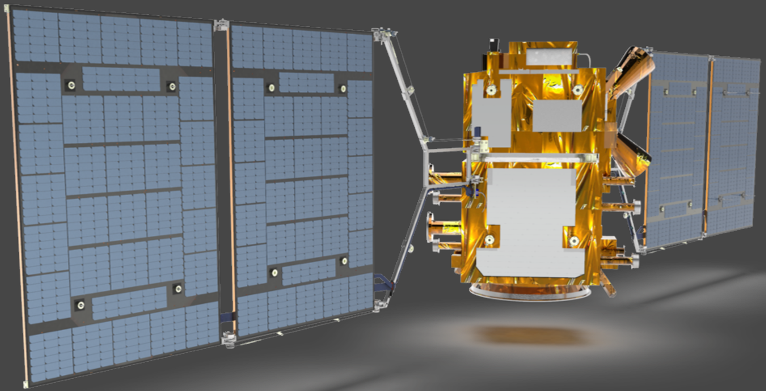
Mission Critical Design Review



SECTION: 07C

Mission Products Simulations

C. Tauro, M. Labanda, P. López, E. Floreani, M. Avila, CONAE

SABIA-Mar Project

April 24-27, 2023

Centro Espacial Teófilo Tabanera, Córdoba, Argentina

CONAE

Ministerio de Ciencia, Tecnología e Innovación
Argentina

Contents

© 2023 CONAE SABIA-Mar

Related documentation

- **SB-0405050100000-RP-00001-A**, Report: SABIA-Mar simulated TOA Radiances and L2 products,
- **SB-0405050105000-RP-00001-A**, L2 Processor Prototype Description,
- **SB-0404020100000-NT-00002-B**, ATBD: Normalized Water Leaving Radiance $[L_w]_N$,
- C. B. Tauro, R. E. Floreani, F. E. Godoy and G. Valvassori, "Advances in the algorithms for the generation of science products of the SABIA-Mar mission," 2022 IEEE Biennial Congress of Argentina (ARGENCON), San Juan, Argentina, 2022, pp. 1-7, doi: 10.1109/ARGENCON55245.2022.9940002.

© 2023 CONAE SABIA-Mar

Contents

© 2023 CONAE SABIA-Mar

Why do we need simulations?

- To know what the products will be like before the actual data is available.
- To test algorithms before lunch.
- To share the files with the users community in order to train them before lunch.
- It allows the maximum exploitation of data from early stages of the mission.

©2023 CONAE SABIA-Mar

Actual development

Single granules.
L1B at 800 and 200m resolution.
L2 only for Global scenario.

Goal

1 day of data of L1B and L2
(1 complete pass as minimun)
for both scenarios.

Products simulation strategy

What kind of simulations do we need?

- Simulate the observation geometry of SABIA-Mar: sun position and angular configuration of VIS-NIR and NIR-SWIR.
- Simulate files at different levels of processing: to check format, contents, execution time, etc.
- Simulate different scenarios: Global (done) and regional (to do).
- Simulate different seasons.
- Simulations at different scales: pixel, line and granule.

© 2023 CONAE SABIA-Mar

Products simulation strategy

What do we want to check doing these simulations?

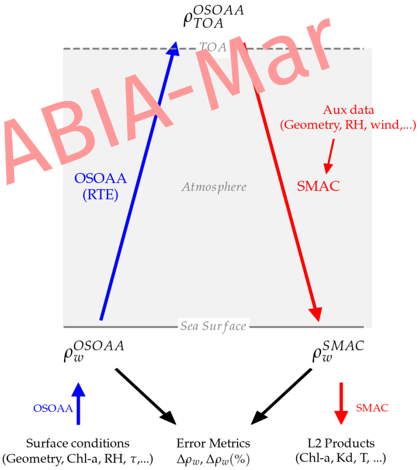
- Pixel level: to check the SABIA-Mar Atmospheric Correction (SMAC) correct implementation, checking the known case of single angle.
- Across track SABIA-Mar line: to check error metrics and continuity of water leaving reflectance. Errors coming from the SMAC (degradation of MA compared with SA), errors requirements.
- Complete scene or granule: global errors, L2 prototype processor, time of execution.

