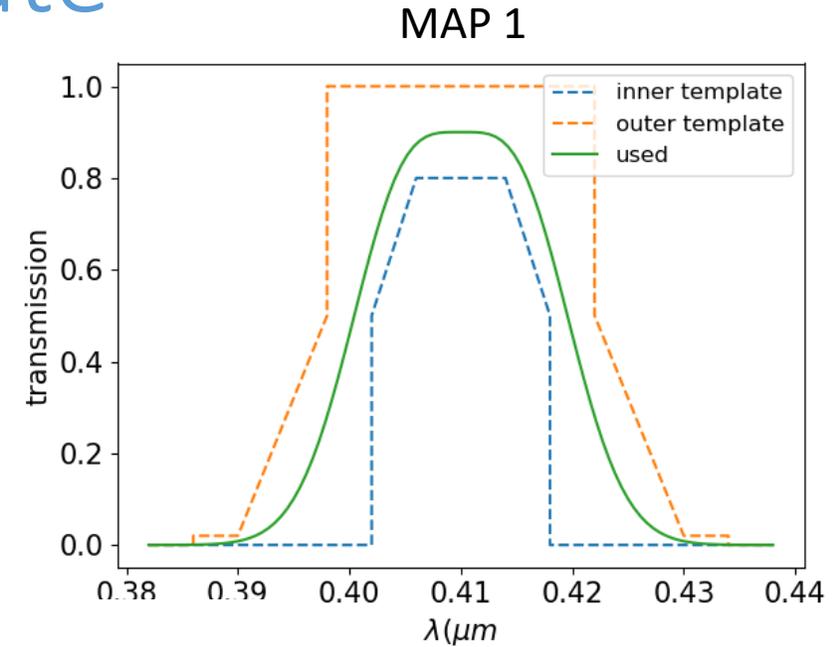
Schedule	M1 Jun-24	M2 Jul-24	M3 Aug-24	M4 Sep-24	M5 Oct-24	M6 Nov-24	M7 Dec-24
WP0	[Blue bar]						
WP1	[Blue bar]		[White bar]				
WP2	[White bar]	[Blue bar]					
WP3	[Blue bar]						
<b>Meetings</b>							
Proposed location	MidTerm (Online)					Final Review (online)	
<b>Main Deliverables</b>							
	Task 1 report Preliminary ancillary data Preliminary test data					Task 2 report Full ancillary Full test data	

# Update MAP and CLIM instrument design

- CLIM :
  - Spectral Response Function update
  - LoS modification (LOS angles for SWIR A/C swapped)
    - No impact on production strategy
- MAP :
  - No Spectral Response Function update
  - Channel dependant footprint / grid
    - L1B scene description files x 7
    - Slightly adapted production scripting
    - but no impact on CPU demand for L1B radiance computation
    - No impact at L1C level

# Spectral response function update

- MAP SRFs unchanged
  - modelled as two gaussian
- CLIM SRFs updated with actual values
  - Update incoming solar flux
    - $$F_0 = \frac{\int F_{0,\lambda} SRF d\lambda}{\int SRF d\lambda}$$
  - Update SIF
  - Update K-distribution coefficients
  - Update integrated cloud and aerosols optical properties



# The Organic Matter aerosol issue

	Optical properties	Extinction profile		CAM5 EAC4 AOD
		CAM5 EAC4 mass mxing	$r_{\text{eff}}$ ( $\mu\text{m}$ )	
Sea Salt	OPAC maritime clean ( $r_H=95\%$ )	Sea salt (0.03 - 0.5 $\mu\text{m}$ )	0.348	SSAOD550
		Sea salt (0.5 - 5 $\mu\text{m}$ )	1.722	
		Sea salt (5 - 20 $\mu\text{m}$ )	7.714	
Dust	Desert dust ( $r_H=50\%$ )	Dust (0.03 - 0.55 $\mu\text{m}$ )	0.374	DUAOD550
		Dust (0.55 - 0.9 $\mu\text{m}$ )	0.704	
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Black Carbon	OPAC continental average ( $r_H=50\%$ )	Hydrophilic black carbon	0.063	BCAOD550
		Hydrophobic black carbon		
Sulphate + Organic matter	OPAC urban ( $r_H=50\%$ )	Hydrophilic organic matter	0.191	OMADO550
		Hydrophobic organic matter		
		Sulphate	0.191	SUAOD550

# The Organic Matter aerosol issue

- In former dataset : an issue was found regarding aerosols class “Sulphate+Organic Matter”

- The profile  $\sigma_{ext550,SUOM}(z)$  is actually accounting for
  1. Hydrophilic organic matter aerosol + Hydrophobic organic matter aerosol
  2. Sulphate aerosol

- But it is normalized with SUAOD550 only

$$\sigma_{ext550,SUOM}(z) = \sigma_{ext,SUOM}(z) \frac{AOD_{SU550} + \cancel{AOD_{OM550}}}{\int \sigma_{ext,SUOM}(z) dz}$$

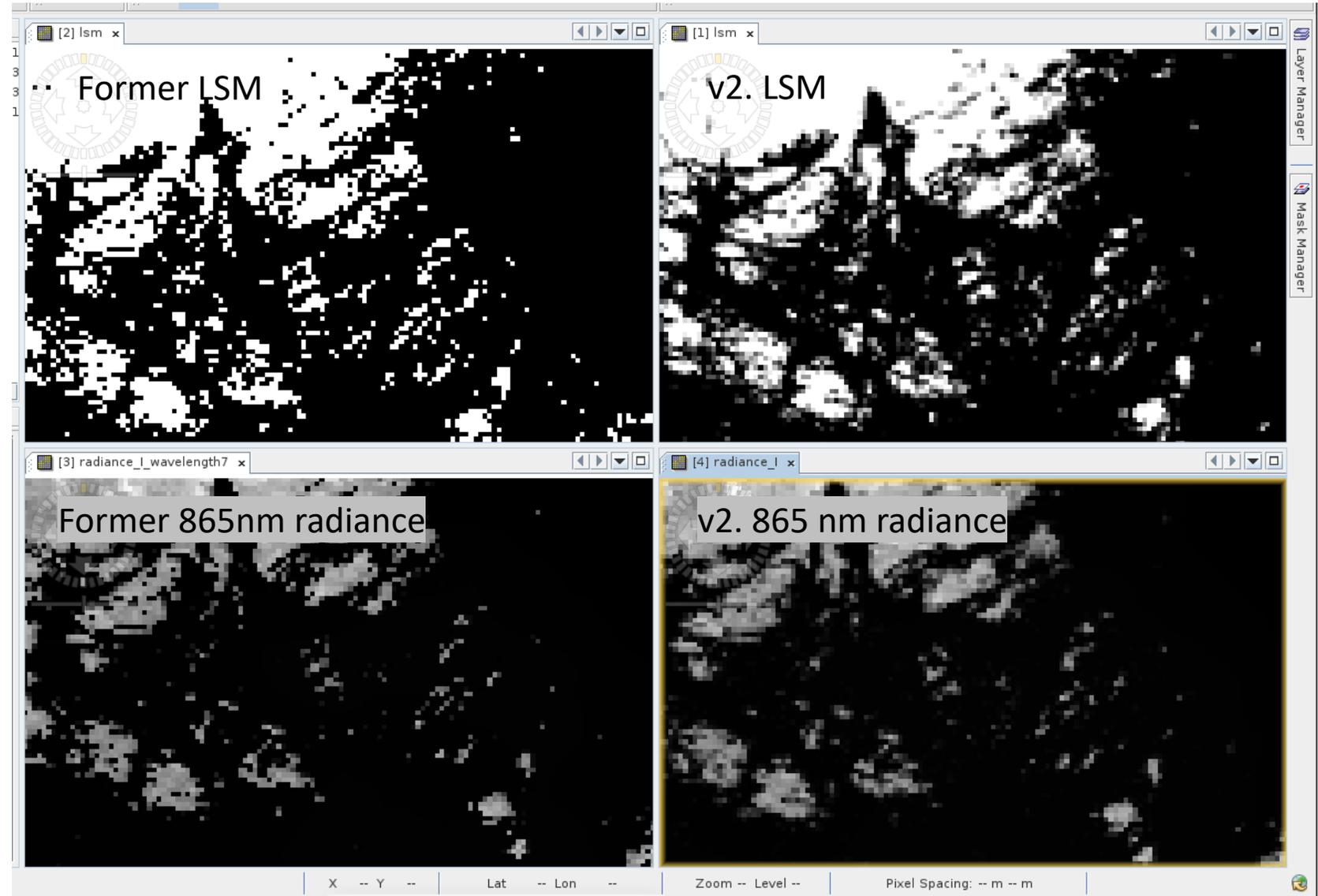
- Corrected in the present product (MAP, CLIM 1B and MAP1C)

