Tutorial on the OSOAA radiative transfer model

Ocean Successive Orders with Atmosphere - Advanced

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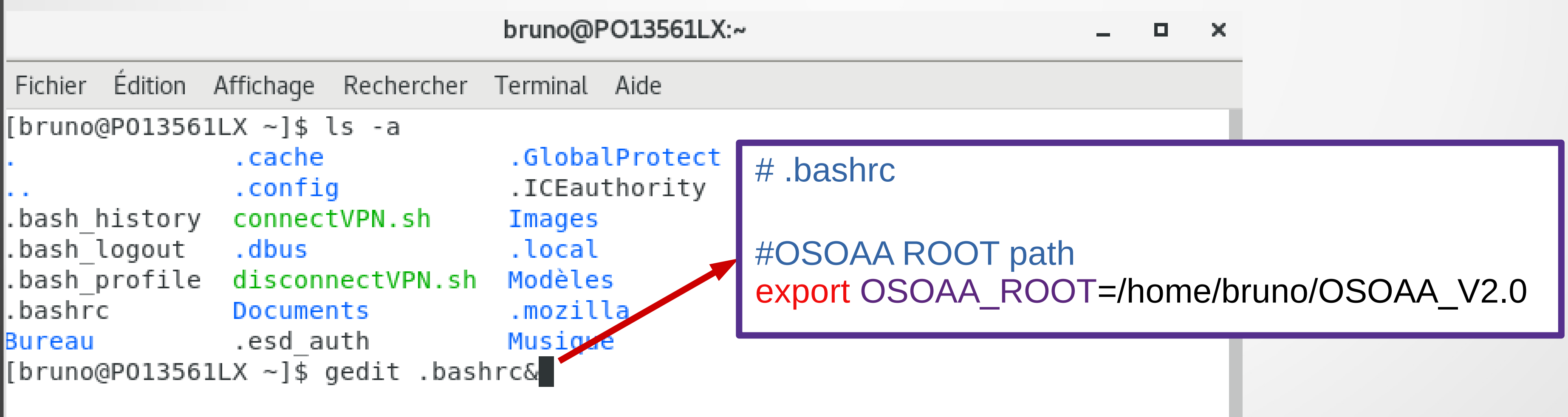
Outlines

- Software installation
- Graphical User Interface (GUI)
- Running the model using GUI
- Output files presentation
- Running the model using command files
- Examples of simulations

Software installation

- Download site (CNES website): https://github.com/CNES/RadiativeTransferCode-OSOAA
- Deposite on personnal OSOAA root repertory
- Define the OSOAA_ROOT path



Software installation

- List of directories

doc /
➡ Documentation

ihm / (GUI)
➡ Graphical User Interface tools

src /
➡ Source programs

inc /
➡ Constant parameters

(e.g., number of Gauss angles, threshold values,...)

gen /
➡ Makefiles for the compilation

obj /
➡ Compiled files

exe /
➡ Executable code

- Compilation :
  - cd $OSOAA_ROOT/gen
  - make -f makefile_OSOAA.gfortran (or *.g77 or *.f77)

fic /
➡ Ancillary database

(e.g. aerosol models, seabed reflectance, ...)

Launch of OSOAA model

- GUI launch
  - Prerequisite

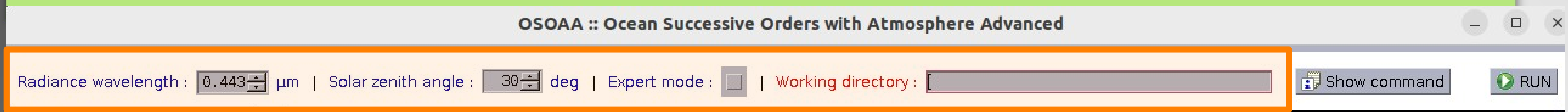
    Test : « java -version »
    Must be version 16 or higher

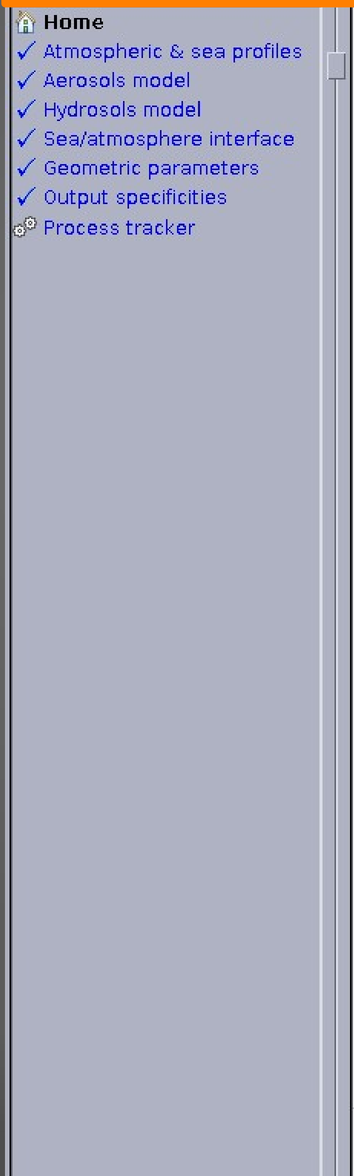
  - cd $OSOAA_ROOT/ihm/bin

    . ./runOSOAAUI.bash

Graphical User Interface (GUI)

Description of the GUI

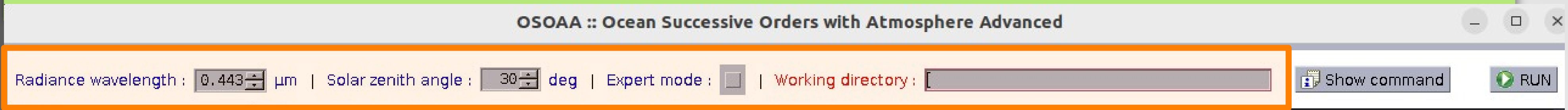


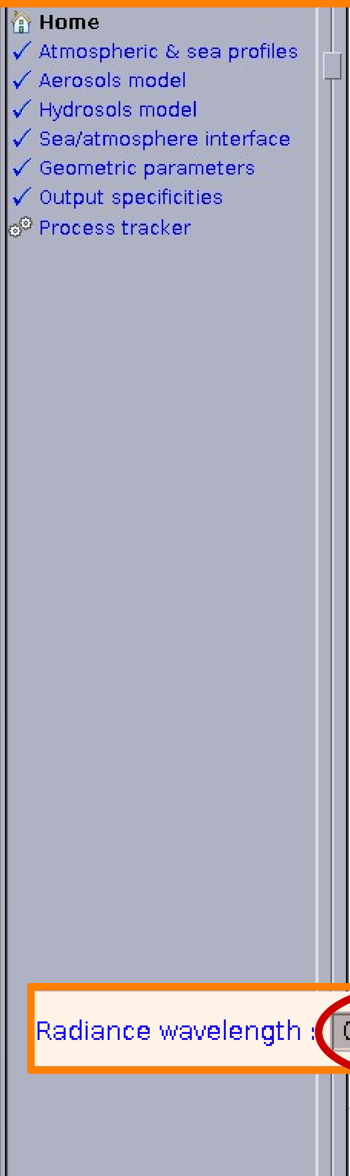


- Top menu bar defines specific parameters
  - Wavelength of simulation (in µm)
  - SZA = Solar Zenith Angle (in degrees)
  - User’s working folder (i.e. output files)

    Requires the name of the full path directory

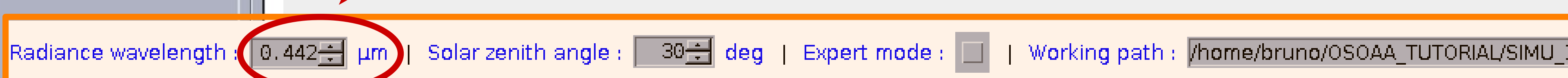
Description of the GUI



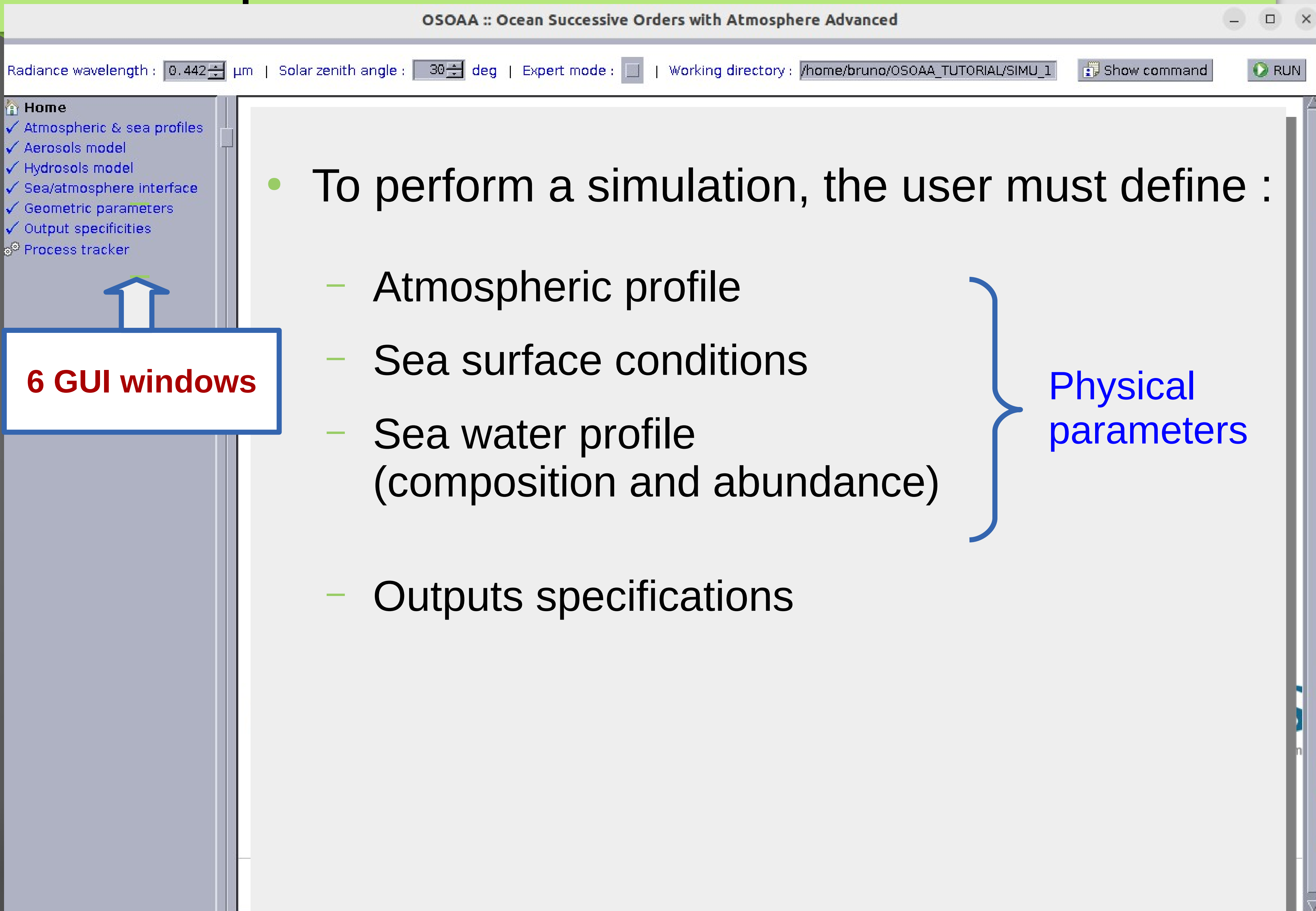


- Top menu bar defines specific parameters
  - Wavelength of simulation (in µm)
    - ▶ *Let's set 0.442 µm*
  - SZA = Solar Zenith Angle (in degrees)
    - ▶ *Let's set 30°*
  - User's working folder (i.e. output files)
    - ▶ *Let's define a working folder, as an example :*