© 2023 CONAE SABIA-Mar

Ministerio de Ciencia, Tecnología e Innovación

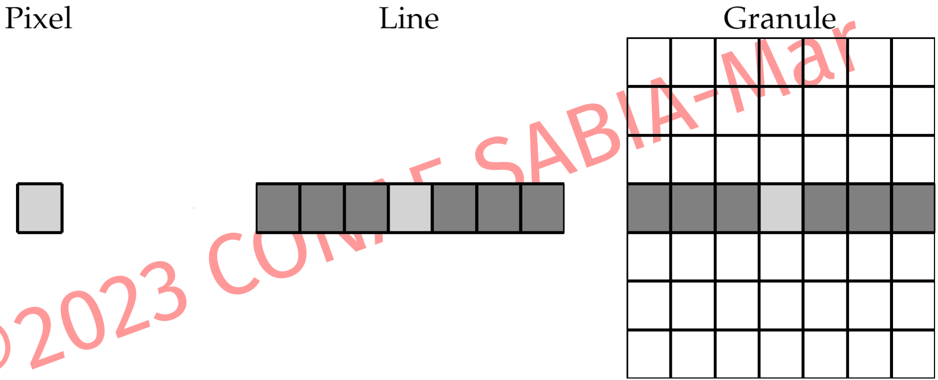
General procedure for physical parameters simulations

- Set the surface characteristics using OSOAA ρ_w^{OSOAA}, this is the *Sea Truth*.
- Extrapolate the ρ_w^{OSOAA} to TOA using OSOAA ρ_{TOA}^{OSOAA}. Here we set also the atmosphere properties.
- Retrieve the water leaving reflectance using our SMAC: ρ_w^{SMAC}.
- Make comparisons between both to estimate errors.
- For practical reasons we will work with ρ (simple unit transformation needed for radiance).



© 2023 CONAE SABIA-Mar

Scales of simulations



©2023 CONAE SABIA-Mar

Contents

© 2023 CONAE SABIA-Mar

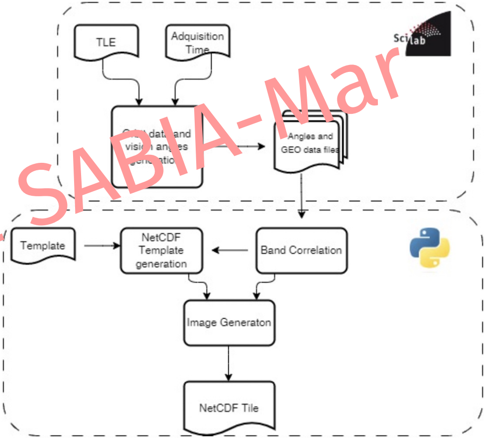
L1B Granule Simulator

Objectives:

- Create a NetCDF granule for Level 1B VIS-NIR and NIR-SWIR products
- Generate a dataset with the observation geometry included into the navigation data group
- Generate a registered band-to-band data set.

Features:

- It is composed by a set of Scilab and Python scripts.
- The simulator generate the observation geometry that its used to compute the band-to-band registration.
- Highly customizing through the use of templates



©2023 CONAE SABIA-Mar

L1B Granule Simulator

Status:

- A set of 5 minutes granules for low resolution (800 meters) VIS-NIR in global scenario has been generated and distributed
- A set of granules for VIS-NIR full resolution (200 meters) and NIR-SWIR over a regional scenario are been generated

©2023 CONAE SABIA-Mar

Contents

© 2023 CONAE SABIA-Mar

TOA and surface simulations

- The TOA and water-leaving reflectance simulations were carried out using the software OSOAA (Ordres Successifs Océan Atmosphère Avancé) of CNES and developed entirely in Fortran77.
- The OSOAA software calculates the RTE considering the ocean-atmosphere interface and allows as input parameters the wavelength, the geometry and the atmospheric and oceanic parameters.
- We have developed a wrapper in Python named **pyOSOAA** for make it easier to manage.