# Surface definition update

- BRDF MCD43 parameters are the nearest wavelength but
  - the 670 forced on the 659 nm
  - the 753 forced on the 858.5 nm
- Surface selection rule and mixing ratio
  - LSM is fractional for MAP
  - LSM at CLIM native resolution is used
  - Fractional Sea Ice at pixel scale for MAP1B, MAP1C and CLIM 1B
  - The “snow depth” ancillary data is not used anymore

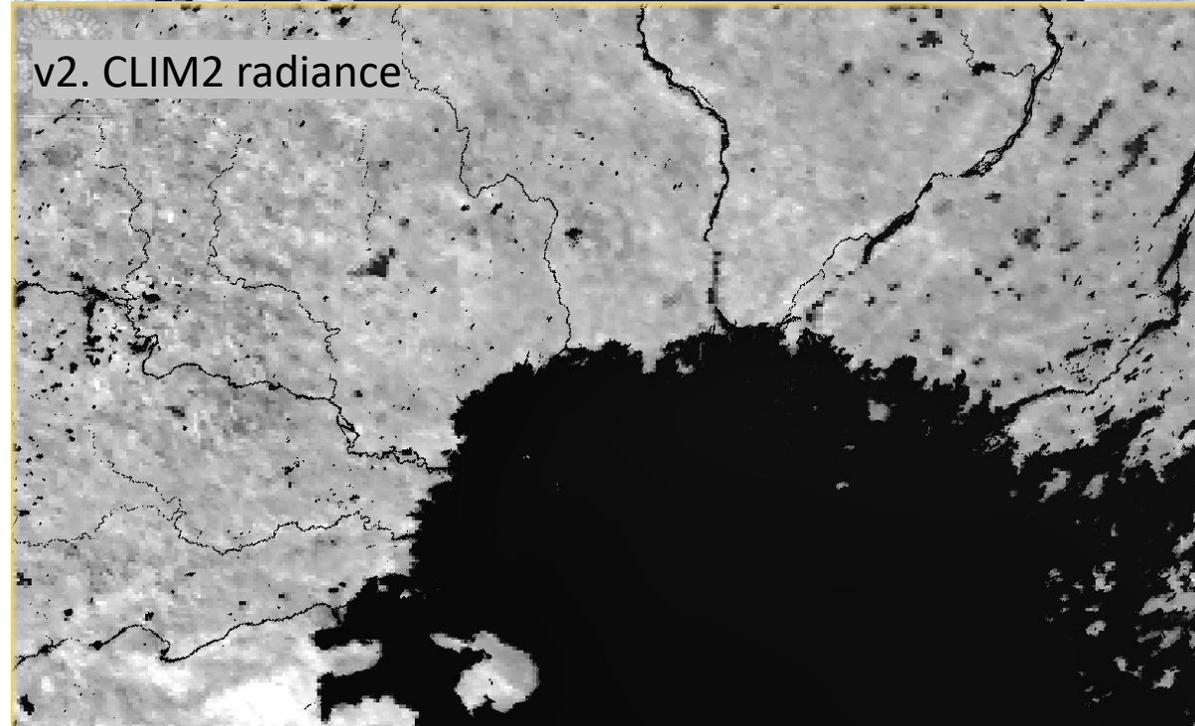
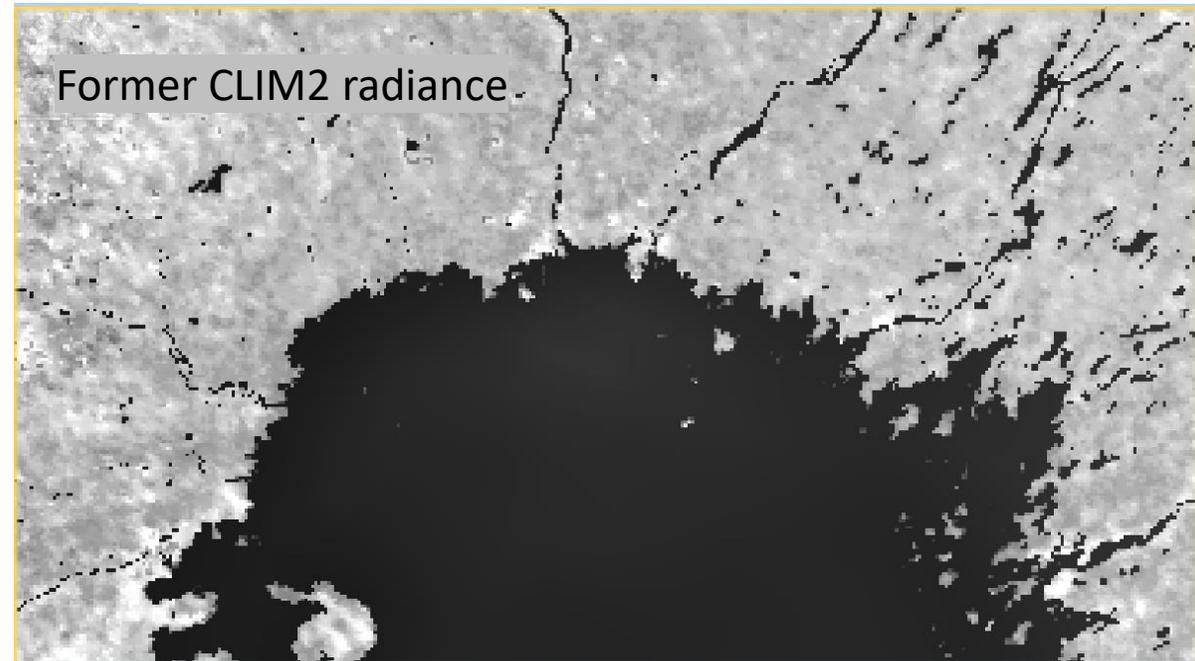
# LSM fraction in MAP

- MAP 1B and 1C pixels: fractionnal LSM provided
- For each pixel with  $0 < \text{LSM} < 1$  both water and land surface radiance are computed then linearly mixed up for resulting radiance