      /home/bruno/OSOAA_TUTORIAL/SIMU_1



Description of the GUI

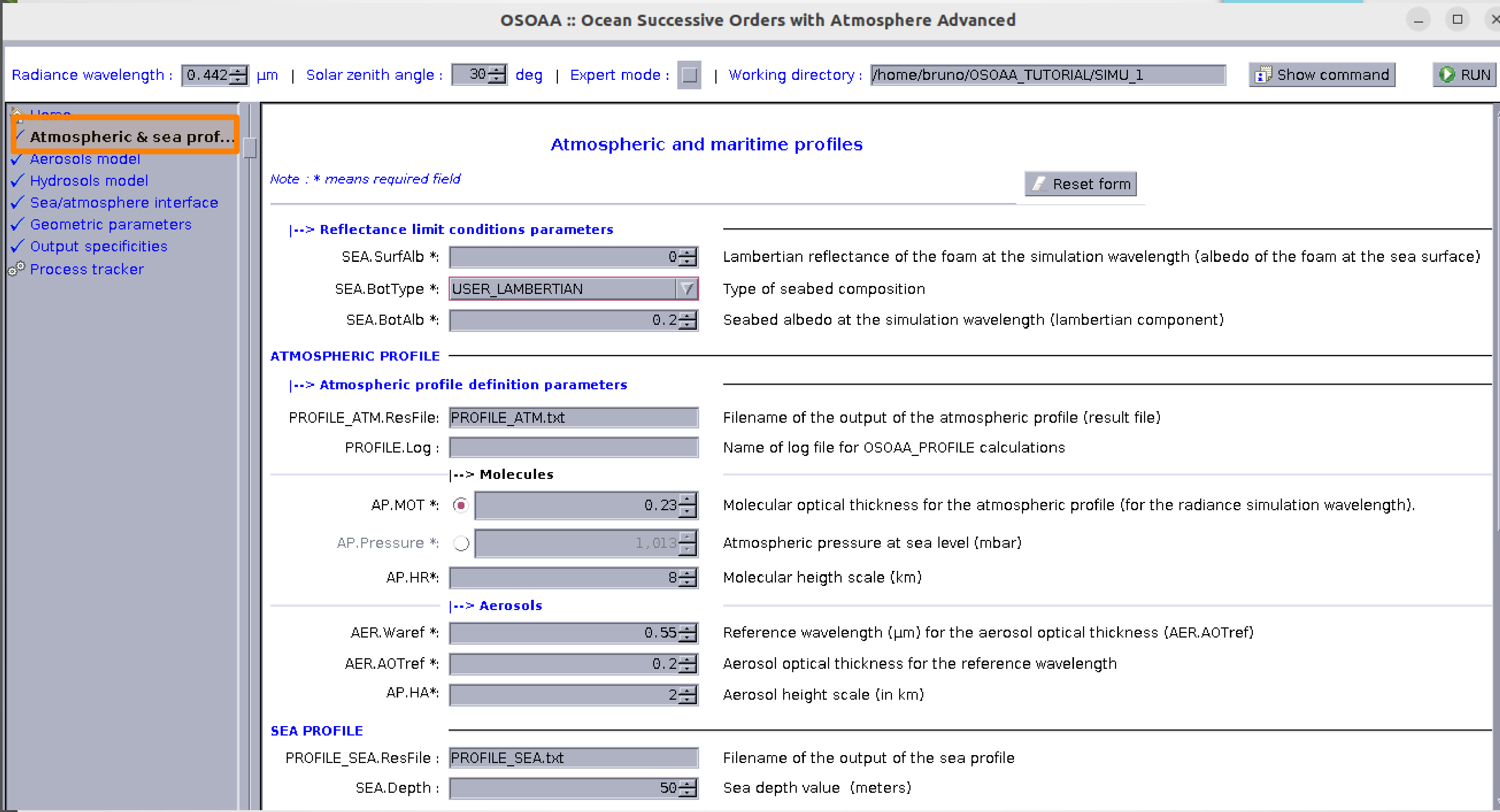


6 GUI windows

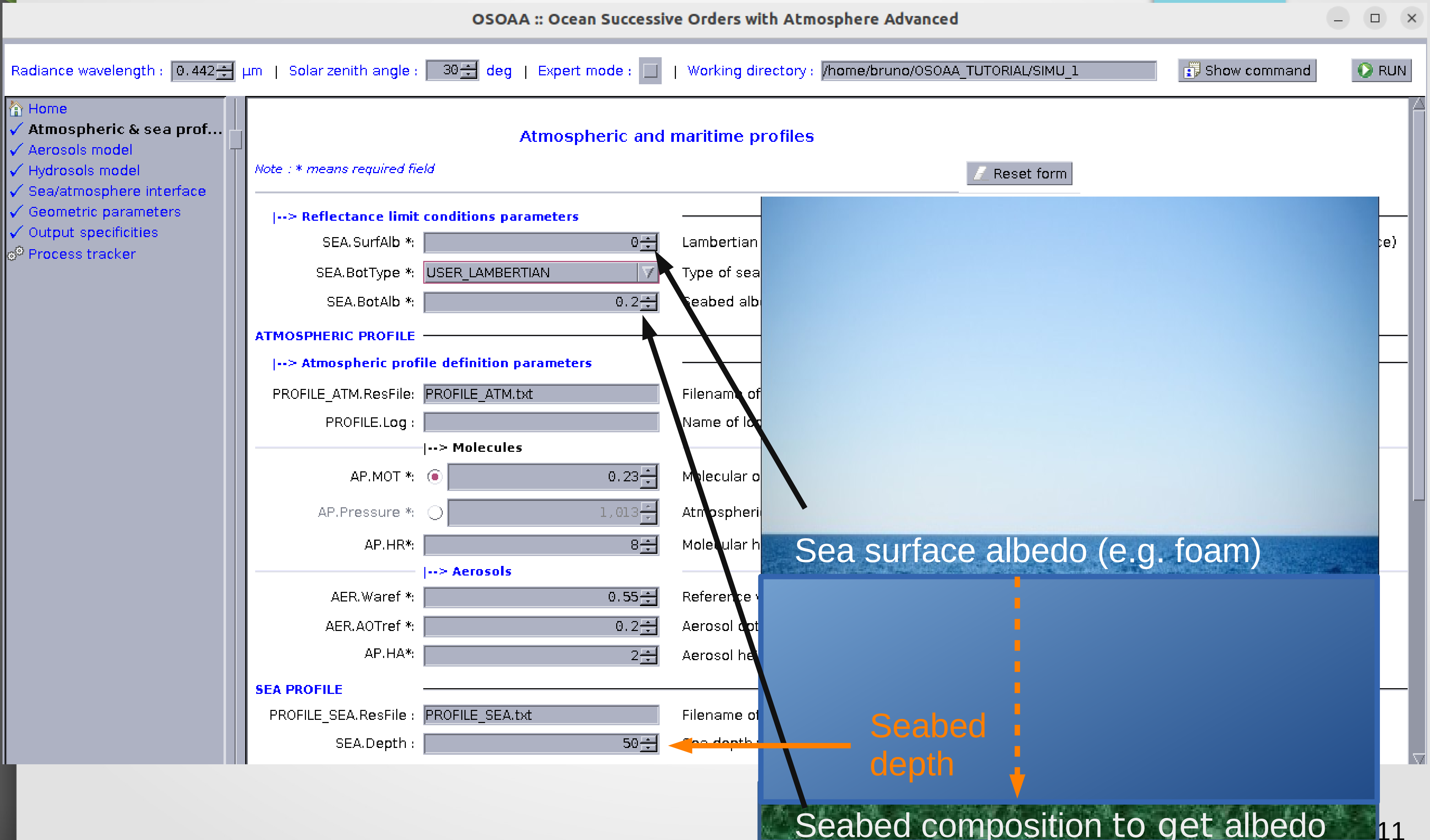
- To perform a simulation, the user must define :
  - Atmospheric profile
  - Sea surface conditions
  - Sea water profile (composition and abundance)
  - Outputs specifications