M. Chami, B. Lafrance, B. Fougnie, J. Chowdhary, T. Harmel, and F. Waquet, *Osoaa: a vector radiative transfer model of coupled atmosphere-ocean system for a rough sea surface application to the estimates of the directional variations of the water leaving reflectance to better process multi-angular satellite sensors data over the ocean*, Opt. Express, vol. 23, pp. 27829–27852, Oct 2015.

©2023 CONAE SABIA-Mar

TOA and surface simulations

- The time required to simulate in OSOAA ~ 4.6 million pixels (size of the scene) for all the SABIA-Mar bands exceeds a reasonable time (~6 years).
- To solve this problem a TOA radiance interpolation method is implemented.
- We have pre-computed Look Up Tables (LUTs), with a discrete set of geometric, oceanic, and atmospheric conditions in OSOAA. The interpolation was made as:
  - Nearest neighbors for the biophysical parameters.
  - Linear for geometric variables.
- We could verified that the error due to this interpolation is less than 4×10^{-5} for all SABIA-Mar bands.

©2023 CONAE SABIA-Mar

Contents

© 2023 CONAE SABIA-Mar

L2 processor prototype description

1. The L2 processor prototype is the current version of the environment (kernel) where the atmospheric correction (SMAC) are mainly developed, which allows us to obtain $[\rho_w]_N$ ($[L_w]_N$).
2. It was developed entirely in Python and contains the following terms of RTE equation already implemented:
   - Sun Glint correction.
   - Whitecaps correction.
   - Rayleigh correction.
   - Aerosol correction.
   - BRDF (not tested yet).
3. In addition, all other calculations to generate the rest of the Level 2 products ([Chl-a], FLH, $Kd(490nm)$, PAR, T) are included in the L2 processor prototype.

©2023 CONAE SABIA-Mar

L2 processor prototype description

- Performs AC for a matrix of pixels with M×N size.
- Partitions the pixel matrix into chunks of 50000 pixels (configurable).
- The required time to process the L2 products for a scene of SABIA-Mar (800m resolution) with ~ 4.6M pixels is in order of 45 min.

- Specific Look Up Tables (LUTs) were generated (by means of OSSOA software and in `.hdf` format):
  - **Rayleigh LUTs**: 15 tables (one for each band) that stores the first three components of Stokes vector (I_0, I_1, I_2) as a function of θ_0, θ_v and σ.
  - **Aerosols LUTs**: 32 tables for the Shettle & Fenn models (Maritime, Urban, Coastal & Tropospheric) containing tables with the following information:
    - *diffuse solar transmittance* coefficients A_0 and B_0,
    - *diffuse view transmittance* coefficients A and B,
    - *single-scattering to multi-scattering* coefficients: a, b, c d, e (to fit with a polynomial of degree 4) or a, b, c (to fit with a polynomial of degree 2).

© 2023 CONAE SABIA-Mar

Tests at pixel level

Ministerio de Ciencia, Tecnología e Innovación

Objectives

- Test performance of each term of SMAC at *pixel level*.
- Consider a wide variety of parameters (geometric, atmospheric & oceanic) to analyze the consistency of the implementation of standard AC (in the SA case).

Error Metrics

- *Absolute difference* ($\Delta\rho_X = |\rho_X^{AC} - \rho_X^{sim}|$) and *Relative difference* ($\Delta\rho_X(\%) = |\rho_X^{AC} - \rho_X^{sim}| / \rho_X^{sim}$) ($X$ being a term of RTE equation.)
- Histograms for $\Delta\rho_X$ and $\Delta\rho_X(\%)$ and correspondent BIAS, RMSE, Median, percentile 25%, percentile 75%.