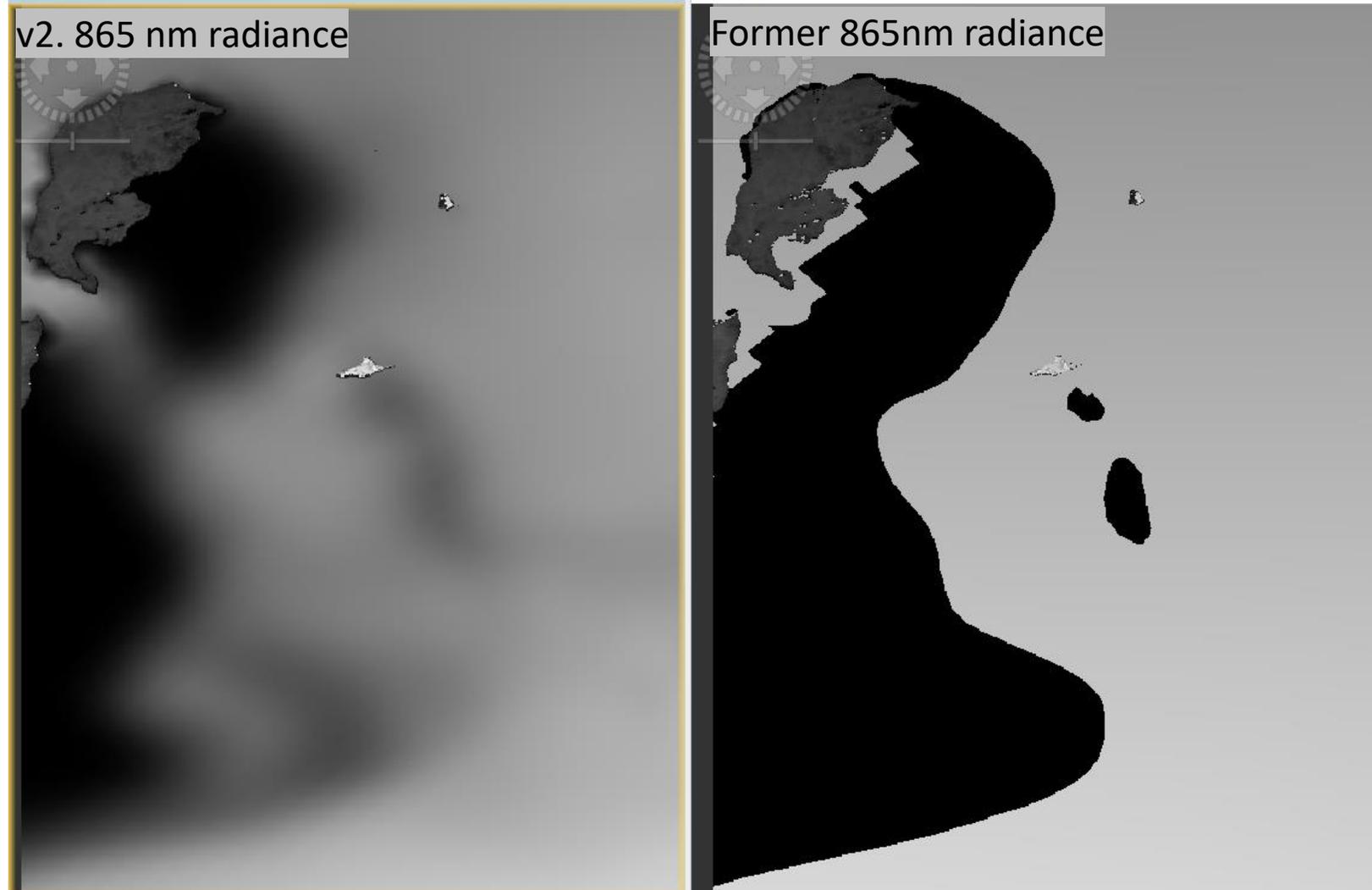
# LSM fraction in CLIM

- CLIM radiance computed in “super pixels” (only varying COT)
  - 7x7 native pixels for CLIM 1 and 2
  - 5x5 native pixels for CLIM 3
- Formerly
  - LSM was 0 or 1 at super pixel scale
- Now
  - For each super pixel with  $0 < \text{LSM} < 1$  both water and land surface are computed
  - Radiance at native scale is peaked up between LSM 0 or 1



# Sea ice fraction

- Snow depth ancillary not used anymore
- Formerly:
  - Either sea ice or water
- Now (both MAP and CLIM)
  - if Sea ice fraction  $> 0$ , computation of radiances for two surfaces (ice and water)
  - Radiance linearly mixed up for resulting radiance



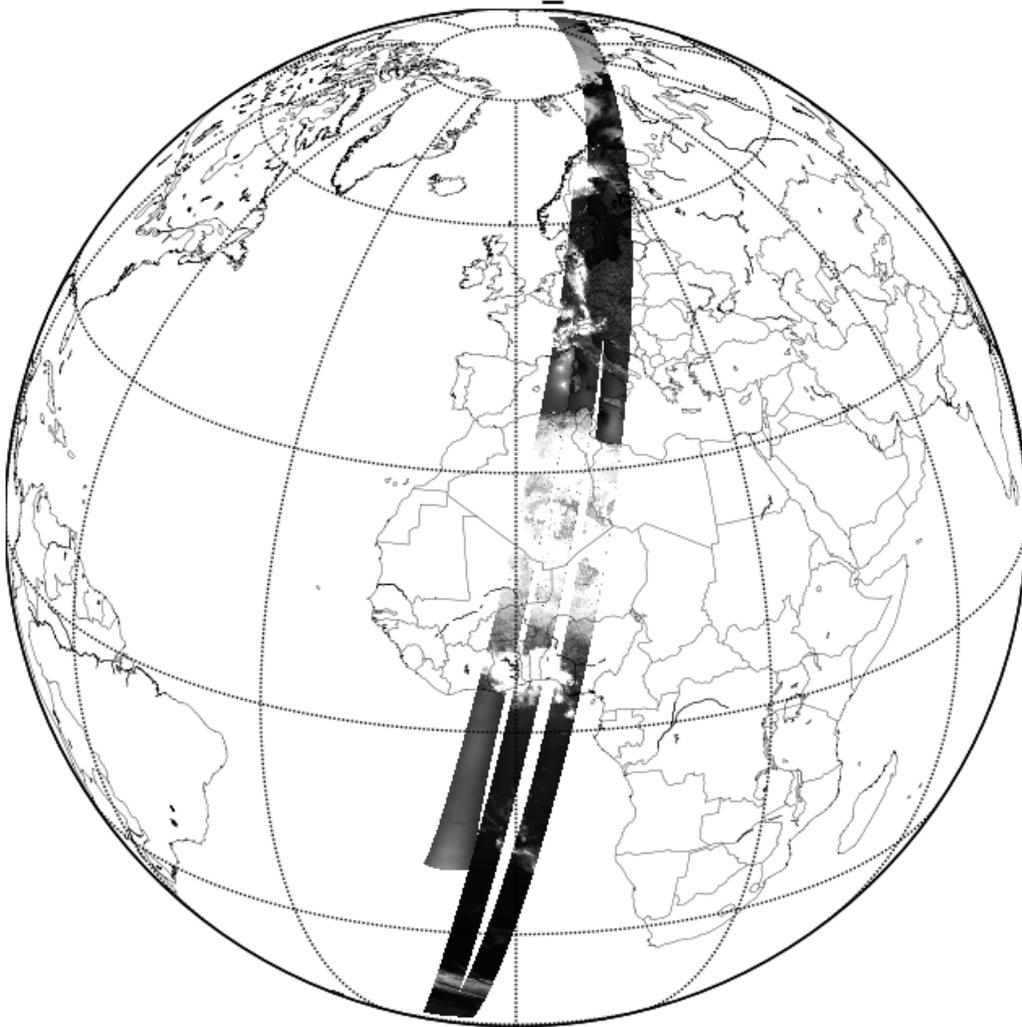
# CPU demand

- 1 680 000 cores-hours were allocated for the project
  - CLIM L1B : 5%, computed at HYGEOS
  - MAP L1B : 87 %, computed at ICARE
  - MAP L1C : 8% computed at HYGEOS
- Up to 1500 cores made available by ICARE while HYGEOS has 92 cores