Physical parameters

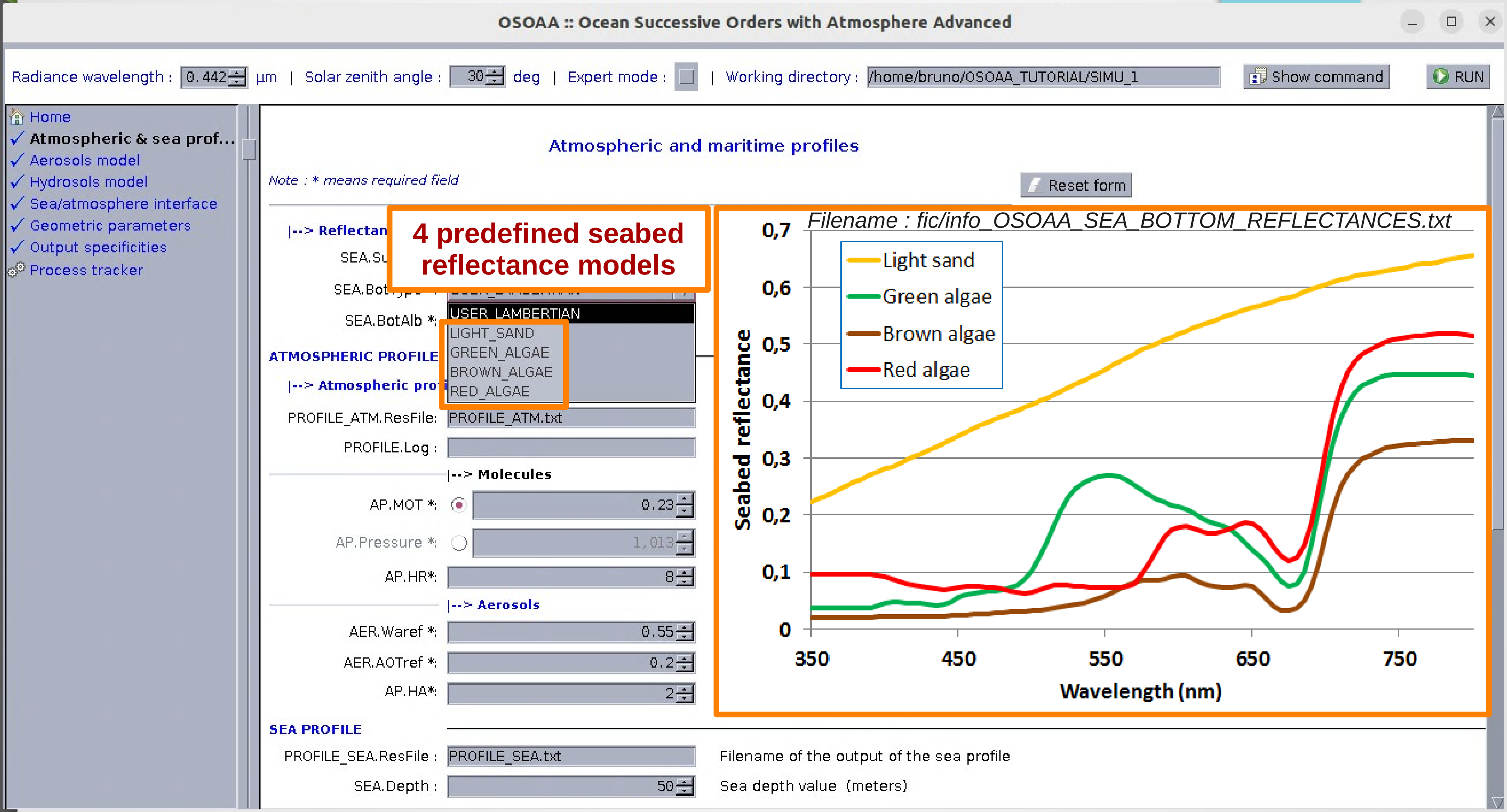
Atmospheric & maritime profiles



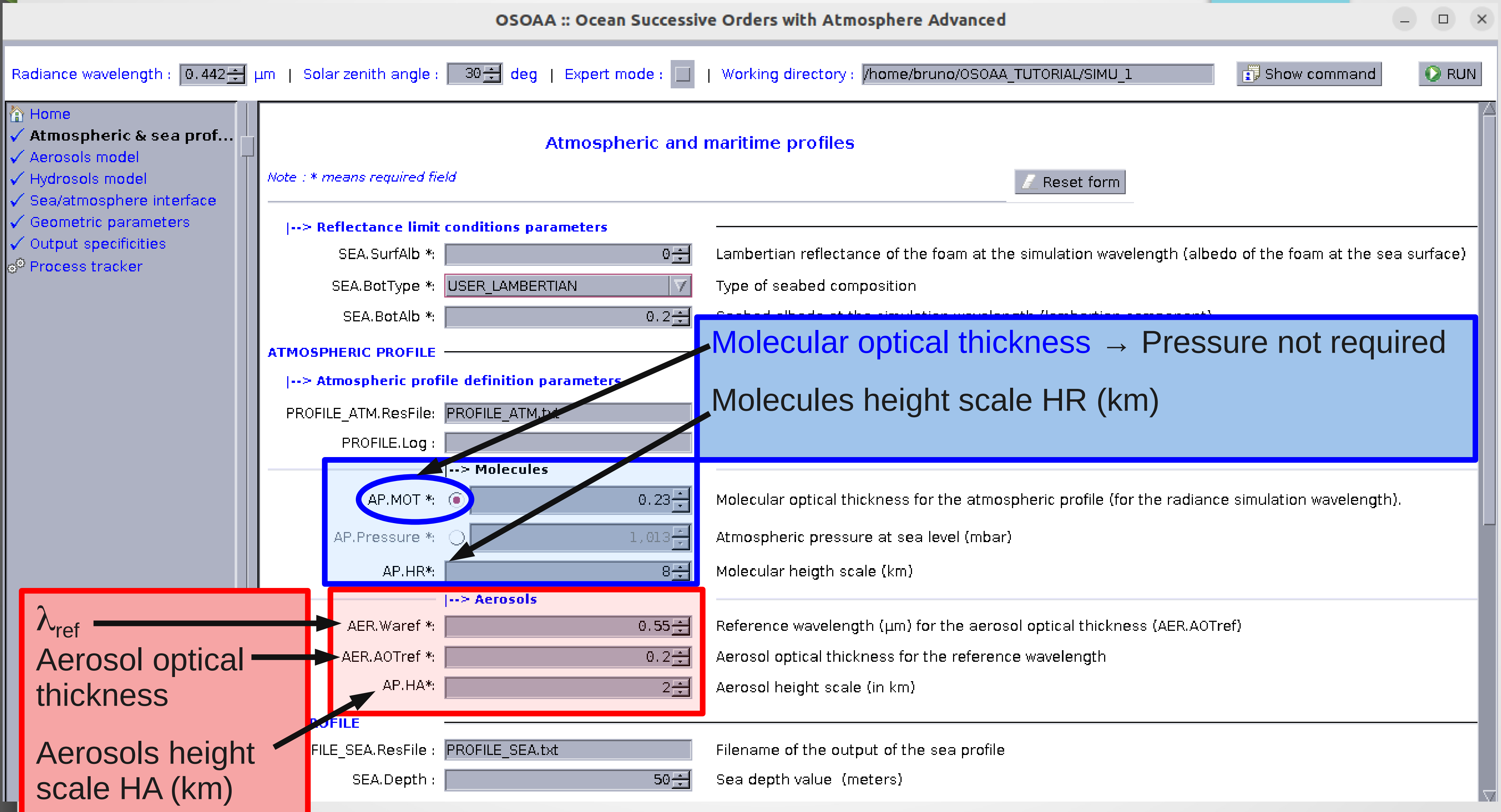
Atmospheric & maritime profiles



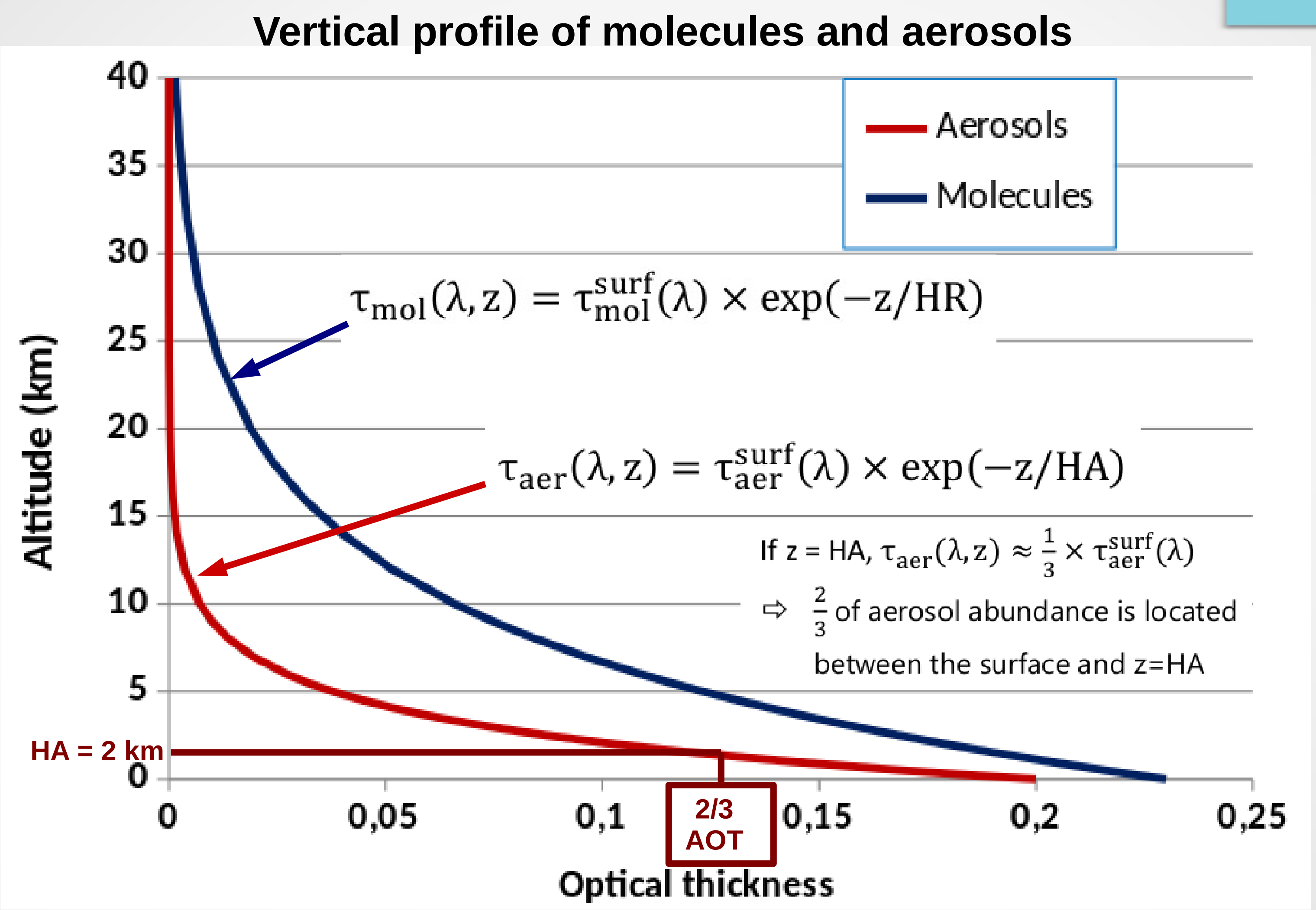
Atmospheric & maritime profiles



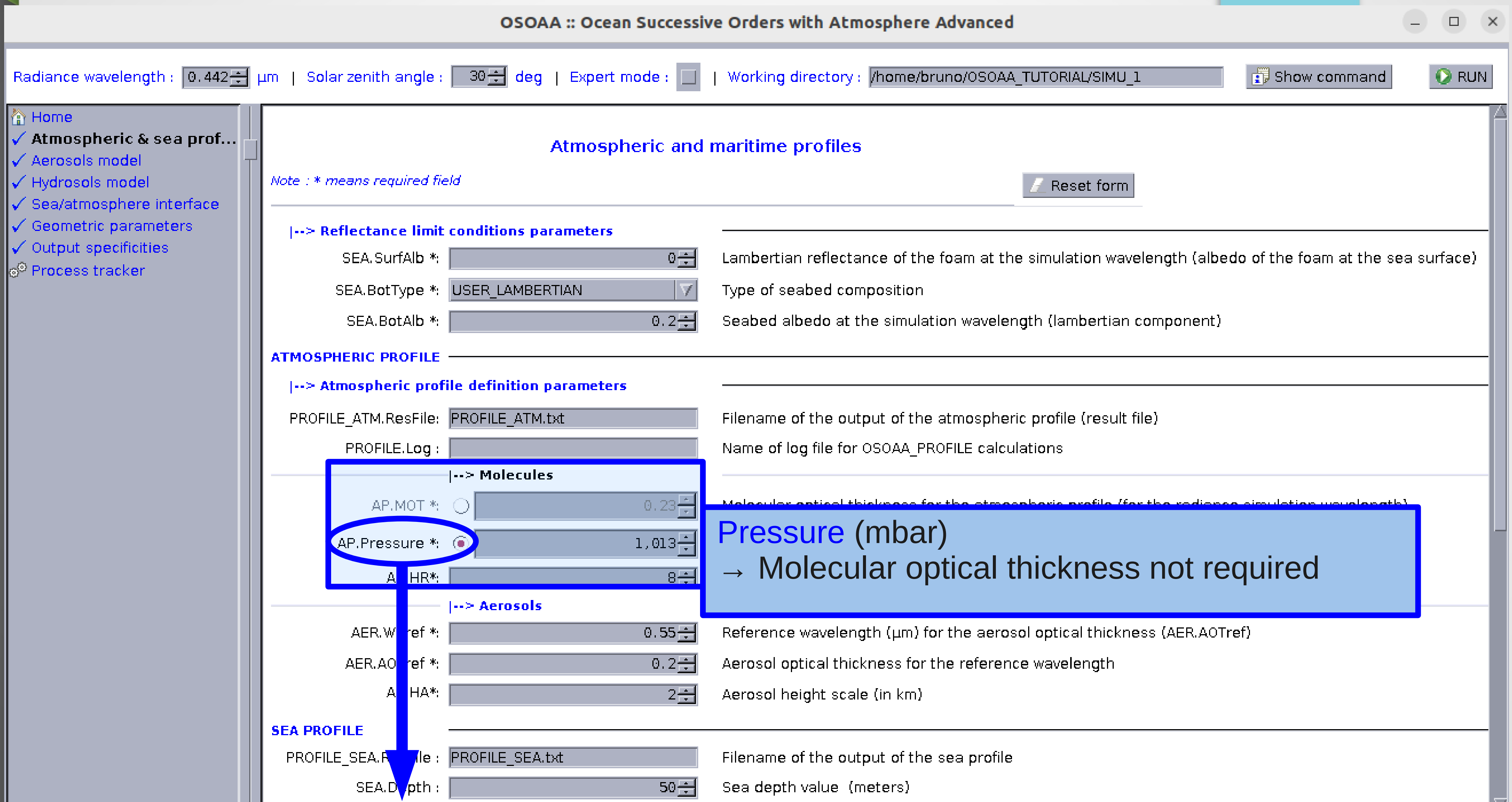
Atmospheric & maritime profiles



Atmospheric & maritime profiles



Atmospheric & maritime profiles



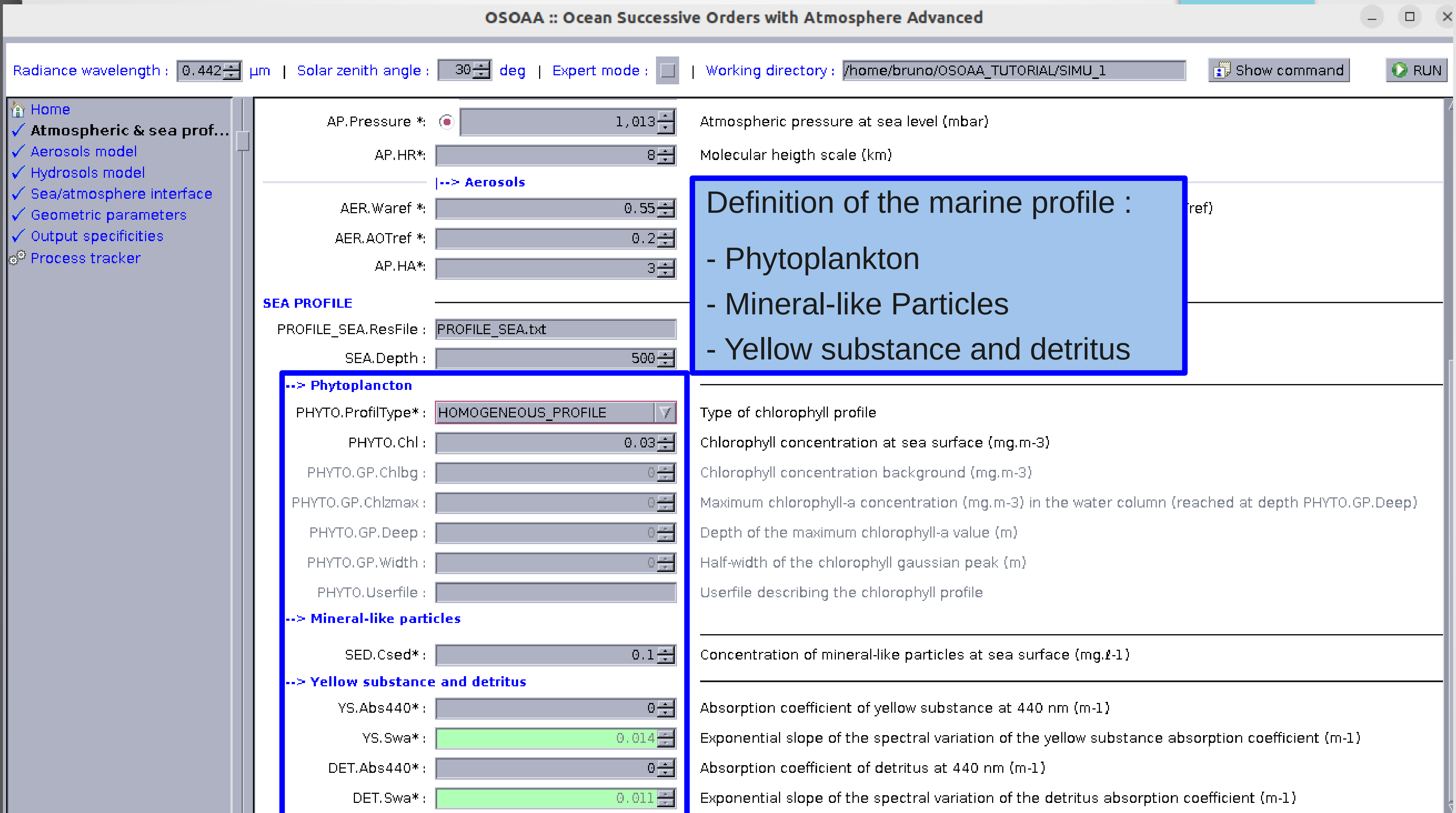
Hansen & Travis (1974) formulation to derive the molecular optical thickness from Pressure

$$\tau_{\mathrm{mol}}^{\mathrm{surf}} = \frac{P}{P_0} \times \left(\frac{84{,}35}{\lambda^4} + \frac{-1{,}225}{\lambda^5} + \frac{1{,}4}{\lambda^6} \right) \times 10^{-4}$$

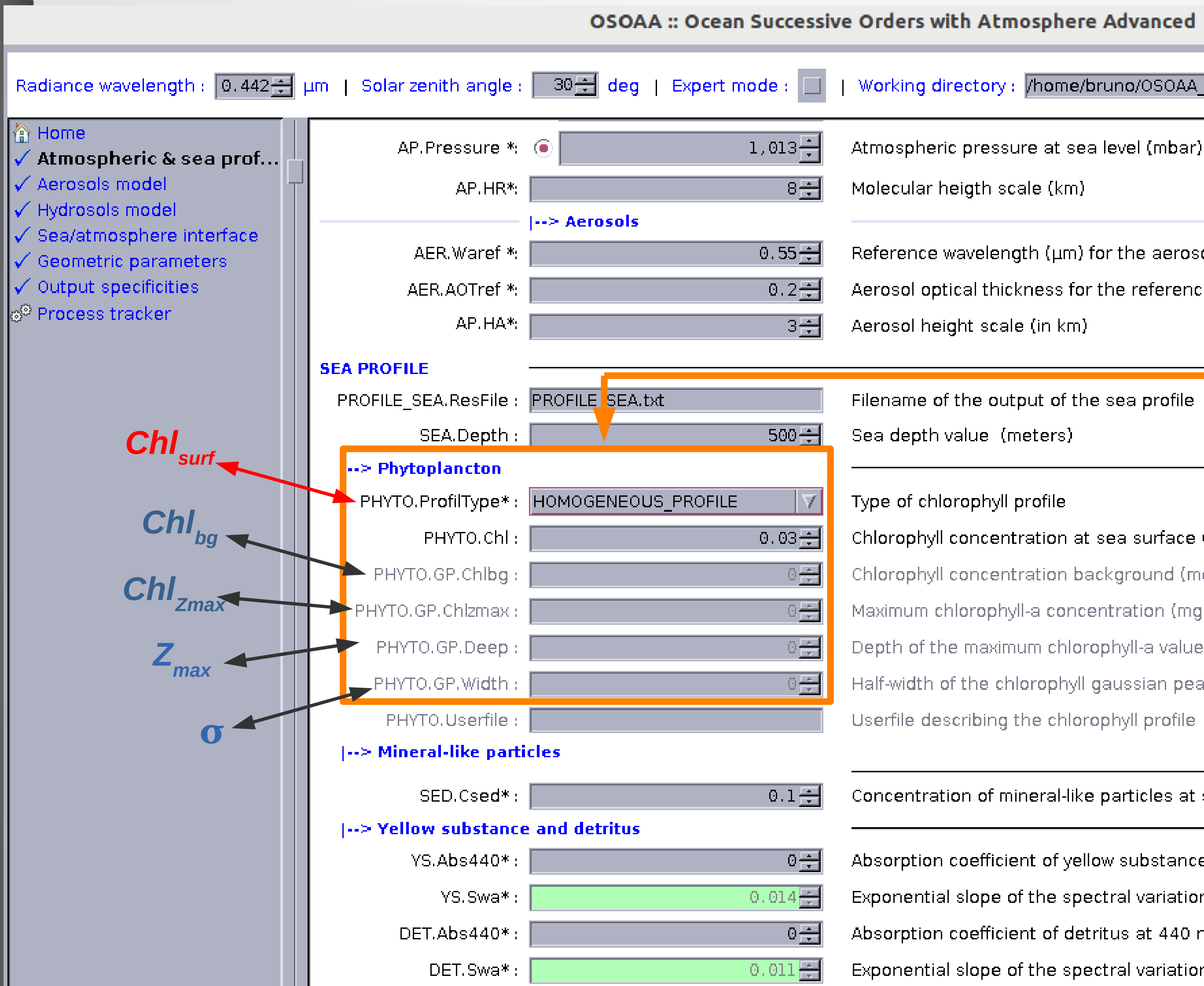
Atmospheric & maritime profiles

- Setting for the example #1 : SIMU_1
  - Open ocean with deep sea bottom and weak surface wind
    - ► *Let's set a depth at 500 m*
    - ► *Let's set the <u>seabed</u> albedo to 0*
    - ► *Let's set the <u>sea surface</u> albedo to 0*
  - Standard atmosphere : sea level pressure and aerosol load (AOT)
    - ► *Let's set the Pressure to 1013 mbar*
    - ► *Let's set the AOT to 0.2 at* λ_{ref} *= 550 nm*
    - ► *Set the molecular and aerosols height scales respectively to 8 and 3 km*

Atmospheric & maritime profiles



Atmospheric & maritime profiles



Chlorophyll profile (phytoplankton)

Homogeneous profile

$$\boxed{Chl(z) = Chl_{surf}}$$

Gaussian profile

$$\mathrm{Chl}(z) = Chl_{bg} + Chl_{Zmax}.\exp\left(-\frac{(z - z_{\max})^2}{2\sigma^2}\right)$$

Lewis et al., 1983 - Morel & Berthon, 1989

User defined profile : Userfile

Z_user (m) ; Chl_user (mg.m^{-3})

Profile of scattering coefficents

$$\sigma_{sca}^{phyto}(\lambda, z) = 0.30 \times \left(\frac{550}{\lambda}\right) \times \mathrm{Chl}(z)^{0.62}$$

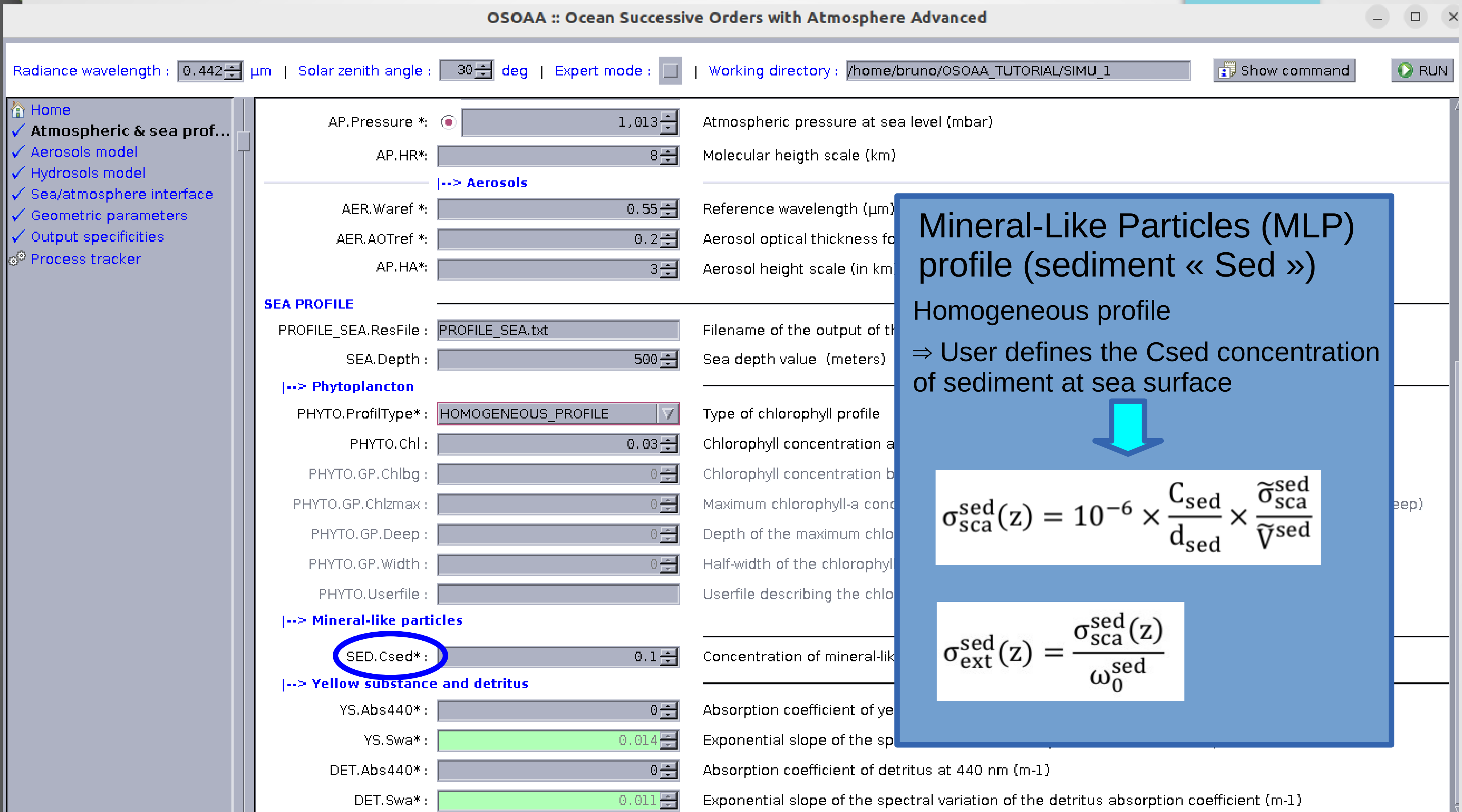
Morel, 1988

Profile of absorption coefficents

$$\sigma_{abs}^{phyto}(\lambda, z) = \mathrm{AP}(\lambda) \times \mathrm{Chl}(z)^{\mathrm{EP}(\lambda)}$$

Bricaud et al. 1998

Atmospheric & maritime profiles



Mineral-Like Particles (MLP) profile (sediment « Sed »)