© 2023 CONAE SABIA-Mar

Summary

RTE term	Error	Conditions
Rayleigh (for all bands)	≈ 10^{-5}	3168
Glint	≈ 10^{-6}	5460
Whitecaps	≈ 10^{-6}	5
Aerosols (for all bands)	≈ 10^{-4}	3960

©2023 CONAE SABIA-Mar

Tests at line level

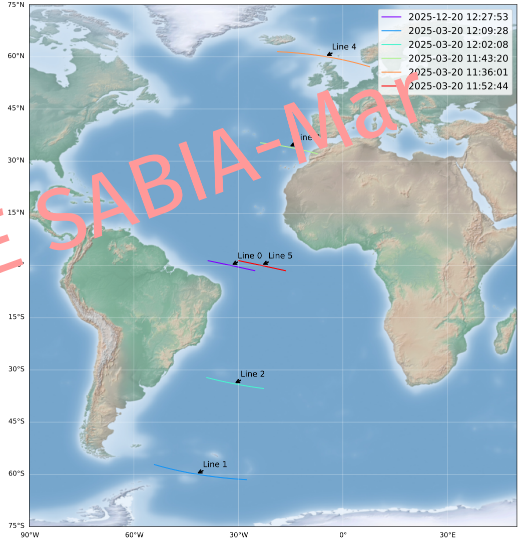
Ministerio de Ciencia, Tecnología e Innovación

Objectives:

- Test performance of SMAC algorithm at **line level**
- Compare multi-angle (MA) with single-angle (SA) measurements
- Evaluate continuity of different parameters along the simulated lines for the MA case

Considerations for each of SABIA-Mar lines:

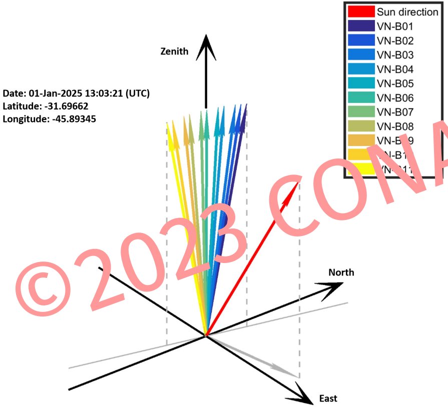
- Represents a SABIA-Mar measurement across-track and has a total of 712 pixels.
- Simulations are performed taking 31 spaces between pixels, giving a total of 24 pixels analysed.

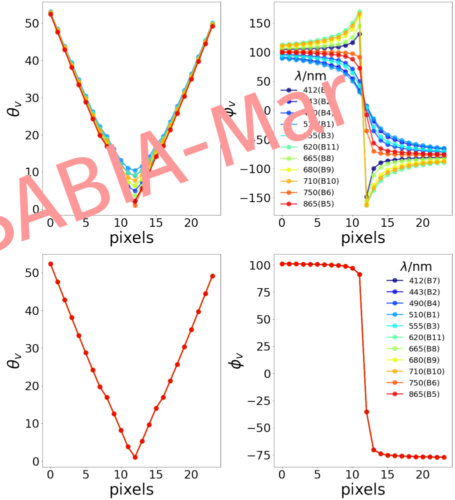


© 2023 CONAE SABIA-Mar

SA and MA cases

- **MA case:** consider SABIA-Mar viewing geometry
- **SA case:** consider all bands with viewing geometry of band B06 (λ = 750nm) which has the closest θ_v to nadir in central pixel.





Viewing angles, θ_v and ϕ_v, of pixels of *Line 0* for **MA** (up) and **SA** (bottom) cases.