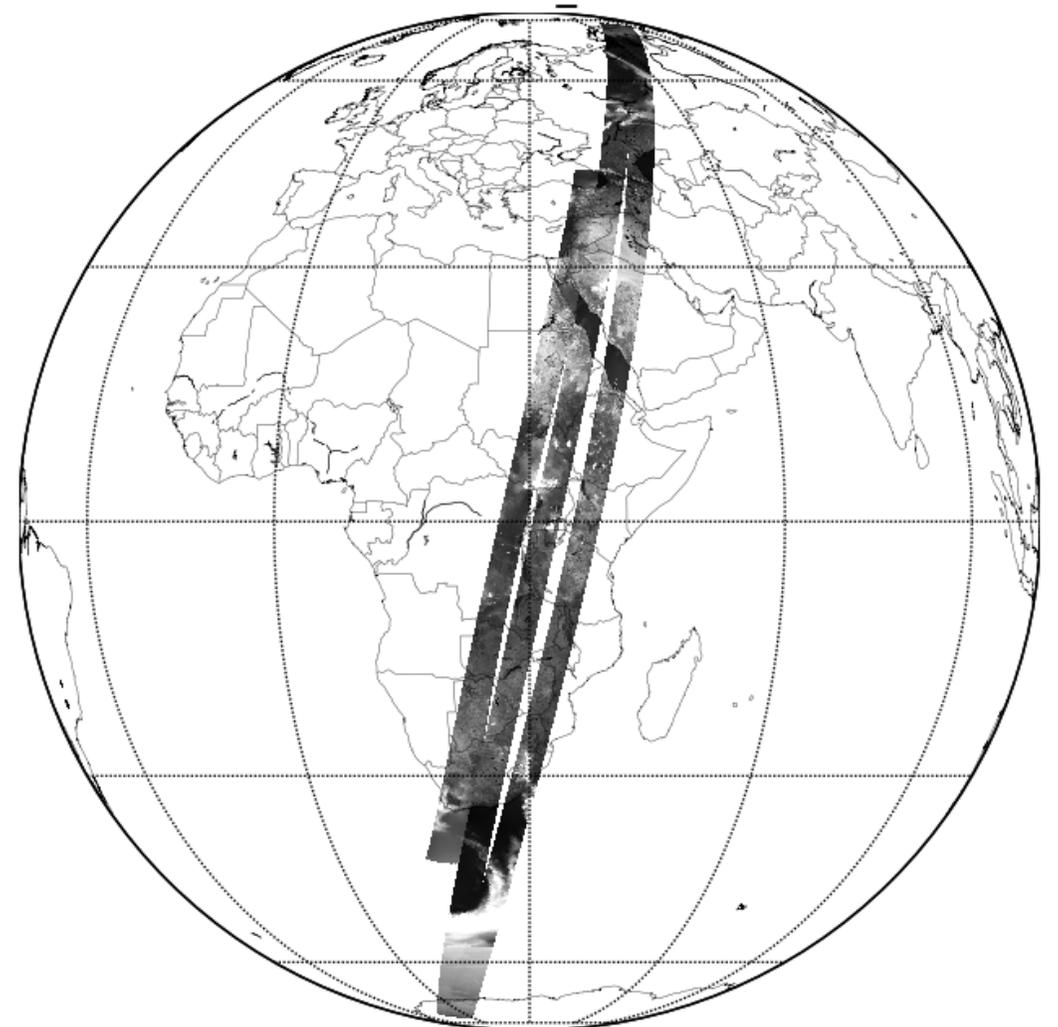


# CLIM L1B radiance

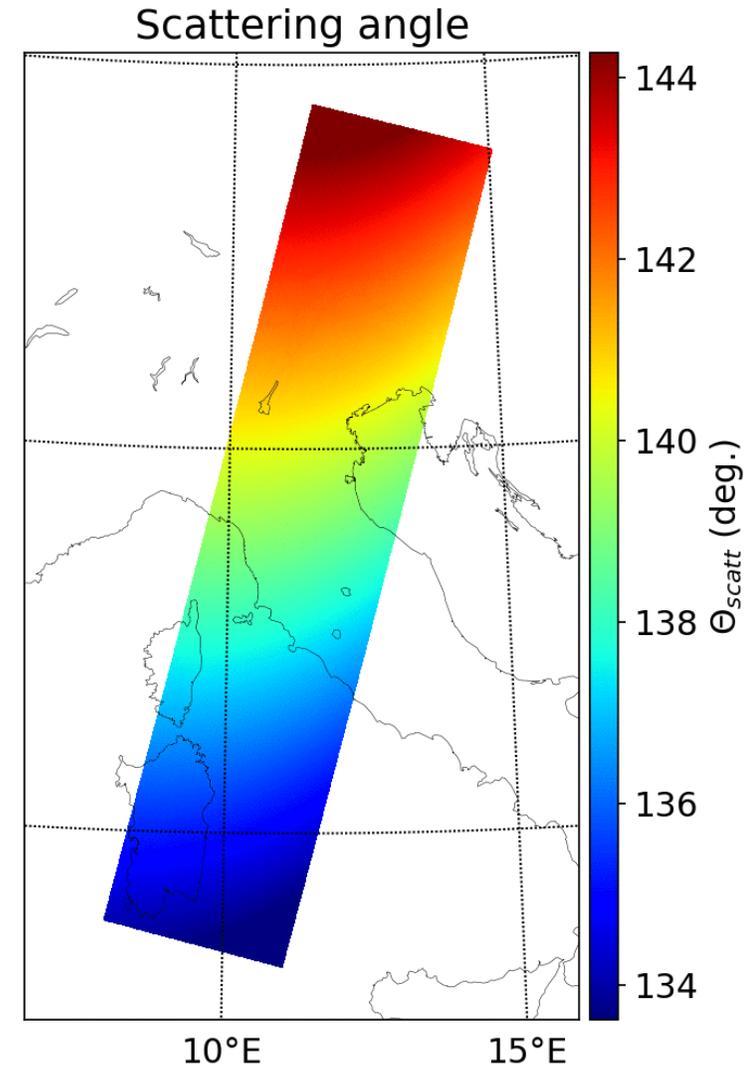
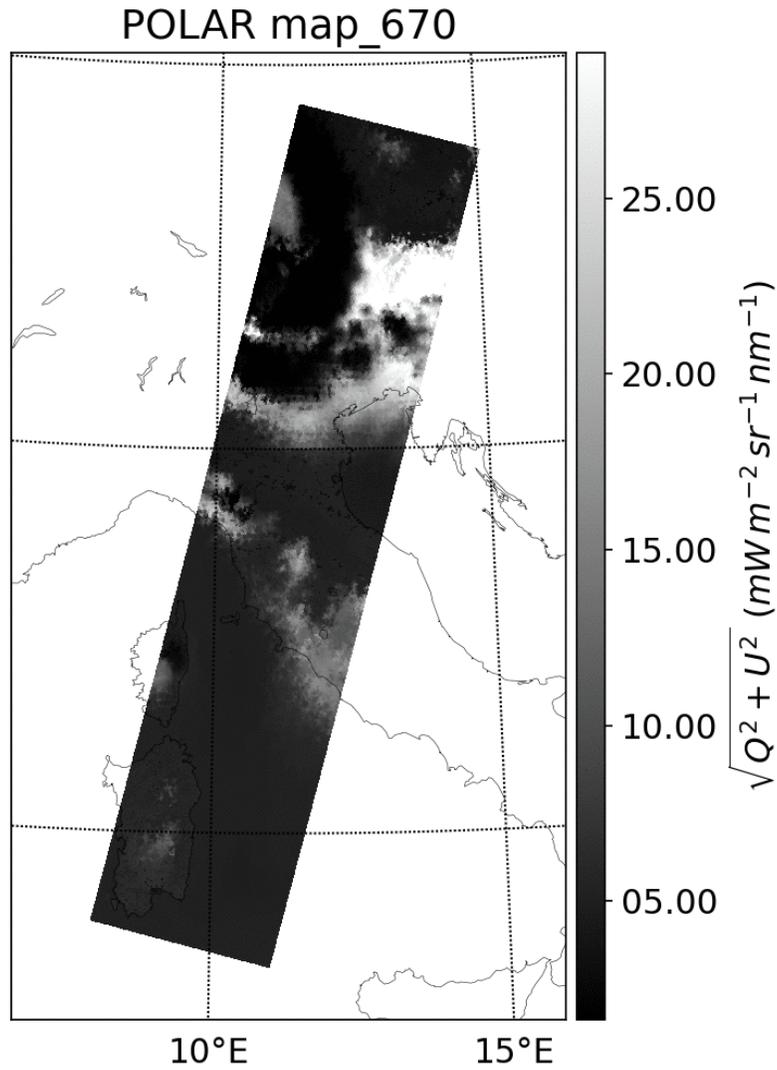
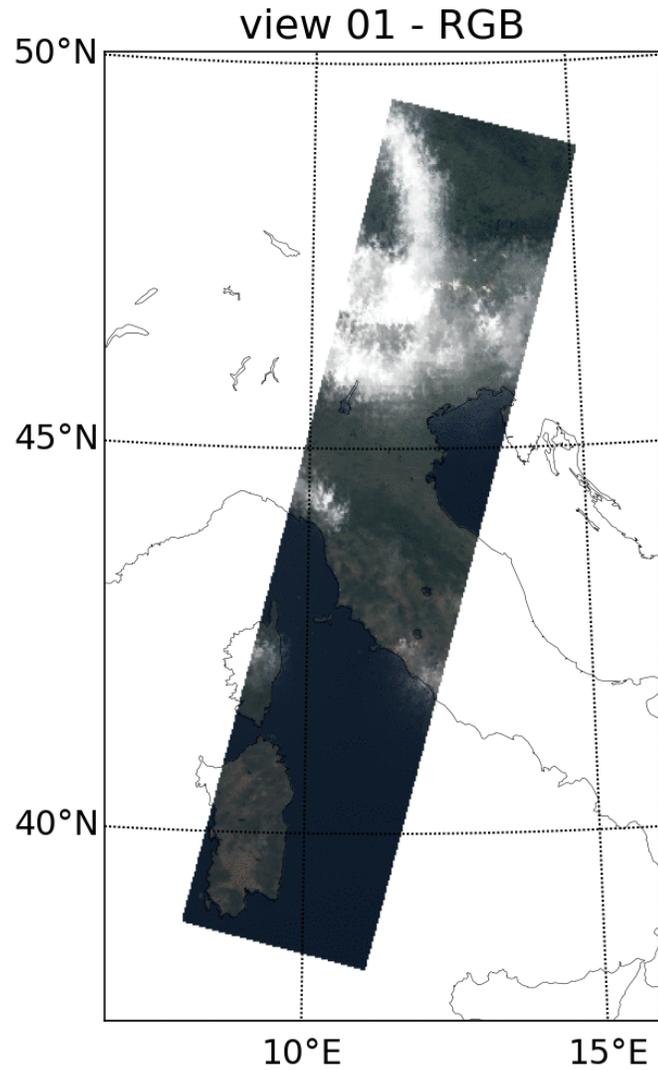
CLIM2 L1B for EU orbits