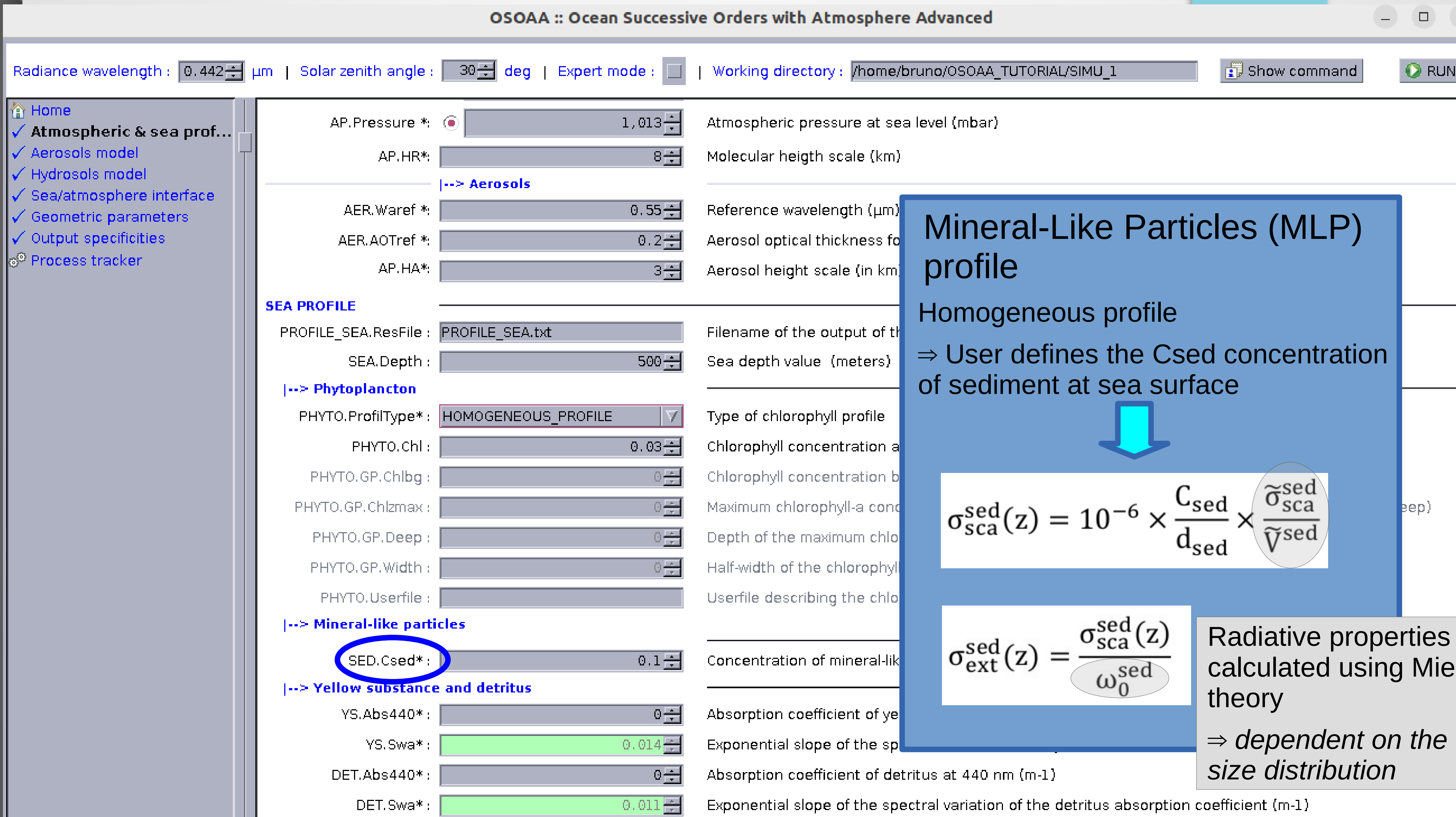
Homogeneous profile

⇒ User defines the Csed concentration of sediment at sea surface

$$\sigma_{sca}^{sed}(z) = 10^{-6} \times \frac{C_{sed}}{d_{sed}} \times \frac{\tilde{\sigma}_{sca}^{sed}}{\tilde{V}^{sed}}$$

$$\sigma_{ext}^{sed}(z) = \frac{\sigma_{sca}^{sed}(z)}{\omega_0^{sed}}$$

Atmospheric & maritime profiles



Mineral-Like Particles (MLP) profile

Homogeneous profile

⇒ User defines the Csed concentration of sediment at sea surface

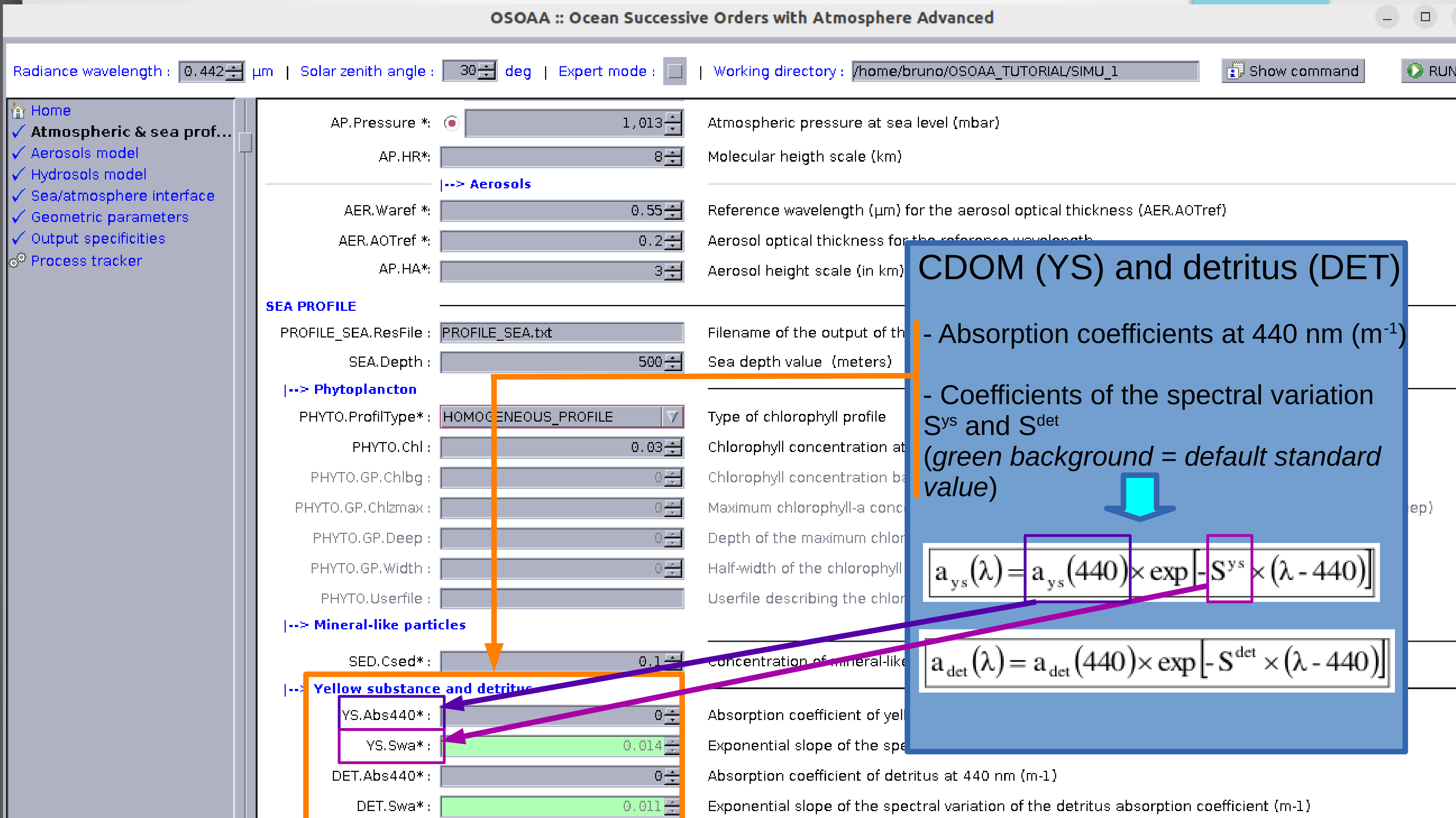
$$\sigma_{sca}^{sed}(z) = 10^{-6} \times \frac{C_{sed}}{d_{sed}} \times \frac{\tilde{\sigma}_{sca}^{sed}}{\tilde{V}^{sed}}$$

$$\sigma_{ext}^{sed}(z) = \frac{\sigma_{sca}^{sed}(z)}{\omega_0^{sed}}$$

Radiative properties calculated using Mie theory

⇒ *dependent on the size distribution*

Atmospheric & maritime profiles



CDOM (YS) and detritus (DET)

- Absorption coefficients at 440 nm (m^{-1})

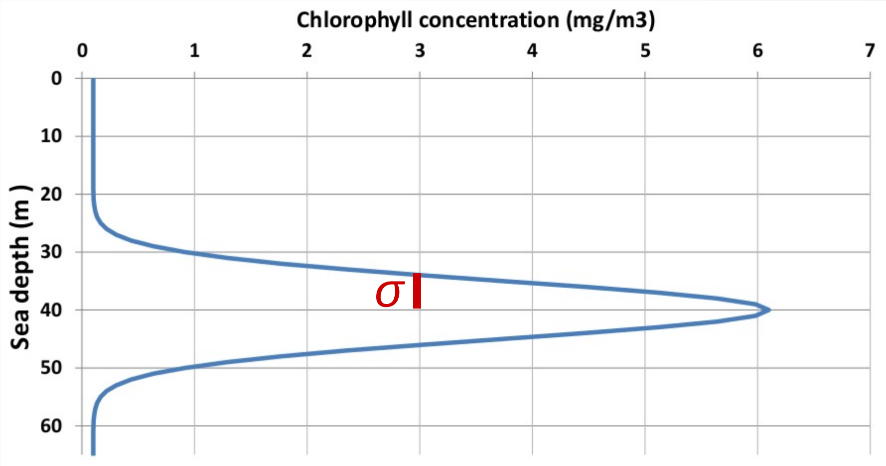
- Coefficients of the spectral variation S^{ys} and S^{det}
(*green background = default standard value*)

$$a_{ys}(\lambda) = a_{ys}(440) \times \exp\left[-S^{ys} \times (\lambda - 440)\right]$$

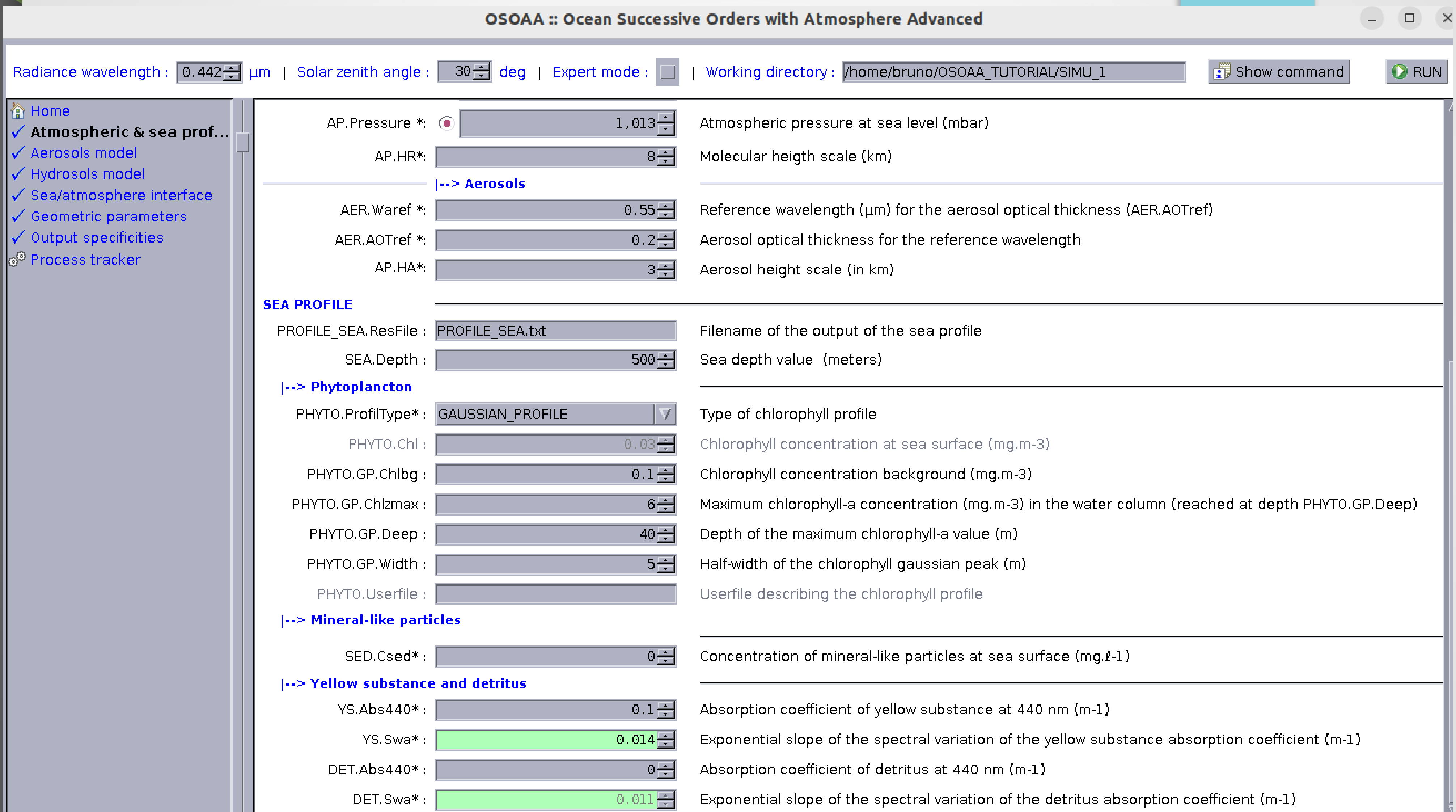
$$a_{det}(\lambda) = a_{det}(440) \times \exp\left[-S^{det} \times (\lambda - 440)\right]$$

Atmospheric & maritime profiles

- Setting for the example #1 : SIMU_1
  - Gaussian Chlorophyll profile
    - ► *Let's set a background concentration : Chl_{bg} = 0.1 $mg.m^{-3}$*
    - ► *Let's set a maximum concentration of the gaussian : Chl_{Zmax} = 6 $mg.m^{-3}$*
    - ► *Let's set the depth of Chl_{Zmax} : z_{max} = 40 m*
    - ► *Let's set a standard deviation (σ) of the peak : σ = 5 m*
  - No Mineral Like Particles
    - ► *Let's set Csed = 0*
  - CDOM
    - ► *Let's set the absorption coefficient YS.Abs440 (a_cdom) = 0.1 m^{-1}*
  - No detritus