©2023 CONAE SABIA-Mar

Results for all simulations II

Ministerio de Ciencia, Tecnología e Innovación

Error metrics for MA case:

		$\Delta\rho_w$					$\Delta\rho_w(\%)$				
λ/nm	N	**Bias**	**Median**	σ	$p_{25\%}$	$p_{75\%}$	**Bias(%)**	**Median(%)**	$\sigma(\%)$	$p_{25\%}(\%)$	$p_{75\%}(\%)$
412	27384	1.86E-03	1.44E-03	4.17E-03	4.59E-04	2.67E-03	4.28	3.32	14.17	1.66	6.43
443	26063	-1.16E-04	3.55E-04	3.46E-03	-6.49E-04	8.14E-04	-1.16	[illegible]	10.57	-3.19	3.51
490	26268	-4.83E-04	-1.06E-06	2.63E-03	-9.24E-04	2.66E-04	-3.36	-0.01	16.70	-6.26	1.81
510	25646	-7.39E-04	-1.87E-04	2.29E-03	-1.22E-03	8.46E-05	-8.43	-2.05	23.80	-13.47	0.92
555	25045	-5.24E-04	-2.45E-04	1.80E-03	-9.19E-04	-4.28E-05	-11.53	-5.23	36.36	-19.54	-0.84

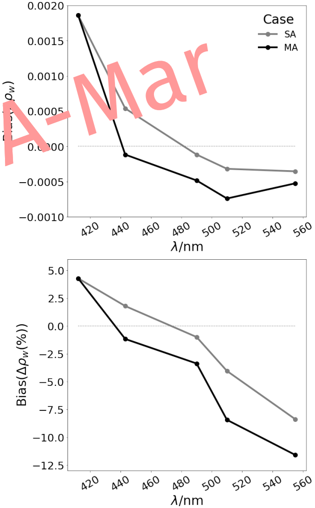
Error metrics for SA case:

		$\Delta\rho_w$					$\Delta\rho_w(\%)$				
λ/nm	N	**Bias**	**Median**	σ	$p_{25\%}$	$p_{75\%}$	**Bias(%)**	**Median(%)**	$\sigma(\%)$	$p_{25\%}(\%)$	$p_{75\%}(\%)$
412	26880	1.86E-03	[illegible]	3.67E-03	5.66E-04	2.65E-03	4.28	3.91	12.28	2.06	6.33
443	26880	5.38E-04	5.19E-04	2.67E-03	-1.04E-04	9.74E-04	1.79	2.18	13.19	-0.55	4.04
490	26880	-1.16E-04	1.29E-04	2.12E-03	-4.65E-04	3.63E-04	-0.99	0.85	13.81	-3.20	2.43
510	26848	-3.18E-04	-3.80E-05	1.79E-03	-6.26E-04	1.57E-04	-4.04	-0.41	19.30	-7.03	1.64
555	26275	-3.53E-04	-1.49E-04	1.25E-03	-5.96E-04	1.31E-05	-8.37	-2.92	26.83	-13.36	0.25

©2023 CONAE SABIA-Mar

Summary

- By means of OSOAA implementation, we have reproduced SABIA-Mar measurements in *6 lines* with different geolocation and considering set of parameter that contains a wide variety of physical conditions.
- We have evaluated SMAC algorithm taking into account *SABIA-Mar viewing geometry* (**MA case**) and compared with the hypothetical case in which *viewing angles of cameras are the same* (**SA case**).
- *Bias* of error metrics present the same order of magnitude:
  - $\Delta\rho \approx 10^{-3}$ (for band with λ = 412nm) and $\Delta\rho \approx 10^{-4}$ (for all other bands),
  - $\Delta\rho(\%) \in [-5, 5]\%$ (for bands with λ = 412, 443, 490nm) and $\Delta\rho(\%) \in [-4, 12]\%$ (for bands with λ =510 and 555nm.)
- Except for band with λ = 412nm, MA case throws values that are systematically below of the SA case, resulting in a higher results for Bias.
- **Results present errors that successfully fulfill the mission requirements.**



© 2023 CONAE SABIA-Mar

Tests at scene level

A SABIA-Mar scene has the following characteristics:

- It is a L1B product file, with netCDF extension (.nc).
- Contains the geometric, date and location characteristics corresponding to a 5-minute pass of the satellite.
- The main datasets and sub-datasets are:
  - navigation_data: [Latitud, Longitud, Height, Sensor_Zenith, Sensor_Azimuth, Solar_Zenith, Solar_Azimuth, SlantRange]
  - observation_data: It contains 33 sub-datasets that are related to the possibility of filling them with the TOA radiance, the uncertainty index and the flags for the VN camera bands (11 for each).