CLIM2 L1B for SA orbits



# MAP L1C test data



# Delivery

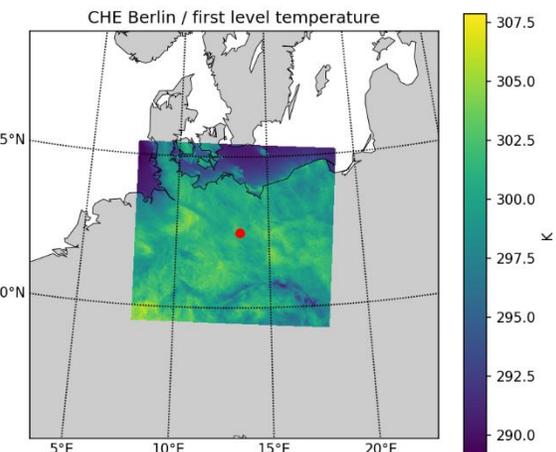
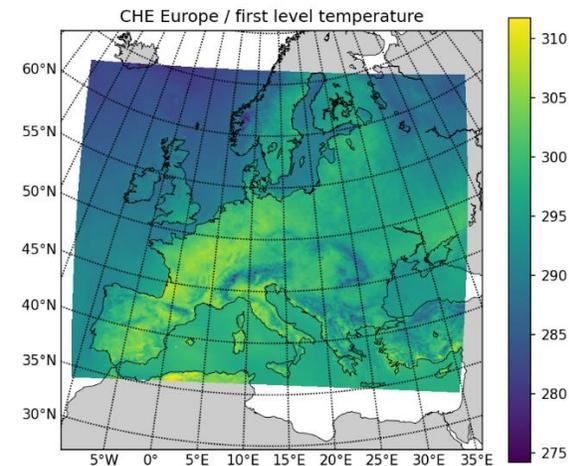
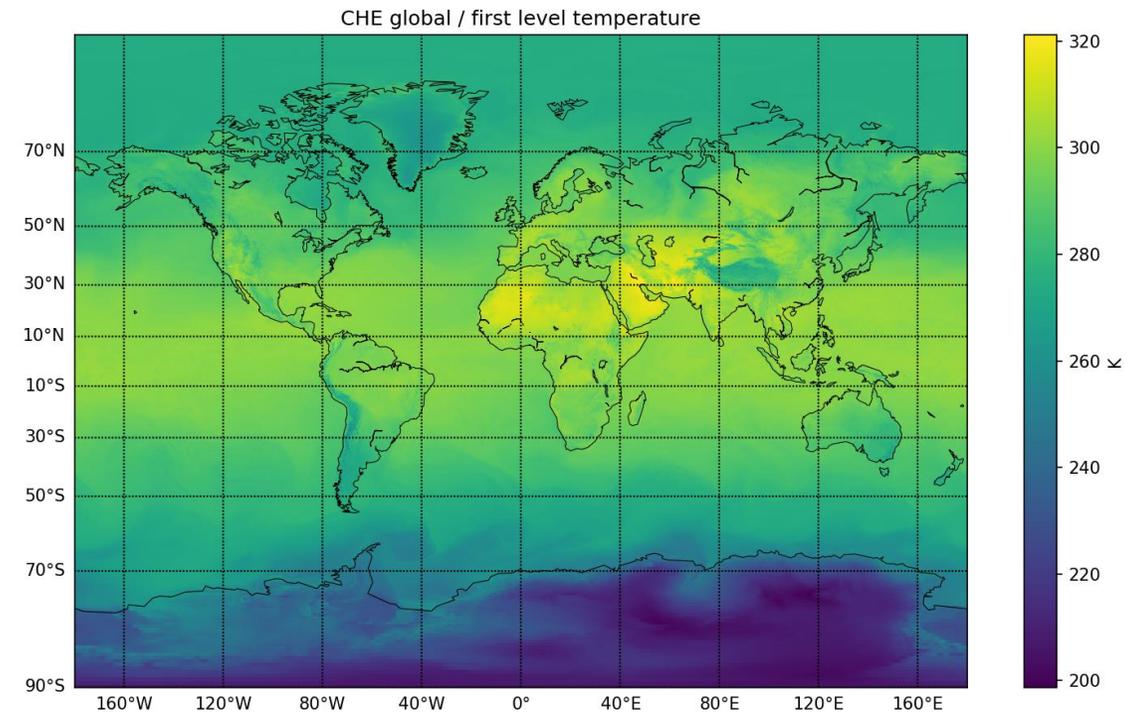
- Updated technical note and delivery note
- 6 orbits of MAP and CLIM test data delivered through the HYGEOs FTP
  - L1B and L1C file format as provided by EUMETSAT (around 6 x 450 Go)
  - Scenario files will be pushed on the FTP (around 6 x 850 Go)

	EUcent	EUwest	EUeast	SAcent	SAwest	SAeast
CLIM 1B	delivered	delivered	delivered	delivered	delivered	delivered
MAP 1B	delivered	delivered	delivered	delivered	delivered	delivered
MAP 1C	delivered	delivered	delivered	delivered	radiance production	radiance production



# Ancillary data : CHE model

- Data from CO2 Human Emissions projects (CAMS)
  - Global : 10 km resolution, surface and 137 levels profiles
  - ~~Europe : 5 km resolution, surface and 21 levels profiles (used only for spectral oversampled data)~~
  - ~~Berlin : 1 km production, surface and 21 levels profiles (used only for spectral oversampled data)~~
- Used parameters
  - Sea ice coverage & Snow depth
  - Geopotential height profile
  - 10m wind speed components (u and v)
  - Surface pressure
  - Profiles of CO<sub>2</sub>, CH<sub>4</sub>, temperature, water vapour
  - Profiles of cloud liquid and ice water content

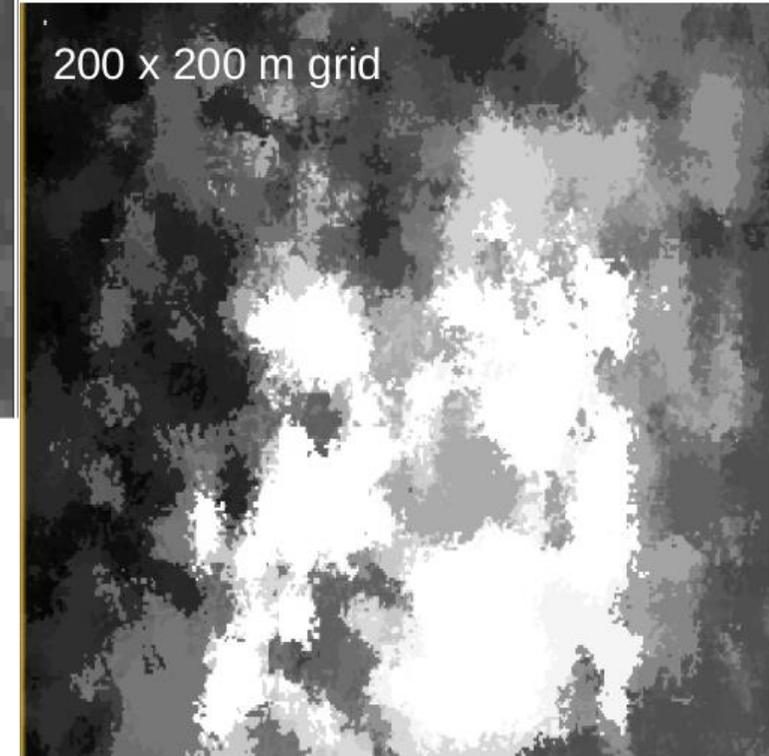
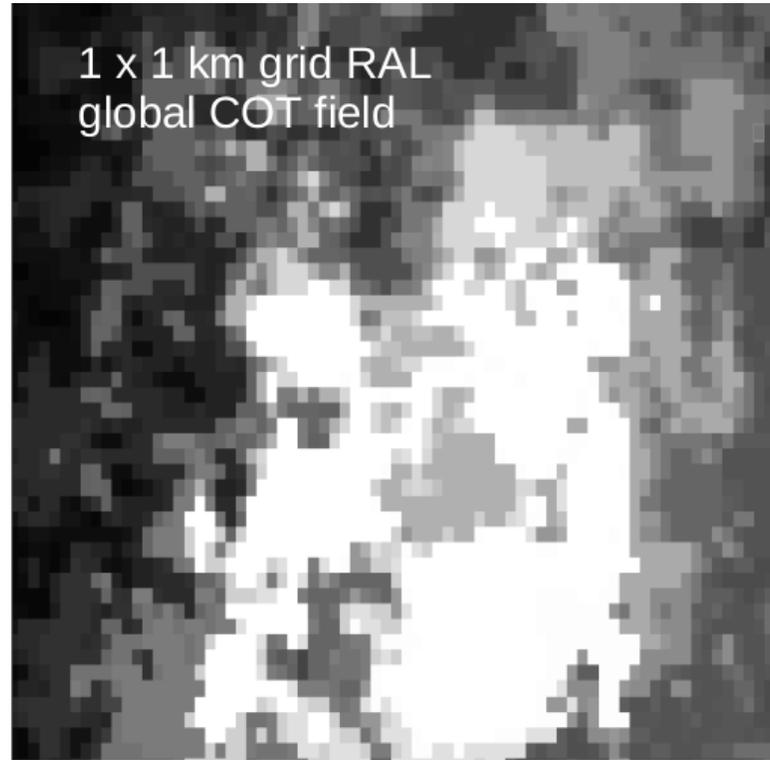


# Ancillary data : CAMS data

- CAMS global reanalysis (EAC4)
  - Global, approx. 80 km resolution, integrated values and 60 levels profiles
- Used parameters
  - 11 aerosols component mass mixing ratio profiles
    - Dust (3 different size bins)
    - Sea Salt (3 different size bins)
    - Hydrophilic and hydrophobic black carbon
    - Hydrophilic and hydrophobic Organic matter
    - Sulphate
  - Total aerosol optical depth at 550 nm
    - for black carbon, dust, organic matter, sea-salt and sulphate
  - Profiles of ozone (at global scale), NO<sub>2</sub>