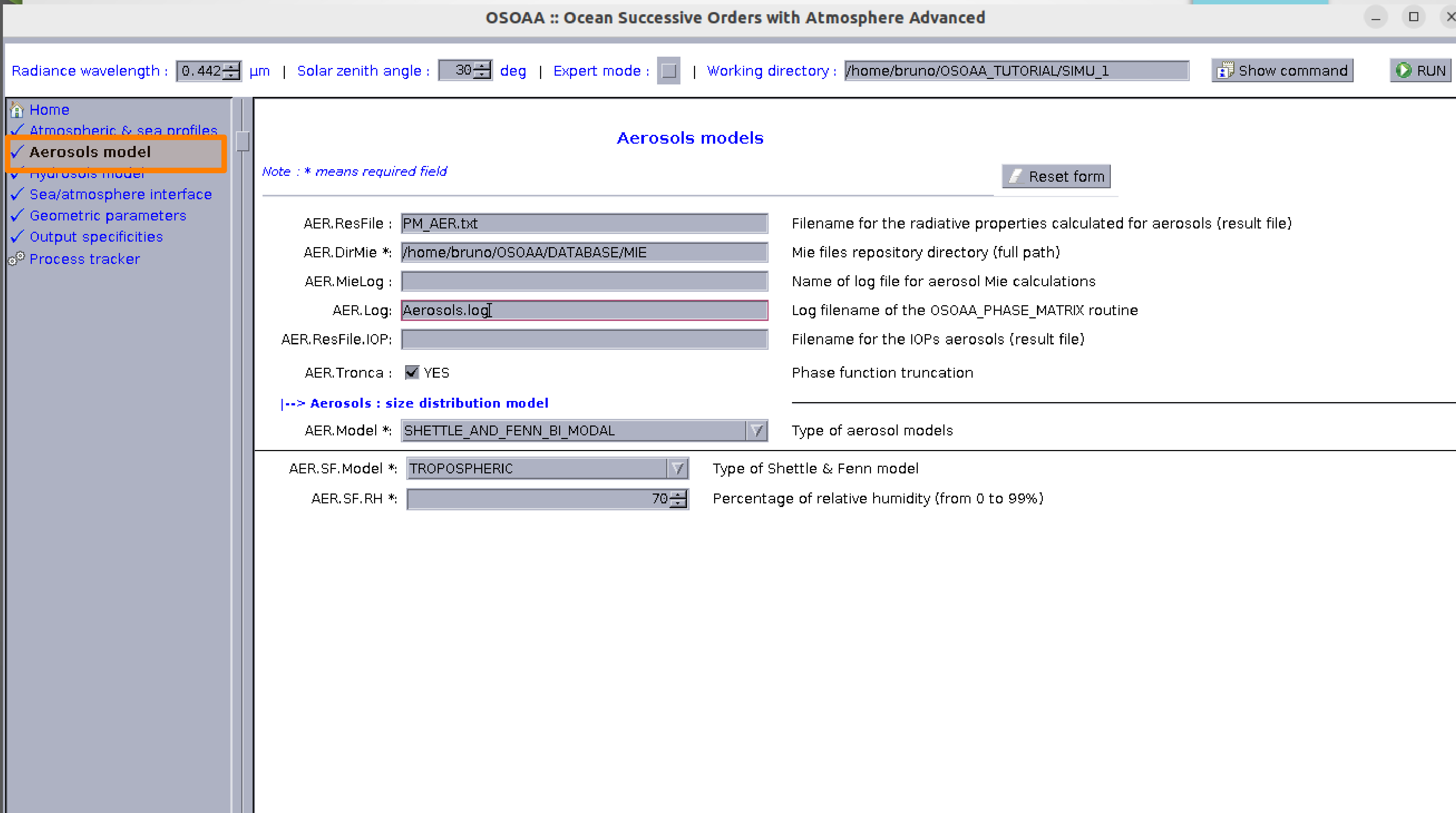


Atmospheric & maritime profiles

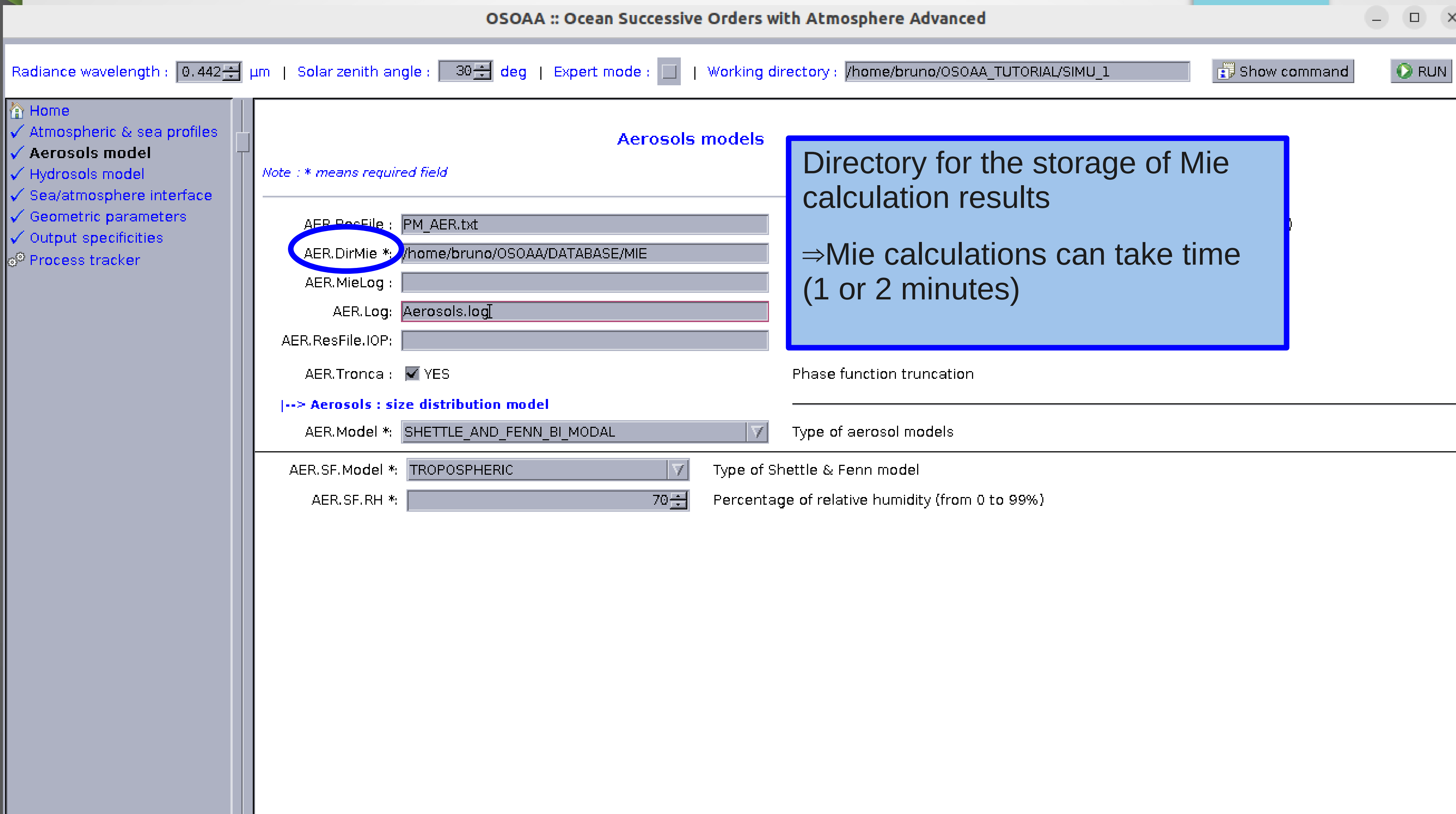


The first GUI window is ready !

Aerosol models



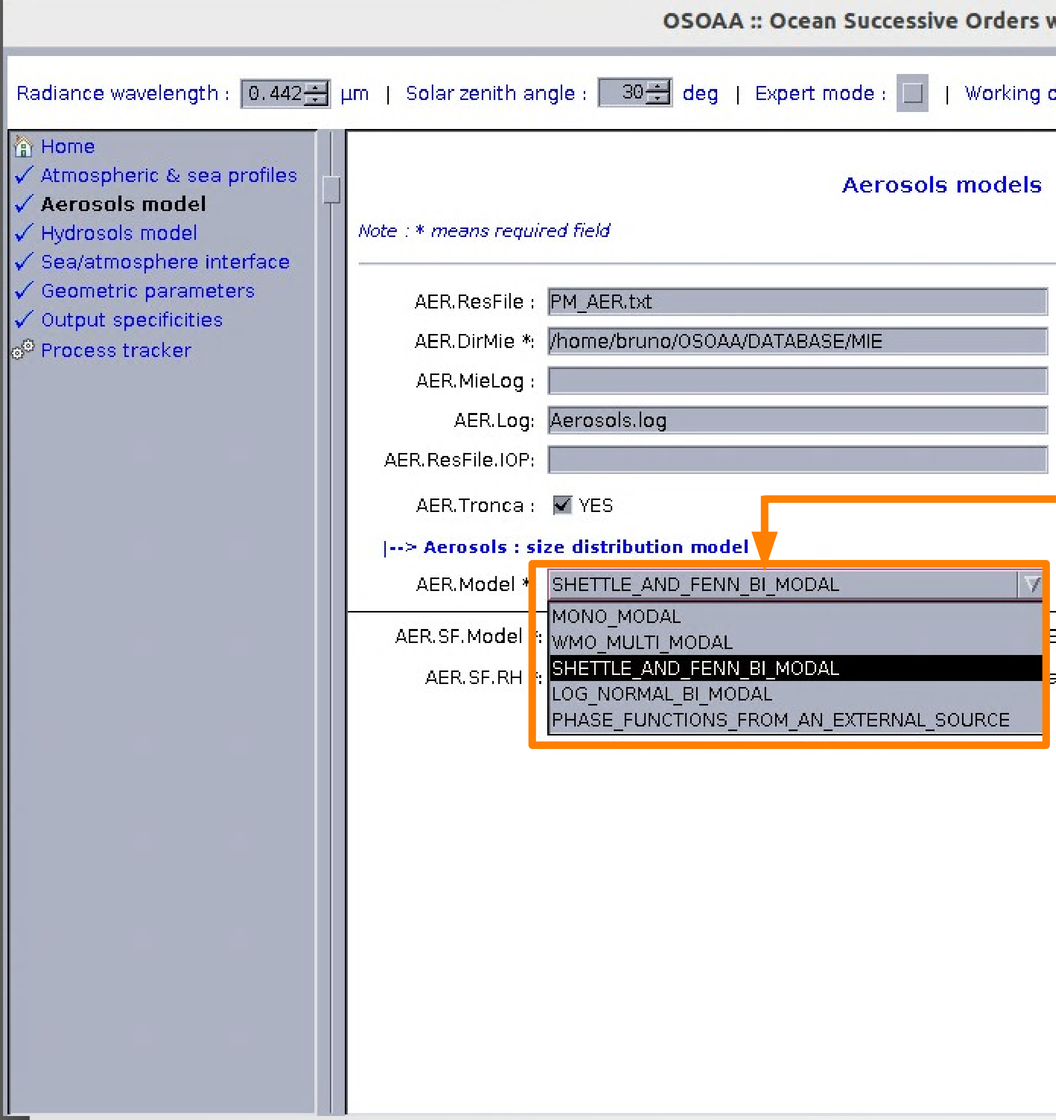
Aerosol models



Directory for the storage of Mie calculation results

⇒Mie calculations can take time (1 or 2 minutes)

Aerosol models



Aerosol models

- Mono modal models
  (i.e. Log-Normal distribution or Junge power law)
- Predefined standard models :
  - WMO models
  - Shettle & Fenn models
- Bi modal models (i.e. user defined)

Mie calculations

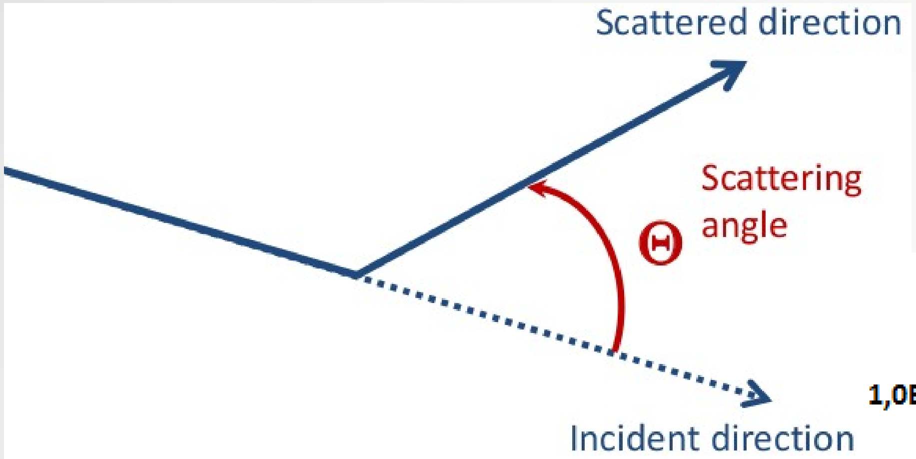
Single scattering albedo

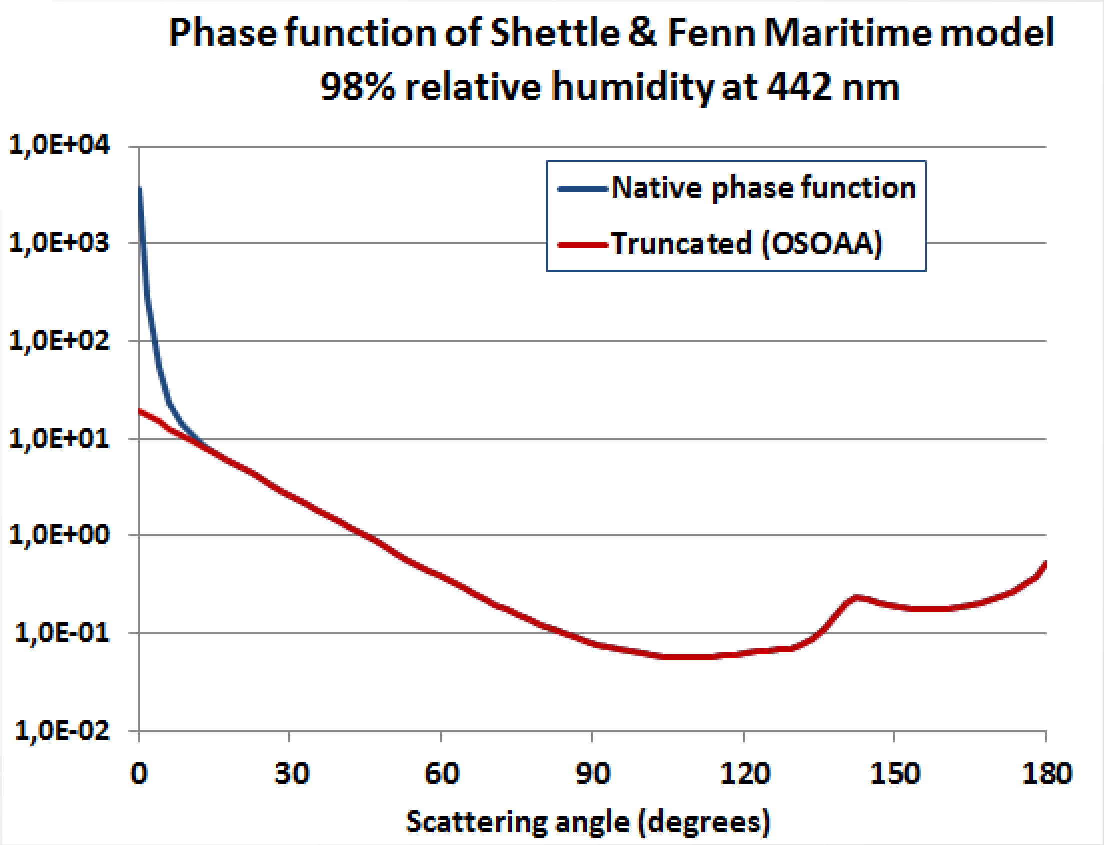
$$\omega_\lambda(\tau) = \frac{\tilde{\sigma}^{\lambda}_{sca}(\tau)}{\tilde{\sigma}^{\lambda}_{ext}(\tau)}$$

Phase matrix : probability of scattering in a given direction

$$\tilde{\tilde{P}}_\lambda(\Theta) = \begin{pmatrix} P_{11}(\Theta) & P_{12}(\Theta) & 0 \\ P_{12}(\Theta) & P_{22}(\Theta) & 0 \\ 0 & 0 & P_{33}(\Theta) \end{pmatrix}$$

Aerosol models

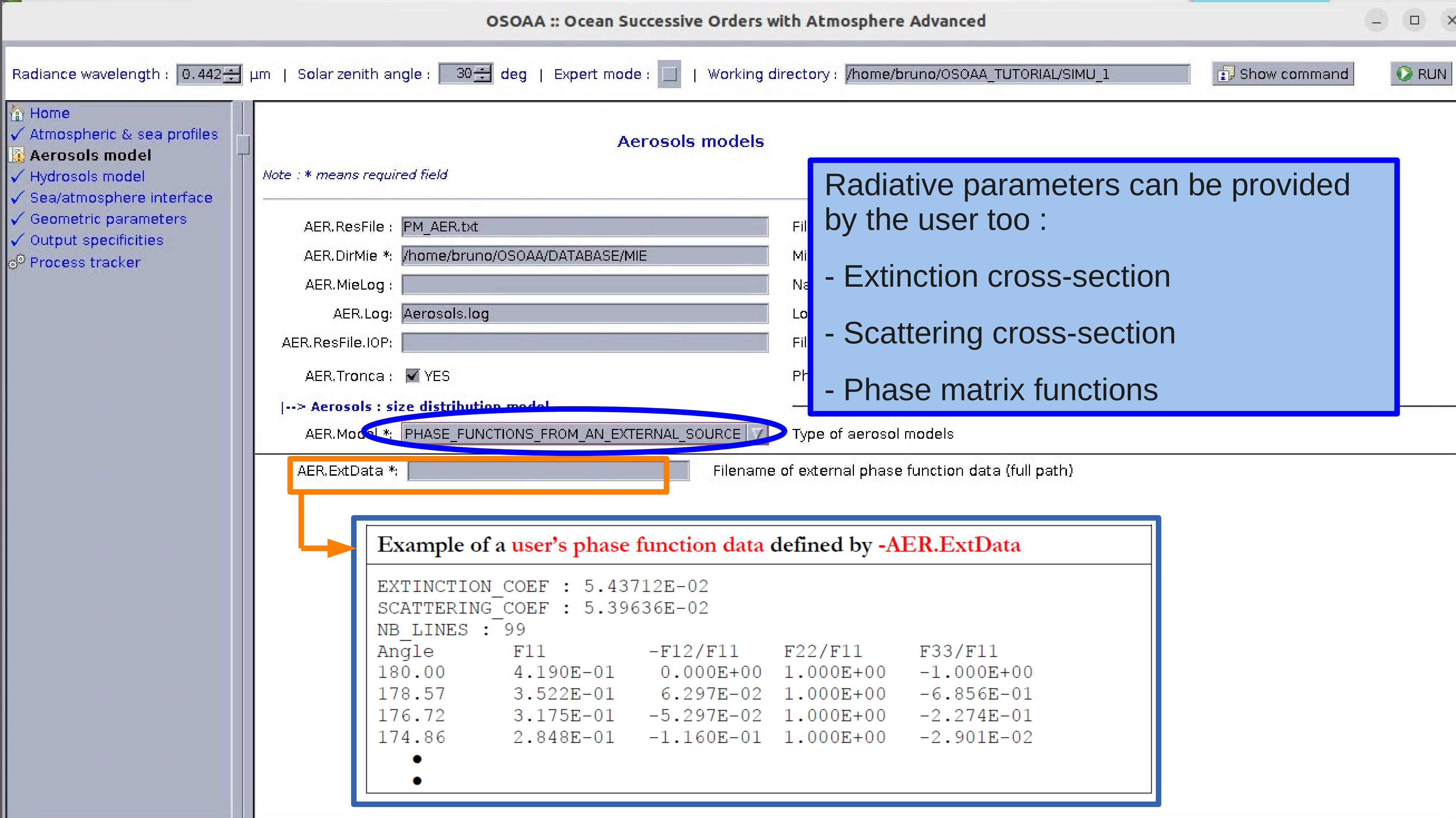




Note:

The native phase function is truncated in the forward peak within OSOAA to reduce the computation time (Lenoble, 1974 ; Chami et al., 2001)

Aerosol models



Radiative parameters can be provided by the user too :

- Extinction cross-section
- Scattering cross-section
- Phase matrix functions

Example of a user's phase function data defined by -AER.ExtData

EXTINCTION_COEF : 5.43712E-02
SCATTERING_COEF : 5.39636E-02
NB_LINES : 99

Angle	F11	-F12/F11	F22/F11	F33/F11
180.00	4.190E-01	0.000E+00	1.000E+00	-1.000E+00
178.57	3.522E-01	6.297E-02	1.000E+00	-6.856E-01
176.72	3.175E-01	-5.297E-02	1.000E+00	-2.274E-01
174.86	2.848E-01	-1.160E-01	1.000E+00	-2.901E-02