©2023 CONAE SABIA-Mar

TOA and Water-leaving Radiance: Simulated Conditions

Ministerio de Ciencia, Tecnología e Innovación

Simulated conditions in OSOAA to generate the LUTs with radiance at TOA and the water-leaving radiance:

- **Oceanic and Atmospheric:**
  - Chl-a = 0.01, 0.05, 0.1, 0.5, 1, 5, 10 mg m^{-3}.
  - τ_a(865 nm) = 0.01, 0.05, 0.1, 0.2, 0.5.
  - RH = 80, 90, 95 %.
  - P = 1013.25 hPa.
  - W_s = 2.5, 5, 7.5, 10 m s^{-1}.
  - Csed = 0, 1, 10 mg L^{-1}.
  - 4 aerosol models of S&F (Maritime, Coastal, Urban, Tropospheric).
- **Geometric:**
  - $\theta_v \in [0.00, 89.07]°$ (49 values).
  - $\theta_s \in [0, 80]°$ with a 1° step.
  - $\Delta\phi \in [0, 180]°$ with a 1° step.

Where $\Delta\phi$ is defined as $\Delta\phi = \phi_v - \phi_s$.

©2023 CONAE SABIA-Mar

L2 Processor Prototype: Inputs

Ministerio de Ciencia, Tecnología e Innovación

Required and optional inputs parameters to L2 processor includes:

- Geometric and TOA data contained in the L1B file: θ_s, θ_v, ϕ_s, ϕ_v and L_{toa} (R)
- RH (R)
- W_s (R)
- P (R)
- τ_a(865 nm) (O; default: 0.01)
- [Chl-a] (O; default: 0.01)
- Yellow substance absorption at 440 nm, a_{ys}(440) (O; default: 0.0)
- Yellow substance exponent, s_{ys} (O; default: 0.0)
- Detritus absorption at 440 nm, a_{det}(440) (O; default: 0.0)
- Detritus exponent, a_{ys} (O; default: 0.0)

©2023 CONAE SABIA-Mar

Statistical Results: Homogeneous Scenes

Statistical results for 9 different scenes put together, counting around 42 million pixels and including values of [Chl-a] $\in [0.05, 0.5]\,\mathrm{mg\,m^{-3}}$, $\tau_a(865\,\mathrm{nm}) \in [0.1, 0.3]$ and $W_s \in [5, 10]\,\mathrm{m\,s^{-1}}$.

	412	443	490	510	555	620	665	680	710	750	865
Mean Abs	0.00103	0.00066	0.00077	0.00077	0.00076	0.00112	0.00075	0.00079	0.00089	0.00054	0.00027
Std Abs	0.00075	0.00069	0.00078	0.00075	0.00060	0.00135	0.00038	0.00115	0.00120	0.00031	0.00007
Median Abs	0.00092	0.00049	0.00054	0.00054	0.00062	0.00097	0.00069	0.00066	0.00075	0.00050	0.00025
Mean Rel(%)	2.36669	2.59437	4.86481	8.77124	18.17712	127.44764	128.76279	149.85012	229.29338	189.33284	98.94130
Std Rel(%)	1.66004	2.77282	4.64940	8.65086	14.53006	176.73805	68.60814	259.69847	378.67657	96.70336	3.37950
Median Rel(%)	2.15552	1.92954	3.45039	6.04009	14.41710	106.43171	119.44596	120.38091	185.42395	175.81897	100.00000

©2023 CONAE SABIA-Mar

Questions?

©2023 CONAE SABIA-Mar