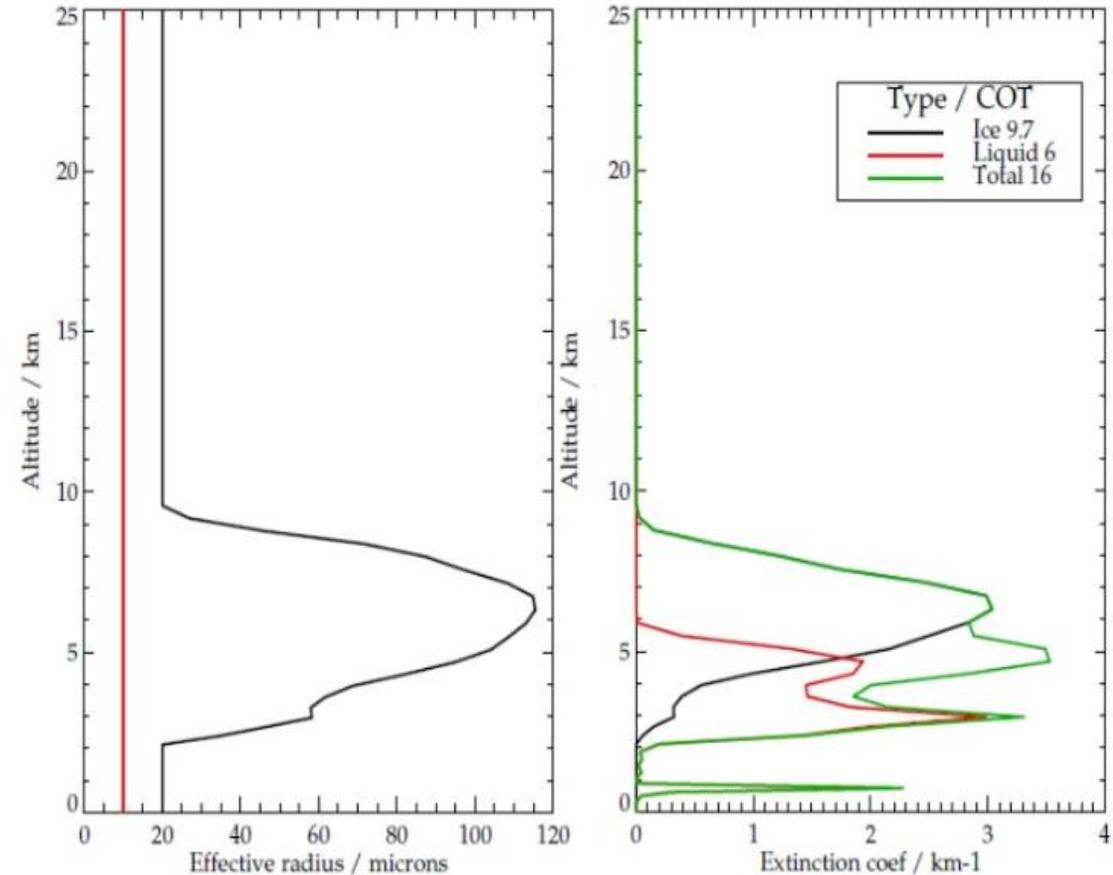
# Ancillary data : Cloud Optical Thickness

- Need to add spatial structure at smaller scale regarding CHE global 10 km resolution
- RAL provide a COT field at 1km resolution
- Artificially downsampled to 200m resolution:
  - using pseudo-random image with spatial structure  $1 / (\text{spatial-wavenumber})^2$
  - Procedure ensures near conservation of the mean of COT back at 1 km
- Same operation performed by RAL to downscale from 10 km to 1km



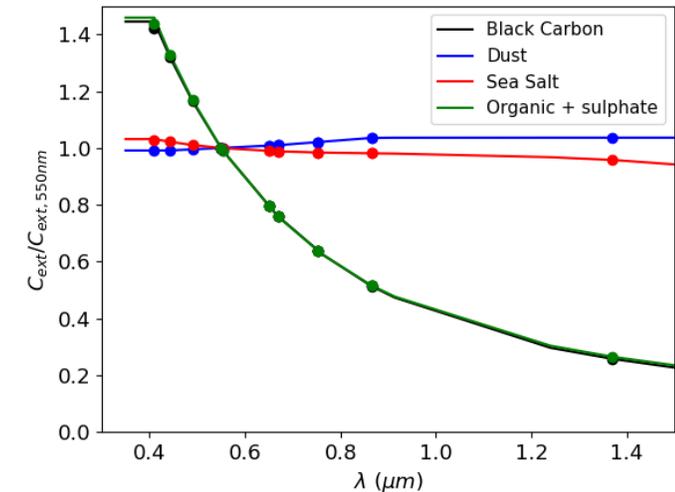
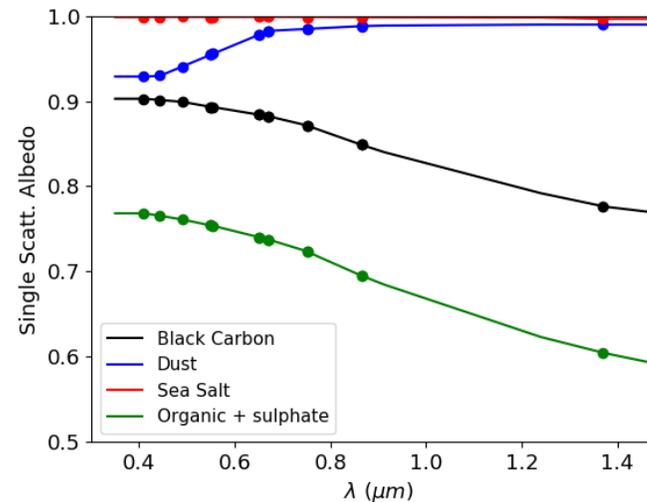
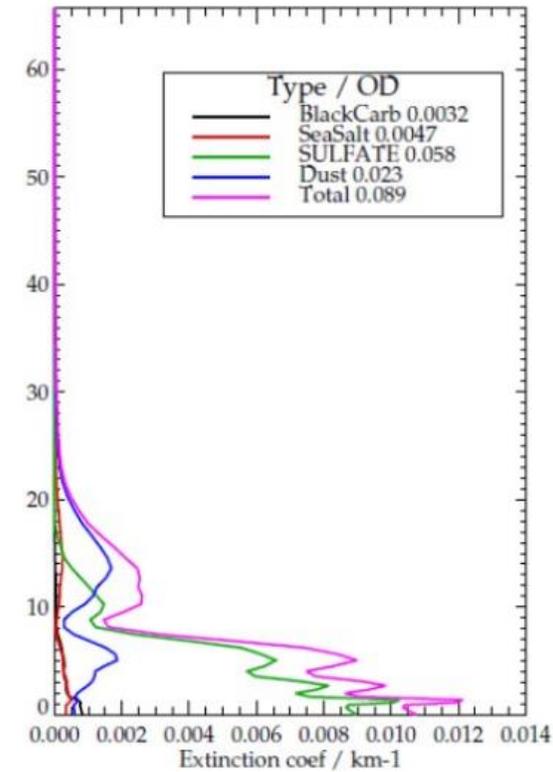
# Cloud scenario

- Extinction profiles defined based on
  - CHE global mass mixing ratio profiles (10 km) interpolated to pixel location
  - Normalized with Cloud Optical Thickness at 200 m
- Effective radius profiles
  - Fixed for liquid,  $r_{\text{eff}} = 10$  microns
  - Varying for ice,  $r_{\text{eff}} = f(\text{IWC})$
- Optical properties :
  - GHM ice model (SSCE model for varying  $r_{\text{eff}}$ )
  - Liquid cloud (as from Libradtran for varying  $r_{\text{eff}}$ )
  - Spectrally averaged in CLIM/MAP SRF
- Ancillary data fixed over an orbit (no cloud motion between over MAP views)



# Aerosol scenario

- Aerosol extinction profiles defined based on CAMS ancillary data
  - Linear interpolation to L1B pixel location
- 4 aerosol classes in the scene
  - (i) Black Carbon (ii) Sea Salt (iii) Sulphate + Organic Matter (iv) Dust
  - Extinction profiles from CAMS
  - Optical properties inherited from 3MI/METimage test data (same as CO2IS test data)
  - All 4 families present in all pixels



# Aerosol scenario

	Optical properties	Extinction profile		CAM5 EAC4 AOD
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# Ancillary data : Surface