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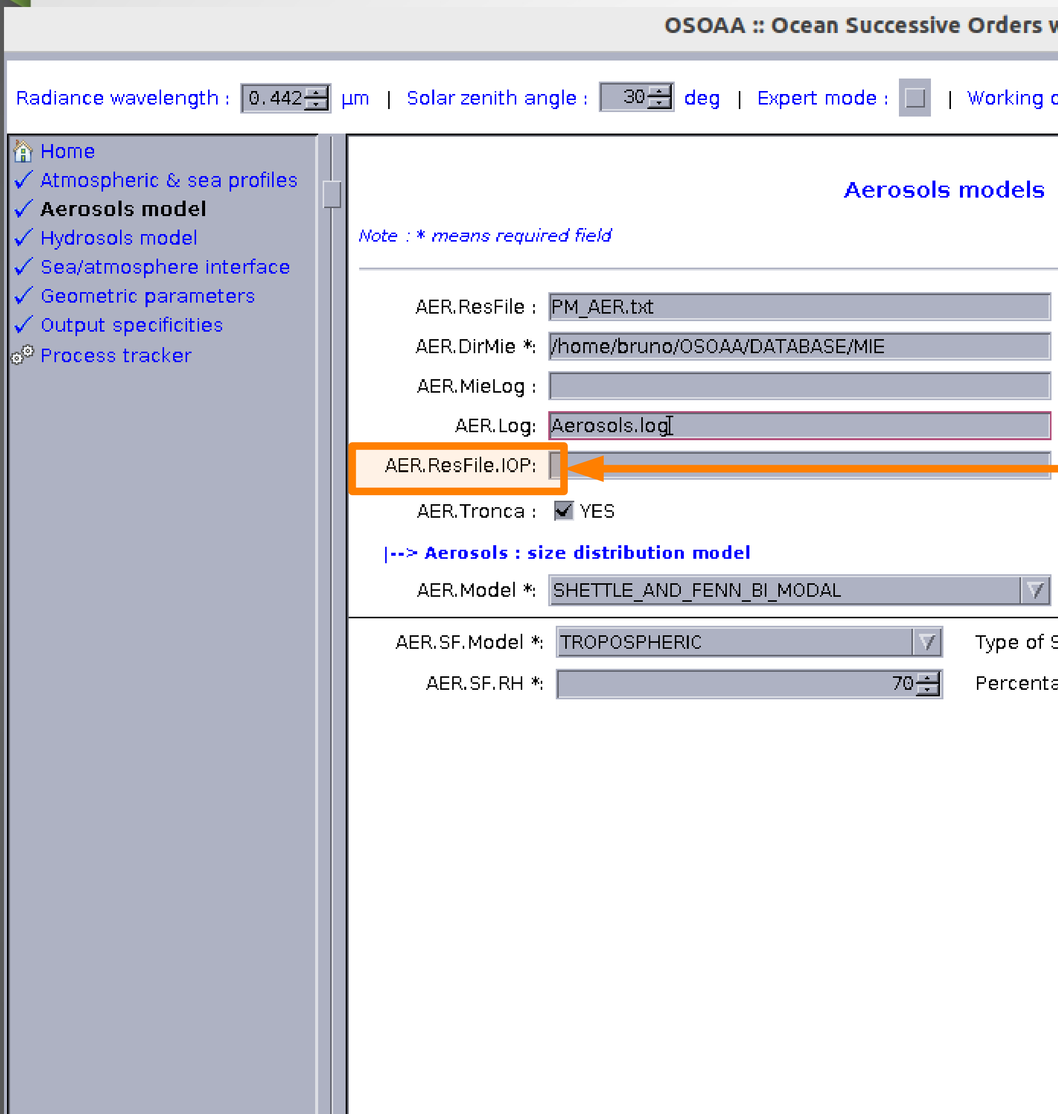
Aerosol models



Optional parameter to request Inherent Optical Properties of aerosols

New output for OSOAA V2.0

```
RADIATIVE PROPERTIES OF AEROSOLS
--------------------------------

Cross-sections:
  Extinction cross-section (mic^2):  0.18008E+00
  Scattering cross-section (mic^2):  0.17968E+00
  Single scattering albedo        :  0.99774

Phase matrix:
   1st column : Scattering angle
   2nd column : Phase function P11
   3rd column : Polarized phase function P12
   4th column : Polarized phase function P22
   5th column : Polarized phase function P33

   180.00    0.5272E+00    0.0000E+00    0.5272E+00   -0.5272E+00
   178.29    0.3849E+00   -0.1455E-01    0.3849E+00   -0.1171E+00
   176.07    0.3244E+00    0.4367E-01    0.3244E+00    0.5076E-01
   173.84    0.2705E+00    0.5072E-01    0.2705E+00    0.7072E-01
   171.61    0.2437E+00    0.4979E-01    0.2437E+00    0.6414E-01
   169.37    0.2258E+00    0.3997E-01    0.2258E+00    0.5761E-01
   167.14    0.2076E+00    0.2873E-01    0.2076E+00    0.4998E-01
   164.90    0.1922E+00    0.1662E-01    0.1922E+00    0.4363E-01
   162.67    0.1830E+00    0.8224E-02    0.1830E+00    0.3953E-01
   *
   *
   *
```

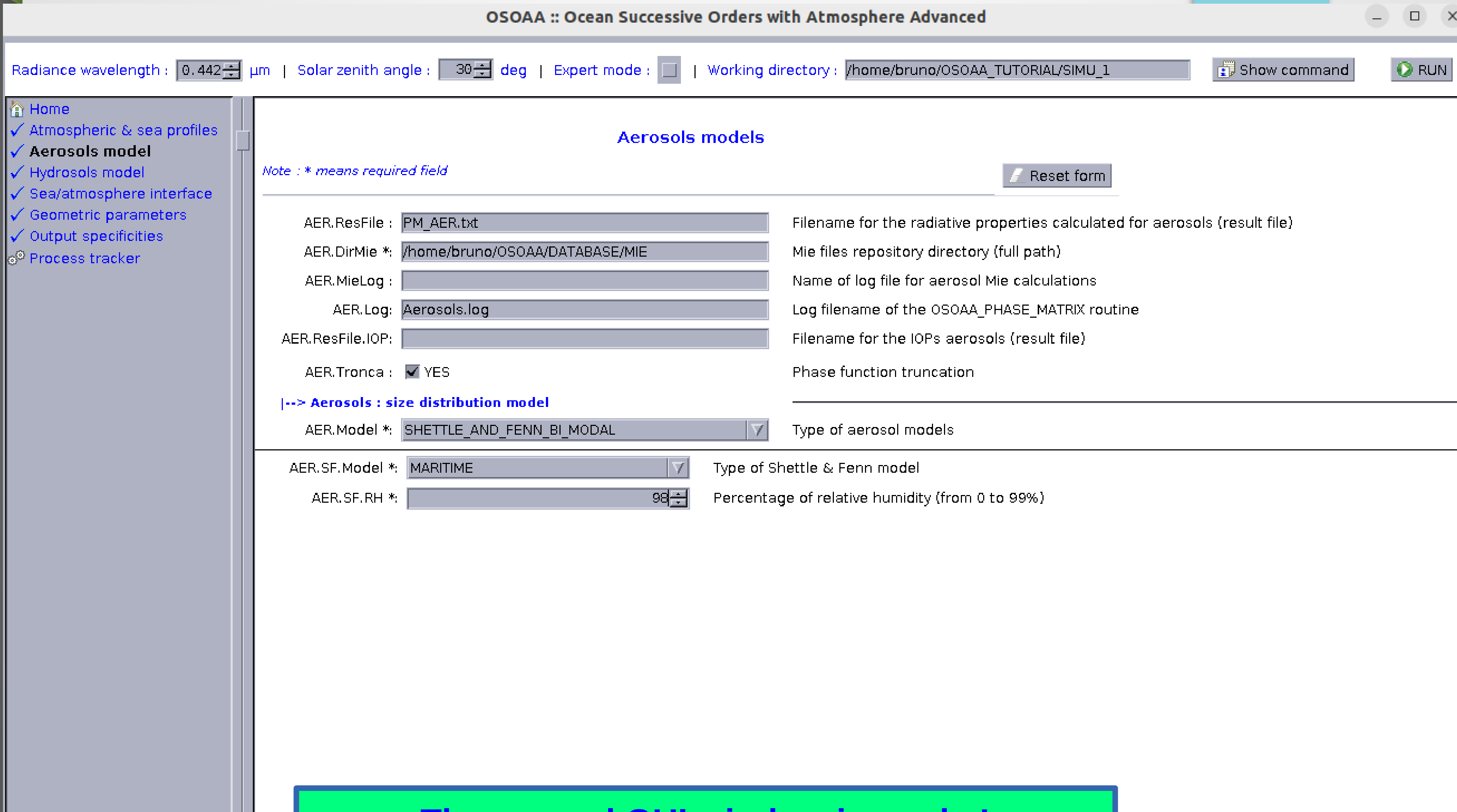
Aerosol models

- Setting for the example #1 : SIMU_1

►*Let's define your own repertory for Mie files storage*

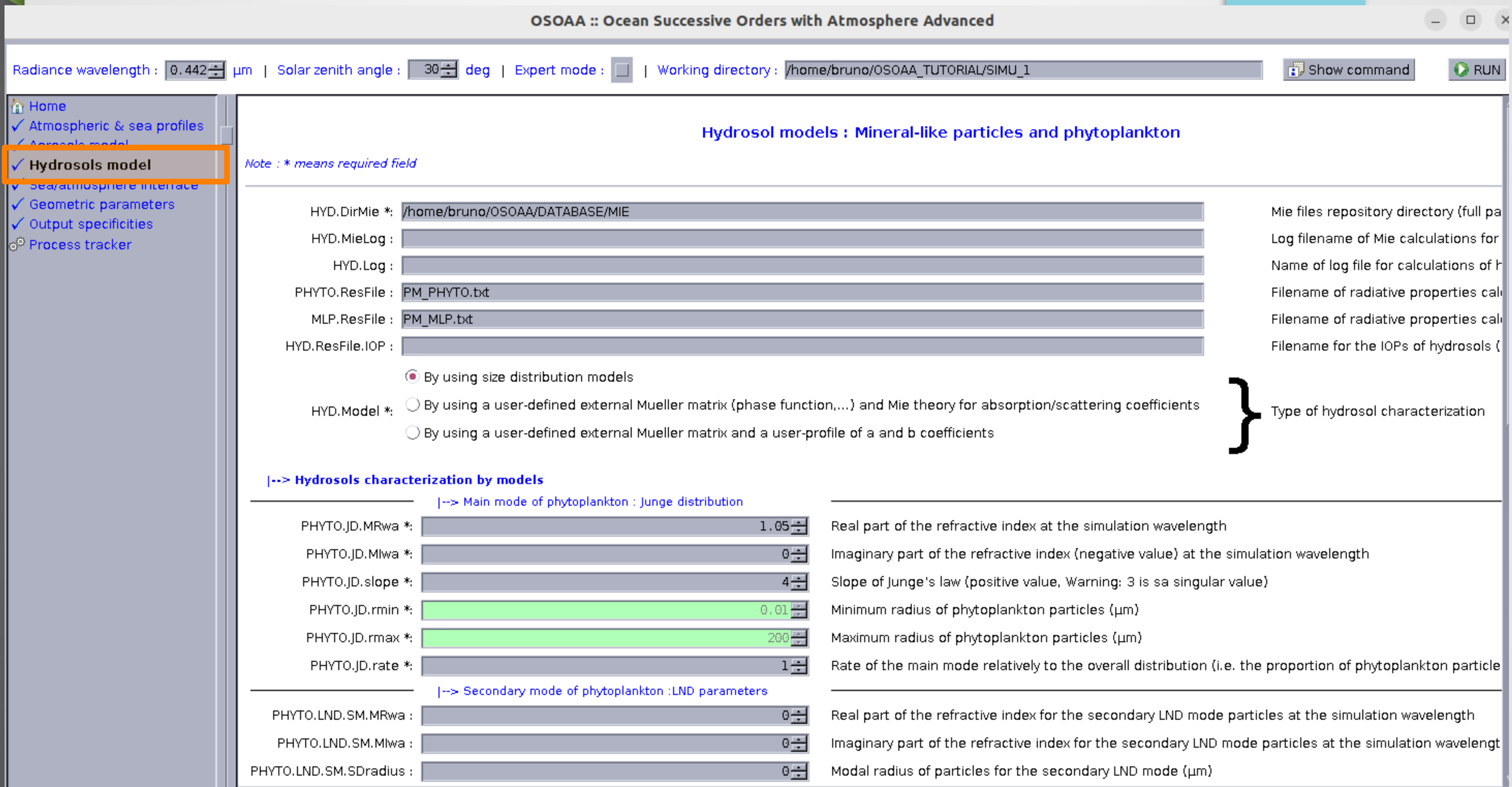
►*Let's set aerosol optical properties are modelled using the Shettle & Fenn Maritime model for a 98 % relative humidity*

Aerosol models

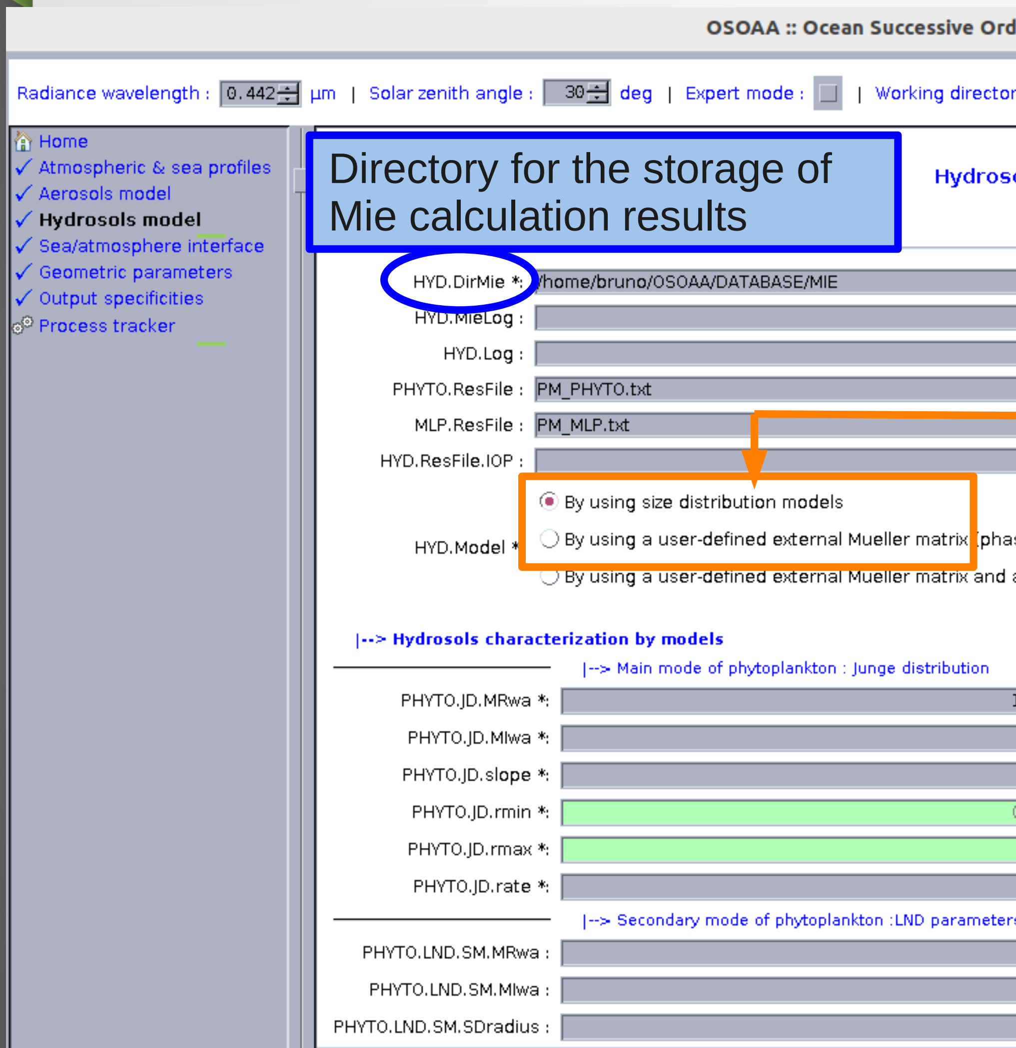


The second GUI window is ready !

Hydrosol models



Hydrosol models



Directory for the storage of Mie calculation results

Hydrosol models

- Multi modal model

Junge's law model: Main mode

$$\begin{cases} r \le r_{min} : N_{hyd}^{Junge}(r) = r_{min}^{-\upsilon} \\ r_{min} < r \le r_{max} : N_{hyd}^{Junge}(r) = r^{-\upsilon} \\ r > r_{max} : N_{hyd}^{Junge}(r) = 0 \end{cases}$$

Log-Normal size Distribution (LND): secondary and tertiary modes

$$N_i^{LND}(r) = \frac{1}{r.\sigma_i.\sqrt{2\pi}} \times \exp\left[\frac{-\ln^2(r/r_i)}{2\sigma_i^2}\right]$$

optional

- Radiative parameters can be provided by user

Mie calculations

Single scattering albedo $\omega_\lambda(\tau) = \dfrac{\tilde{\sigma}_{sca}^{\lambda}(\tau)}{\tilde{\sigma}_{ext}^{\lambda}(\tau)}$

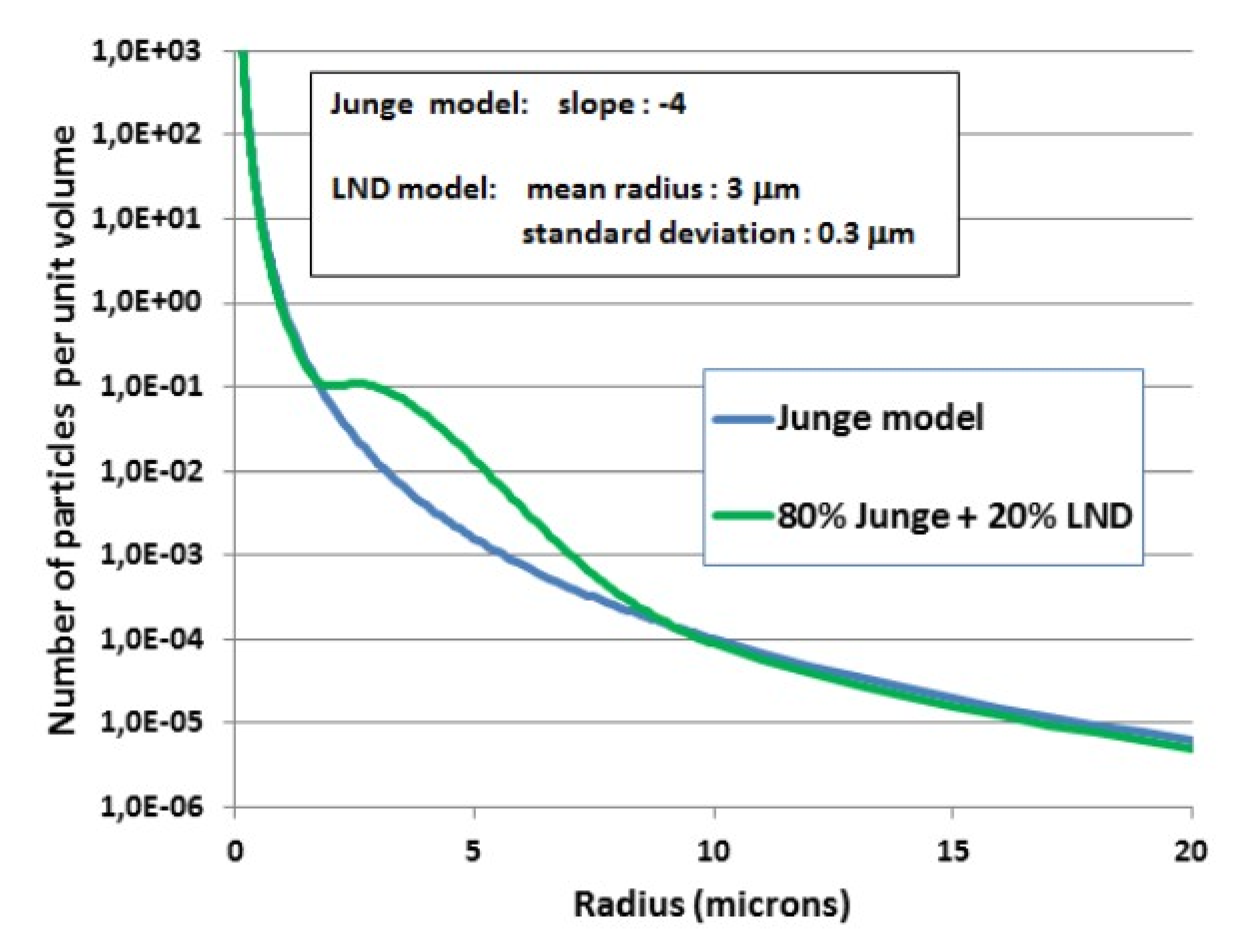
Phase matrix

$$\tilde{P}_\lambda(\Theta) = \begin{pmatrix} P_{11}(\Theta) & P_{12}(\Theta) & 0 \\ P_{12}(\Theta) & P_{22}(\Theta) & 0 \\ 0 & 0 & P_{33}(\Theta) \end{pmatrix}$$

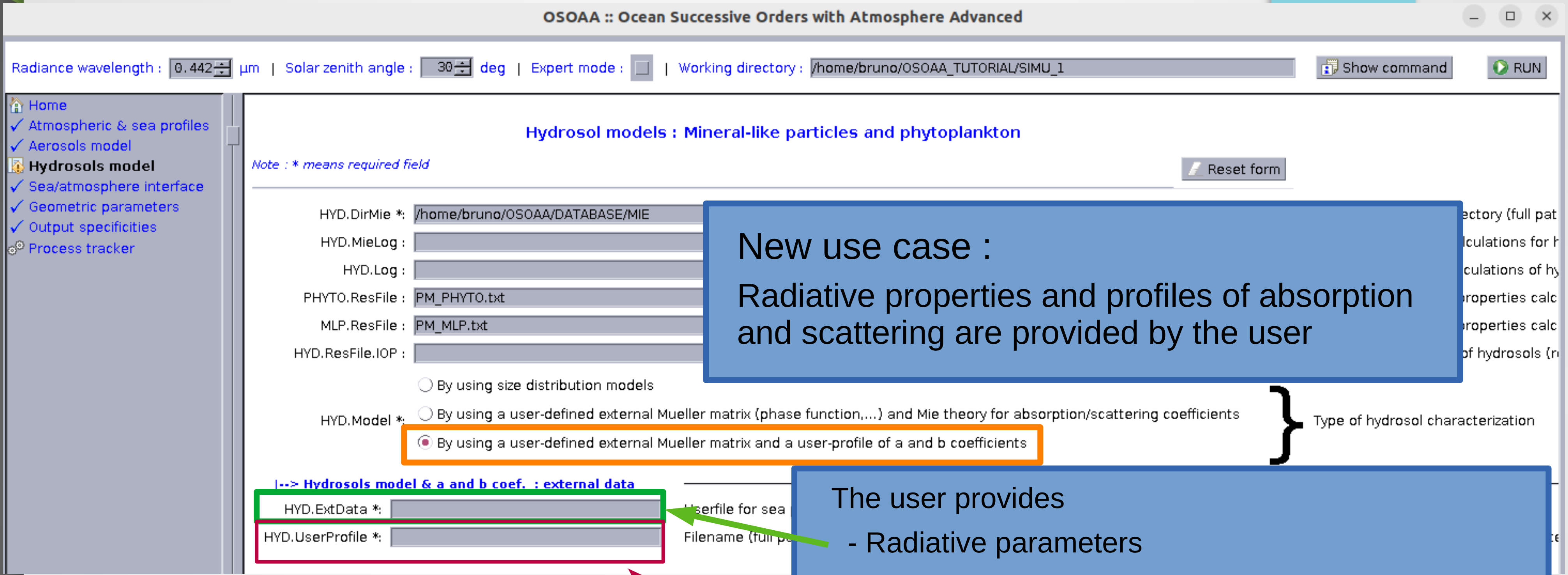
P_{11} = Phase function of hydrosols
P_{12} = Polarized phase function

For these use cases, absorption and scattering profiles (a & b coefficients) are defined on the basis of models

Hydrosol models



Hydrosol models



New use case :

Radiative properties and profiles of absorption and scattering are provided by the user

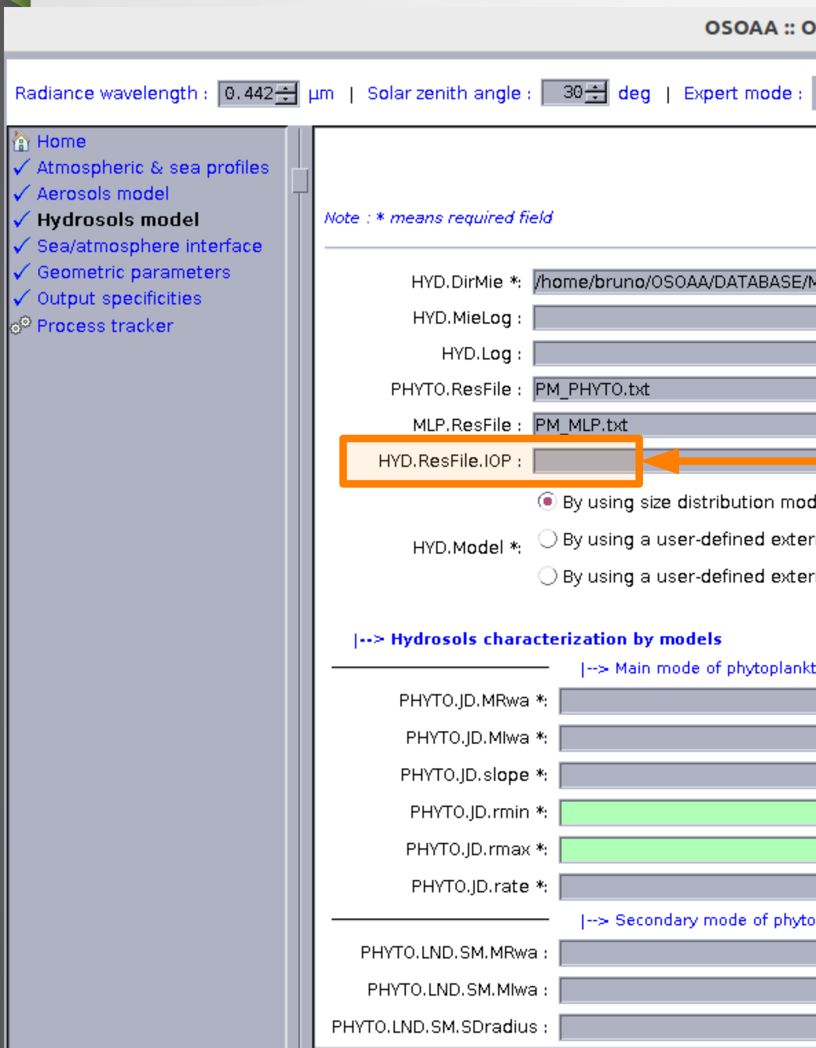
The user provides

- Radiative parameters
- Measured profiles of absorption and scattering coefficients of non-water constituents

	Total absorption coefficient / Pure seawater absorption coeff	Total scattering coefficient / Pure seawater scattering coeff
z_{user}	$a(z_{user}) - a_w$	$b(z_{user}) - b_w$
Depth (in m)	**Hydrosols absorption** coefficient (in m^{-1})	**Hydrosols scattering** coefficient (in m^{-1})

New feature for OSOAA V2.0

Hydrosol models



Optional parameter to request Inherent Optical Properties of hydrosols

New output for OSOAA V2.0

```
RADIATIVE PROPERTIES OF HYDROSOLS
---------------------------------

PHYTOPLANKTON:
--------------

Phase matrix:
   1st column : Scattering angle
   2nd column : Phase function P11
   3rd column : Polarized phase function P12
   4th column : Polarized phase function P22
   5th column : Polarized phase function P33

   180.00    0.2927E-01    0.0000E+00    0.2927E-01   -0.2927E-01
   178.29    0.1973E-01   -0.3624E-03    0.1973E-01   -0.7189E-02
   176.07    0.1580E-01   -0.2264E-03    0.1580E-01   -0.1060E-01
      *
      *
      *
     3.93    0.1571E+03    0.1298E+00    0.1571E+03    0.1571E+03
     1.71    0.4230E+03    0.2201E+00    0.4230E+03    0.4230E+03
     0.00    0.1895E+05    0.0000E+00    0.1895E+05    0.1895E+05

Phase function integration (no truncation)
  Phase function integration from 0 to 180 deg:   2.0031944636763619
  Phase function integration from 90 to 180 deg:   1.4899820768392236E-002


-----------------------
MINERAL-LIKE PARTICLES:
-----------------------
      *
      *
      *

-------------------------------------
SCATTERING and BACK-SCATTERING PROFILES
-------------------------------------

          |  PHYTOPLANKTON                     |  MINERAL-LIKE PARTICLES            |  GLOBAL MIXTURE OF PARTICLES
 Depth (m)  b (/m)       bb (/m)      bb/b        b (/m)       bb (/m)      bb/b          b (/m)       bb (/m)      bb/b
   0.00     0.89549E-01  0.66713E-03  0.74499E-02  -0.00000E+00 -0.00000E+00  0.00000E+00   0.38093E-01  0.28379E-03  0.74499E-02
   0.05     0.89549E-01  0.66713E-03  0.74499E-02  -0.00000E+00 -0.00000E+00  0.00000E+00   0.38093E-01  0.28379E-03  0.74499E-02
   0.10     0.89549E-01  0.66713E-03  0.74499E-02  -0.00000E+00 -0.00000E+00  0.00000E+00   0.38093E-01  0.28379E-03  0.74499E-02
      *
      *
      *
  39.95     0.11454E+01  0.85330E-02  0.74499E-02  -0.00000E+00 -0.00000E+00  0.00000E+00   0.92739E+00  0.69090E-02  0.74499E-02
  40.00     0.11454E+01  0.85333E-02  0.74499E-02  -0.00000E+00 -0.00000E+00  0.00000E+00   0.92742E+00  0.69092E-02  0.74499E-02
  40.05     0.11454E+01  0.85330E-02  0.74499E-02  -0.00000E+00 -0.00000E+00  0.00000E+00   0.92739E+00  0.69090E-02  0.74499E-02
      *
      *
      *
```

Phase matrix for Phytoplankton and for Mineral-like particles

b, bb, bb/b profiles for Phytoplankton, Mineral-like particles, and for the global mixture

Hydrosol models

- Setting for the example #1 : SIMU_1

  ► *Let's define a directory for the storage of Mie calculations*

  - Phytoplankton

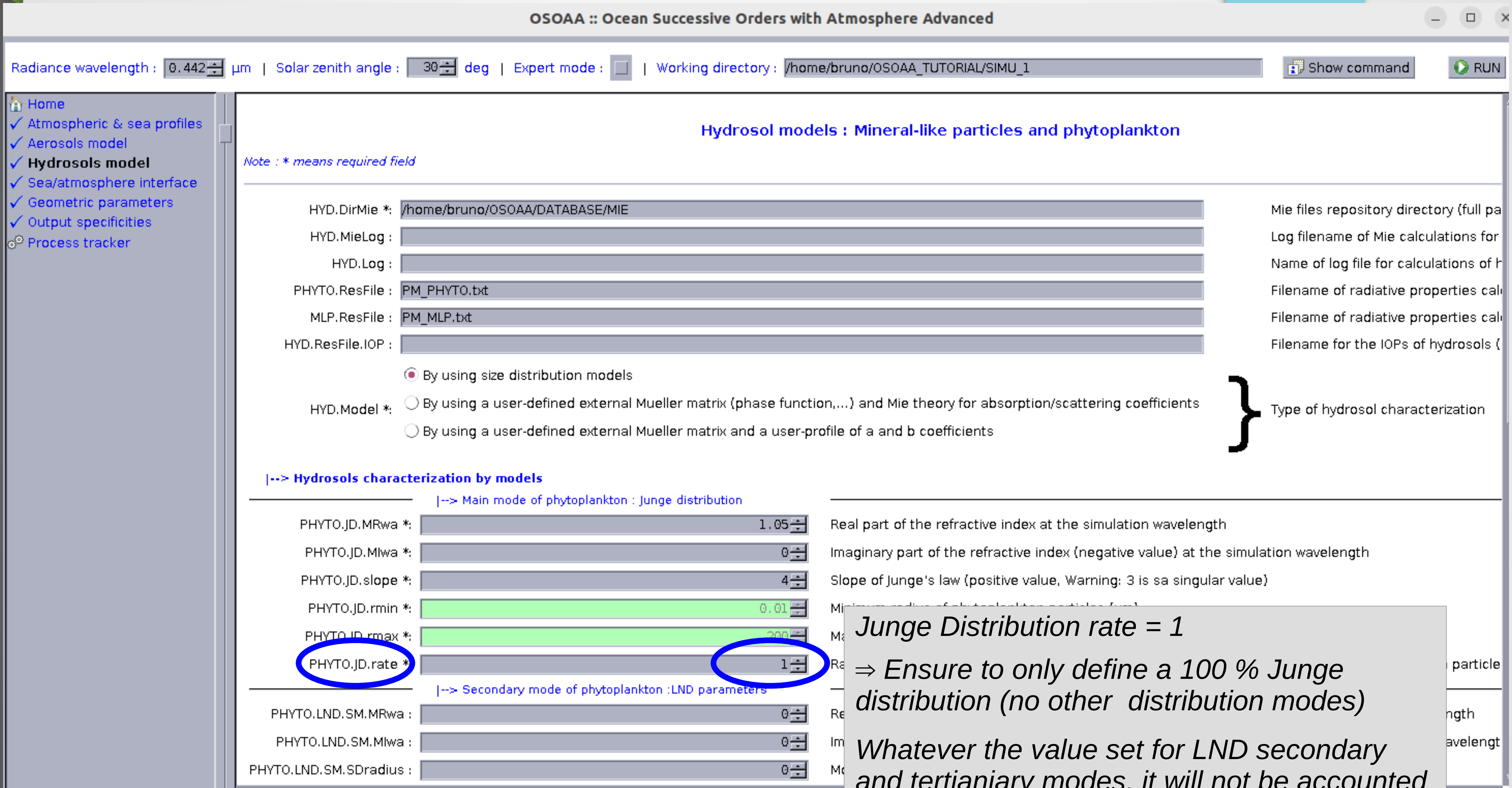
    ► *Let's set a refractive index = 1.05 (no imaginary part)*