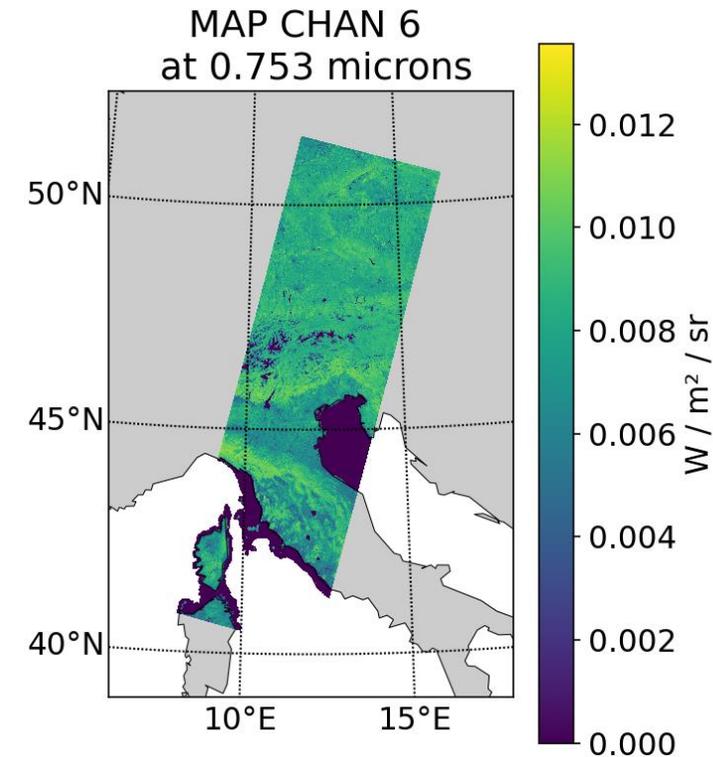
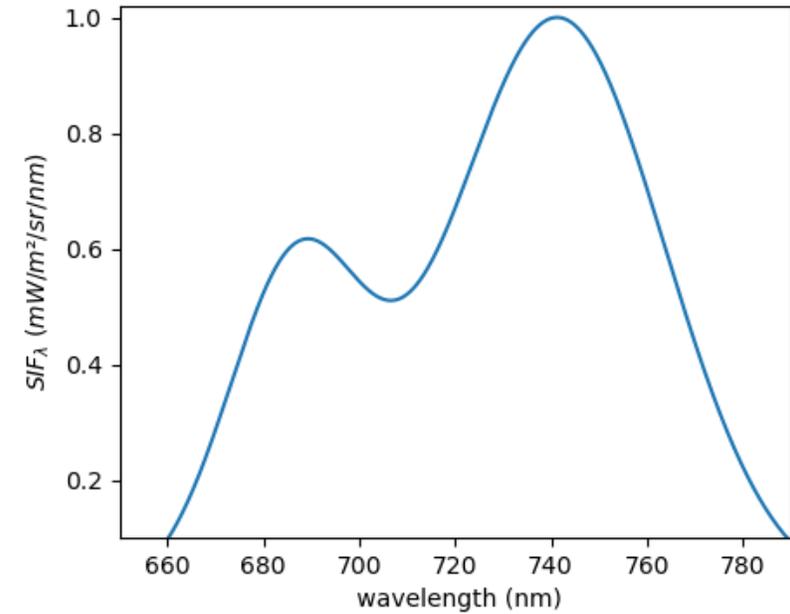
- MODIS MCD43 Gap filled BRDF parameters
  - Resolution approx. 1km
  - “Daily” Isometric, Volumetric, Geometric parameters available for 7 channels (centred at 469, 555, 659, 858.5, 1240, 1640 and 2130 nm).
  - Supplementary treatment to avoid non defined pixels
- Climate Change Initiative Ocean Colour
  - Resolution approx. 5 km
  - Monthly water reflectance at 412, 443, 490, 510, 555 and 670nm
  - Supplementary treatment to avoid non defined pixels
- IGBP land classification MODIS MCD12Q1 yearly land classification
  - resolution of approx. 500 m
  - Used for bidirectional polarization distribution function parametrization

# Surface scenario

	LAND	WATER	SNOW / ICE
Selection rule	<p>if <math>0 &gt; \text{LSM} \geq 1</math>, A land contribution is added to the pixel</p>	<p>if <math>0 \leq \text{LSM} &lt; 1</math> A water contribution is added to the pixel</p>	<p>if <math>0 &lt; \text{sea ice fraction} \leq 1</math> a sea ice fraction contribution is added to the pixel</p>
Model	<p><b><i>Li Ross BRDF with Hot Spot</i></b></p> <ul style="list-style-type: none"> <li>The ISO, VOL and GEO parameter (MCD43 product, nearest wavelength)</li> </ul> <p><b><i>Maignan BPDF</i></b></p> <ul style="list-style-type: none"> <li>IGPB parameter (MCD12Q1)</li> </ul> <p><b><i>Sun Induced Fluorescence (see next slide)</i></b></p>	<p><b><i>Sun glint (isotropic Cox and Munk) + shadowing effect + whitecaps + water reflectance</i></b></p> <ul style="list-style-type: none"> <li>The wind speed (CHE global)</li> <li>CCI OC data</li> </ul>	<p><b><i>Li Ross BRDF with Hot Spot</i></b></p> <ul style="list-style-type: none"> <li>Default ISO for snow, VOL = 0 and GEO = 0</li> </ul> <p><b><i>Maignan BPDF</i></b></p> <ul style="list-style-type: none"> <li>For snow/ice</li> </ul> <p><b><i>No SIF</i></b></p>

# Sun induced Fluorescence

- SIF computed from NDVI
  - $SIF_{\lambda}(740 \text{ nm}) = 2.15 \text{ NDVI} - 0.280 \text{ mW} / \text{m}^2 / \text{nm} / \text{sr}$
  - $NDVI = \frac{NIR - VIS}{NIR + VIS}$  with  $NIR = ISO_{MCD43, 858\text{nm}}$  and  $VIS = ISO_{MCD43, 555\text{nm}}$
  - Fixed spectral shape
- Spectral integration into MAP and CLIM SRF (or micro-channels for the spectral over-sampling case)
- Accounted for using surface emission term in adding-doubling code



# Satellite Radiance Data Simulator (SRDS)

## *I/O access*

- Load static libraries
- Load scenario files

## *Loop over pixels*

### *Pre processing (scene definition)*

- Build scene from ancillary data
- convert to ARTEDCO/RTTOV input format

### *RTE solving*

- run ARTEDCO or RTTOV

## *I/O access*

- Write results netcdf

- HYGEOS/LAO/ICARE in Lille, France jointly developed the Satellite Radiance Data Simulator (SRDS)
- This was driven by several EUMETSAT projects
  - EPS-SG 3MI & METimage test data
  - Geostationary high spectral resolution test data
  - MTG FCI 24h test data
  - CO2M (Sentinel 7) MAP & CLIM test data
  - MTG-IRS test data
- Adaptable to most LEO/GEO passive existing or hypothetical sensors
- SRDS is a radiance simulator and does not include orbit propagation

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## *I/O access*

- Write results netcdf

- Footprint/spatial sampling and view geometries are an input
  - L1B from actual orbit propagation and instrument specifications
  - hypothetical/arbitrary
  - Fixes output spatial sampling for the radiance
- Scenario files providing the spatial/temporal geophysical parameters variability
  - ancillary data (e.g. ECMWF, CAMS, MODIS L2 product) resampled into the final footprint/spatial sampling
- Static libraries for gas / cloud / aerosols optical properties
  - Eventually resampled, averaged or parametrized according to instruments SRFs

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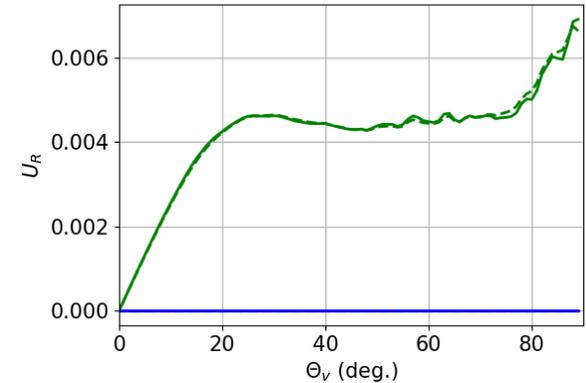
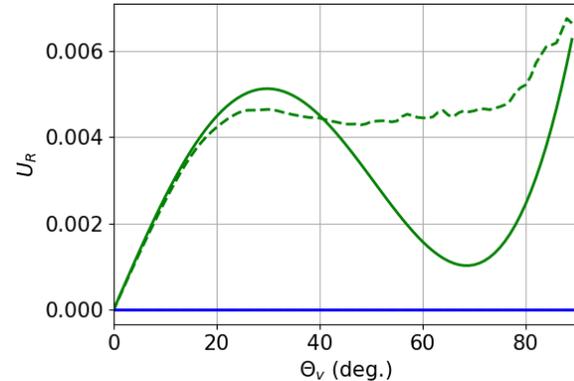
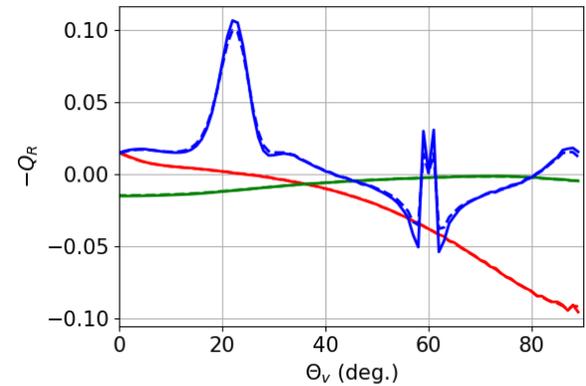
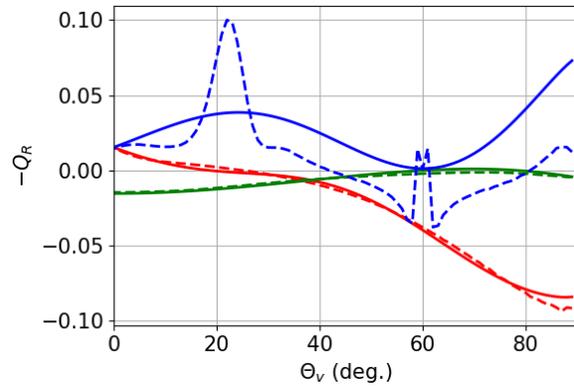
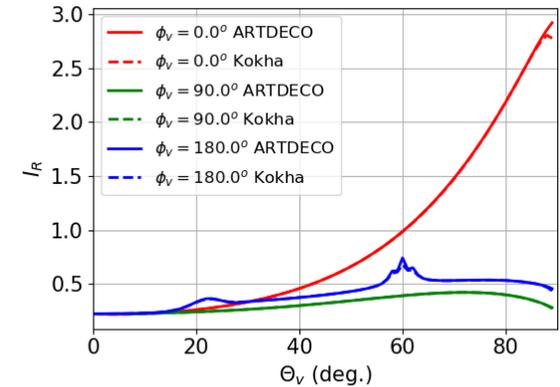
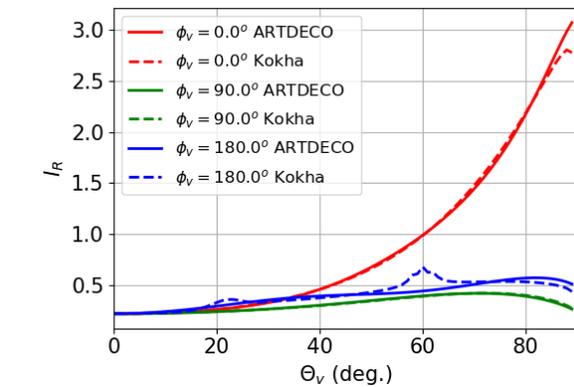
## *I/O access*

- Write results netcdf

- Ancillary data processing to build actual RT solver input : scene definition
- Radiative transfer solved pixel by pixel using
  - **RTTOV** very efficient for thermal infrared to MW spectral region
  - **ARTDECO** well adapted for the UV to SWIR spectral region including polarisation
- 1D / plan parallel / independent pixel approximation
- Adaptable accuracy / CPU demand trade-off
- Adapted for deployment on large HPC clusters

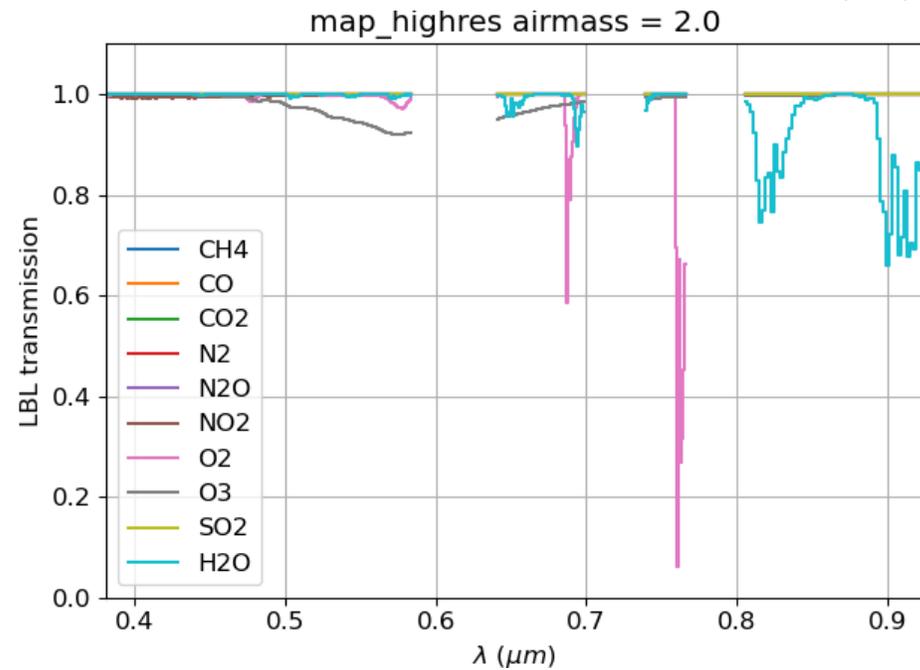
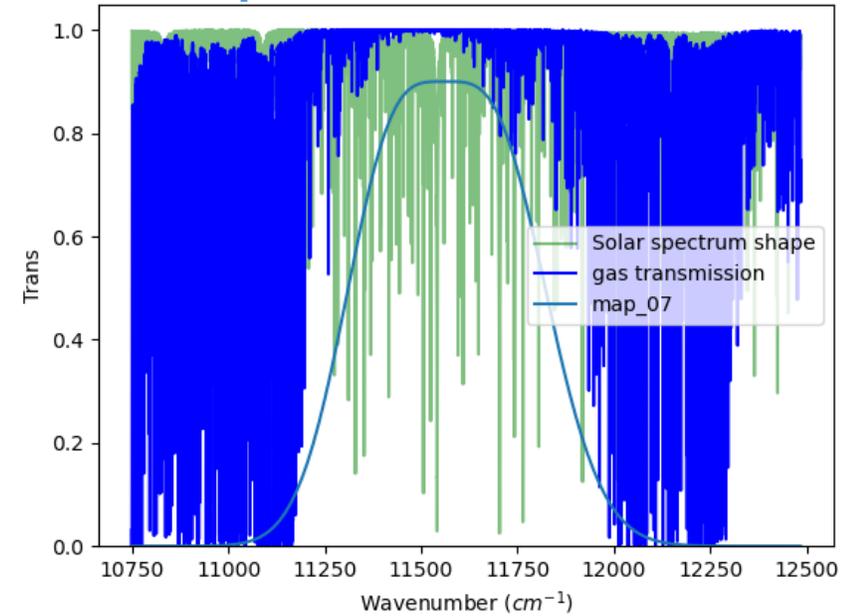
# Radiative transfer setting

- ARTDECO tool used to solve RTE
  - Adding Doubling code
- Accuracy / CPU demand trade-off
  - 8 computational angles
  - Delta-M phase matrix truncation
  - First scattering order correction applied (TMS) for atmosphere and surface
    - TOA polarized radiance “scattering” accuracy around 1 % away from glory and cloudbow
  - CHE global profile deduced to 34 levels
- Rayleigh optical depth computed (Bodhaine et al. 1999)



# Radiative transfer setting : gas absorption

- Accounted for using correlated K-distribution (transmission accuracy around 1% for airmass=2)
- Specific sets of coefficients produced with PyKdis
  - MAP & CLIM SRF
- Only H<sub>2</sub>O, O<sub>3</sub>, O<sub>2</sub> and NO<sub>2</sub> have significant impact (T<0.999 for airmass=2)



# CLIM production strategy

- Only Cloud Optical Thickness ancillary varies and spatial scale close to CLIM resolution
  - CLIM resolution :  $\approx 90$  m for CLIM 1 / 2 and  $\approx 170$  m for CLIM 3
  - Ancillary data resolution : 200 m for COT and 1 km at best for the other ancillaries (MCD43 product)
- Reduced resolution RT computation to save CPU:
  1. Set “super pixels”
    - 7x7 native pixels for CLIM 1 and 2
    - 5x5 native pixels for CLIM 3
  2. All ancillary data (but COT) projected to super-pixel grid
  3. RT solved for each super-pixel for appropriated COT range (similar to building a LUT)
  4. For each native pixel in a given sub-pixel : interpolation of radiance in  $\log_{10}$  COT