    ► *Let's set hydrosol size distribution by a Junge model with :*

    - *Minimal radius : r_{min} = 0.01*
    - *Maximal radius : r_{max} = 200 µm*
    - *Slope of the Junge power law : -ν = - 4*

  - No mineral-like particles

Hydrosol models

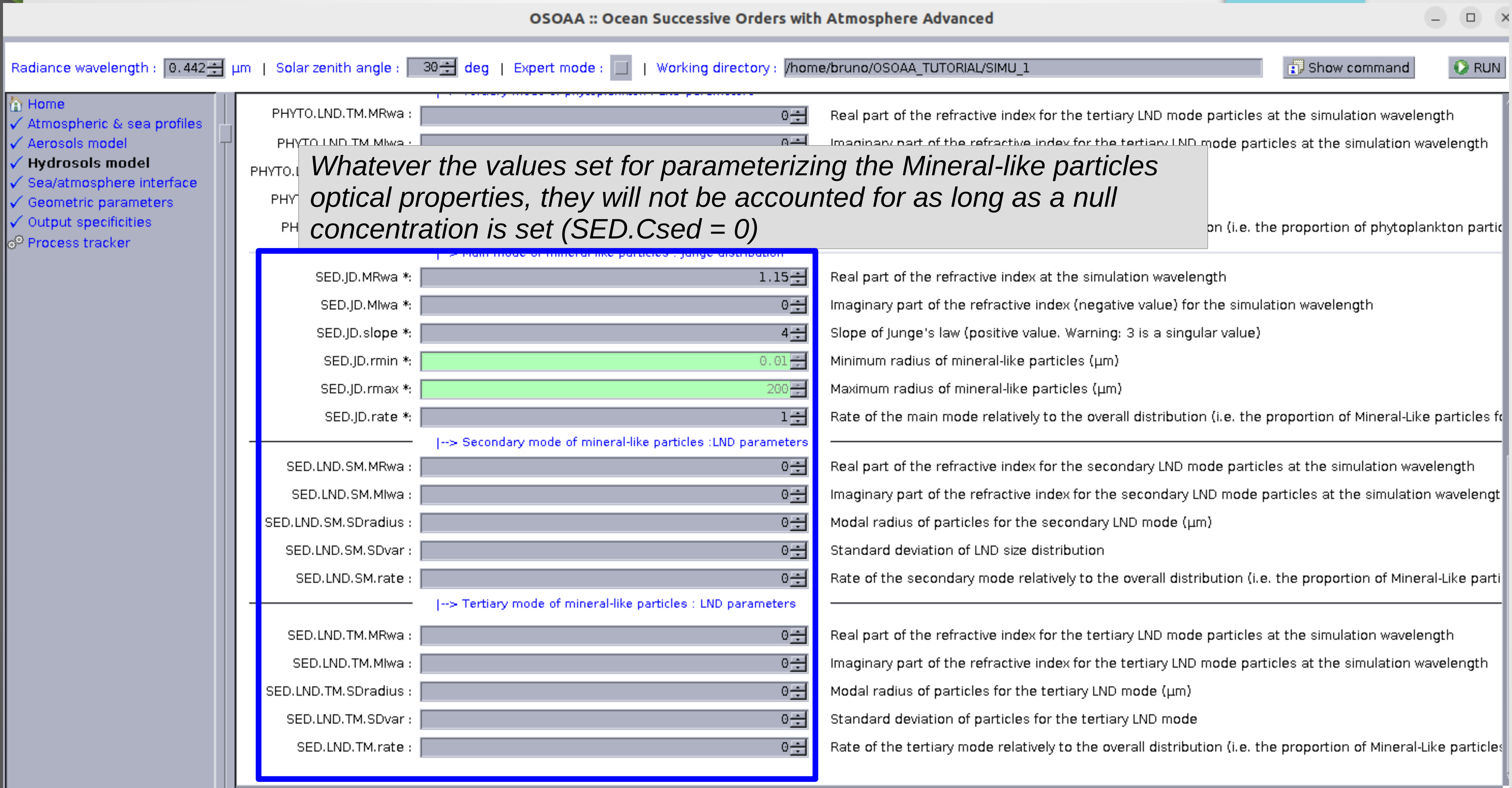


Junge Distribution rate = 1

⇒ Ensure to only define a 100 % Junge distribution (no other distribution modes)

Whatever the value set for LND secondary and tertianiary modes, it will not be accounted for as long as PHYTO.JD.rate = 1

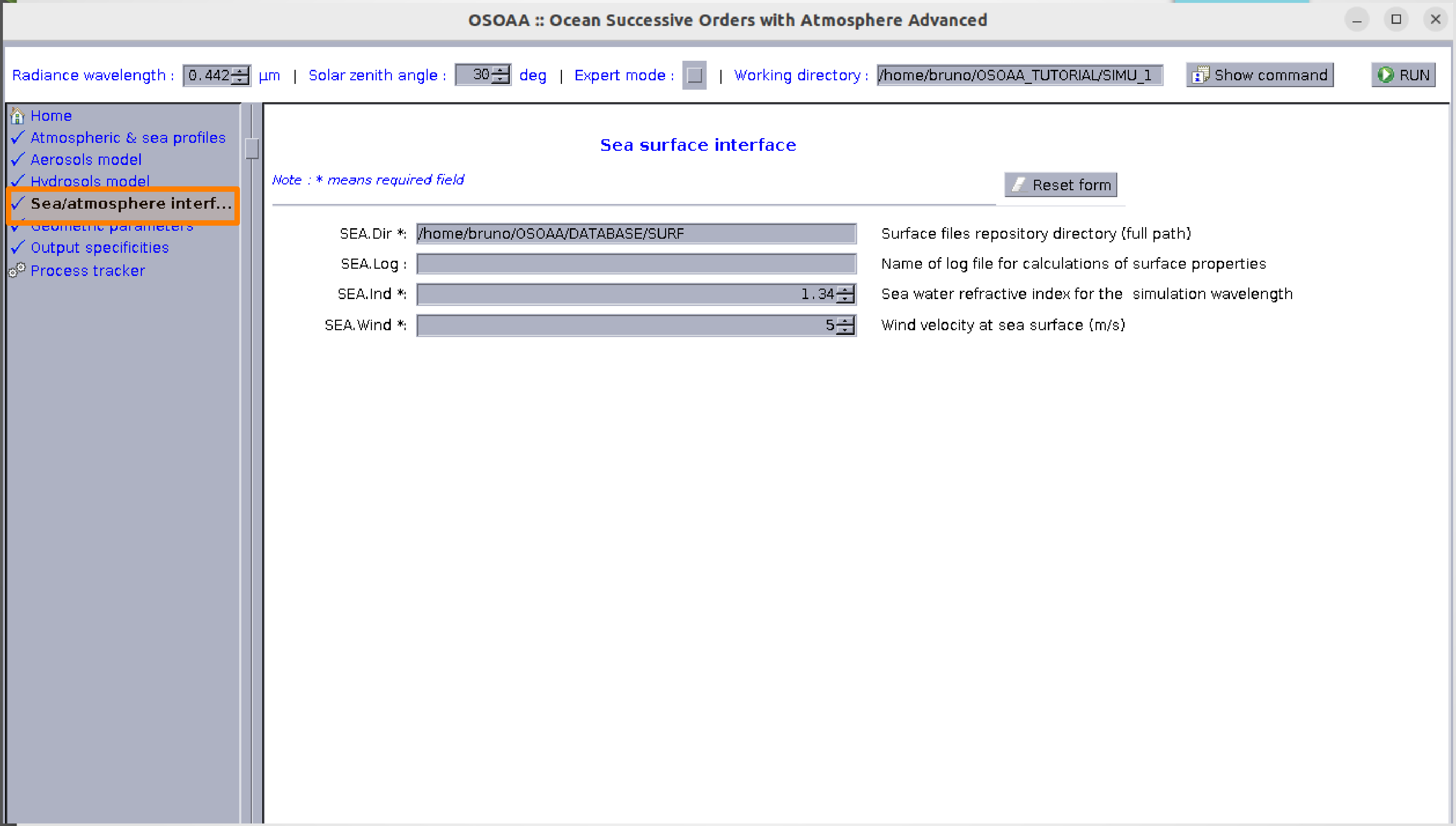
Hydrosol models



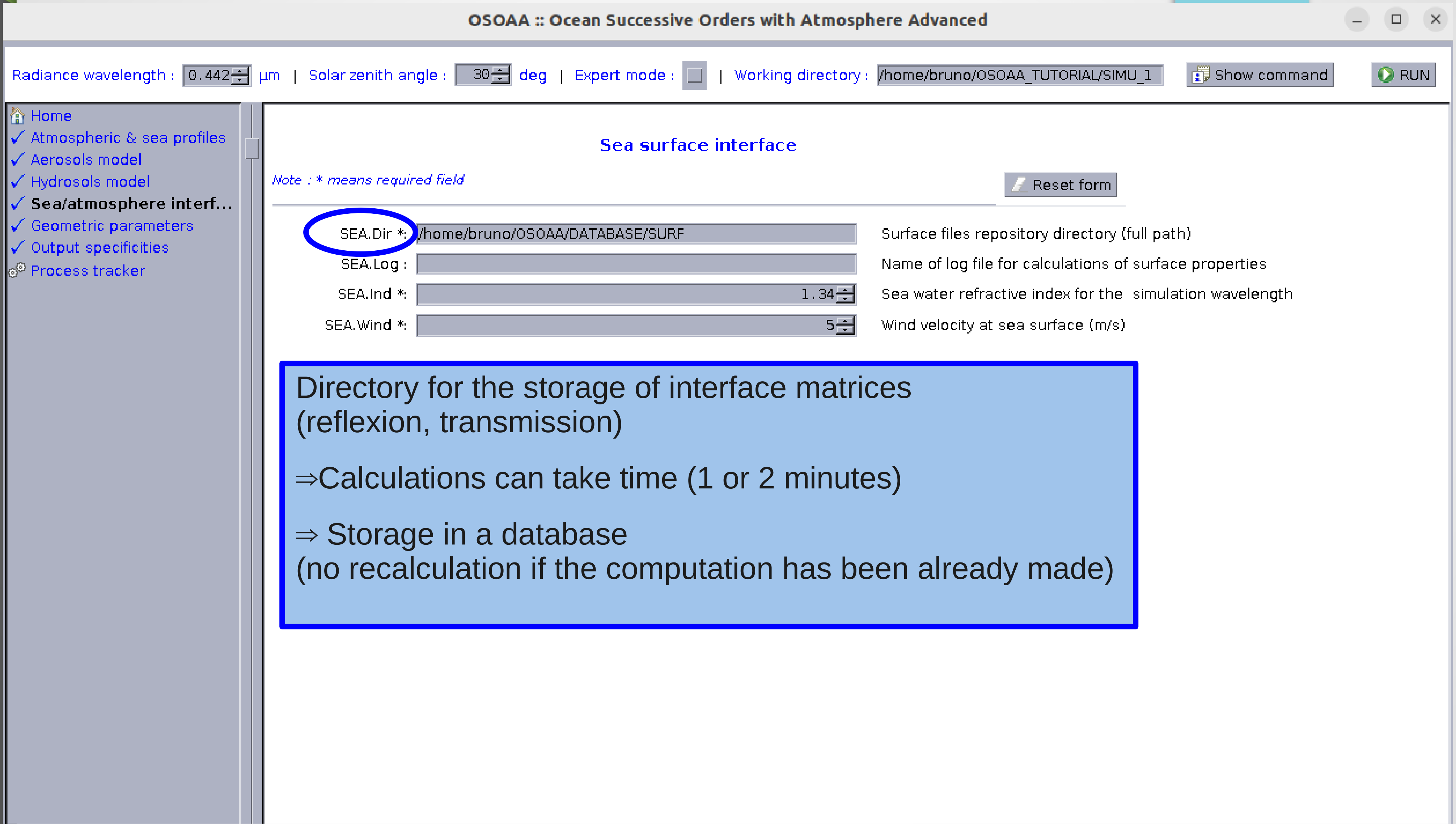
Whatever the values set for parameterizing the Mineral-like particles optical properties, they will not be accounted for as long as a null concentration is set (SED.Csed = 0)

The third GUI window is ready !

Sea / atmosphere interface



Sea / atmosphere interface



Directory for the storage of interface matrices
(reflexion, transmission)

⇒Calculations can take time (1 or 2 minutes)

⇒ Storage in a database
(no recalculation if the computation has been already made)

Sea / atmosphere interface

- Setting for the example #1 : SIMU_1

► *Let's define a directory for the storage of surface reflexion and transmission matrices*

► *No logfile for surface matrices computations*

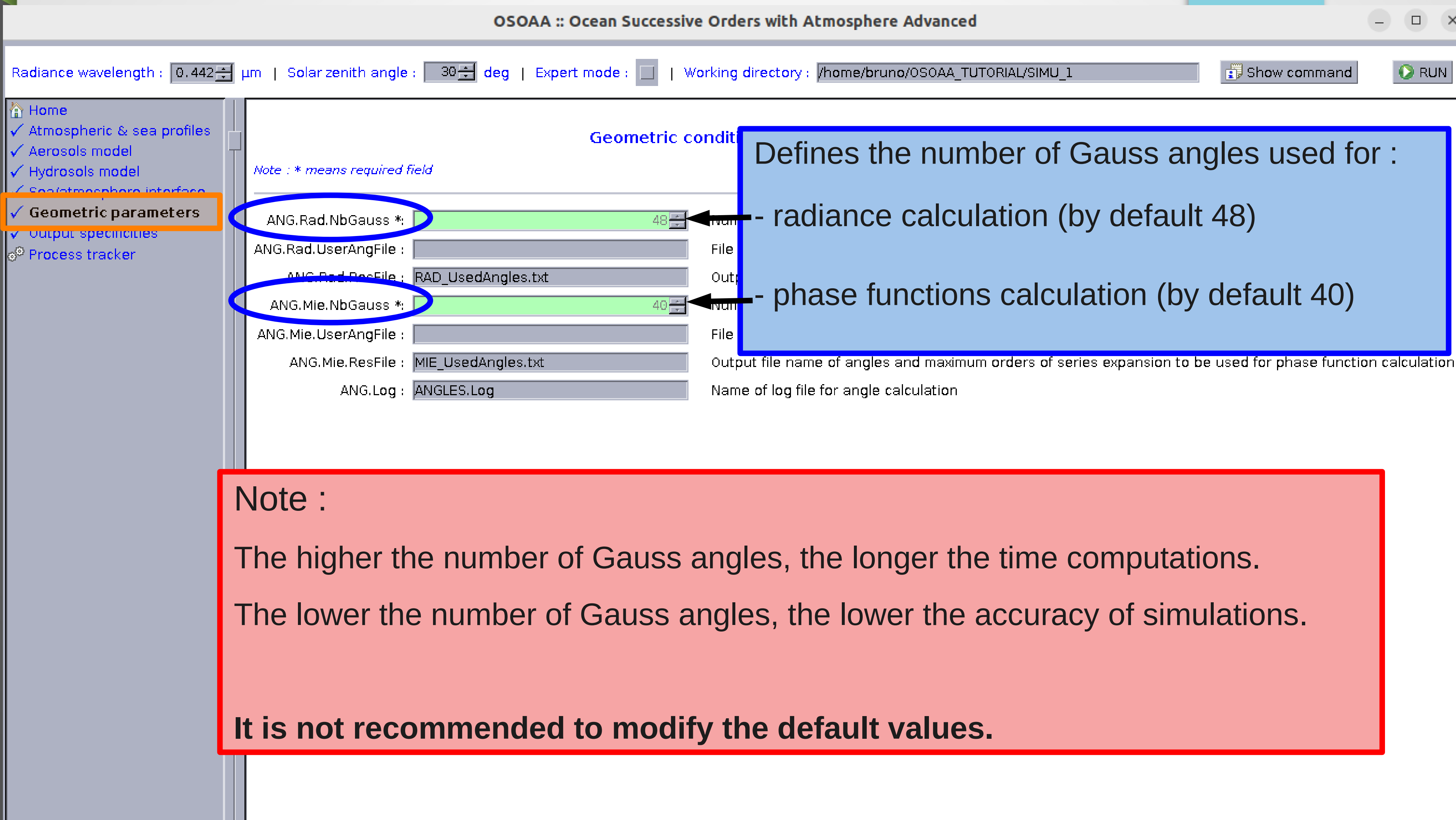
► *Let's set a surface wind speed null*

► *Let's set a refractive index sea/atmosphere = 1.34*

Sea / atmosphere interface

The fourth GUI window is ready !

Defining the number of angles used for calculations



Defines the number of Gauss angles used for :

- radiance calculation (by default 48)

- phase functions calculation (by default 40)

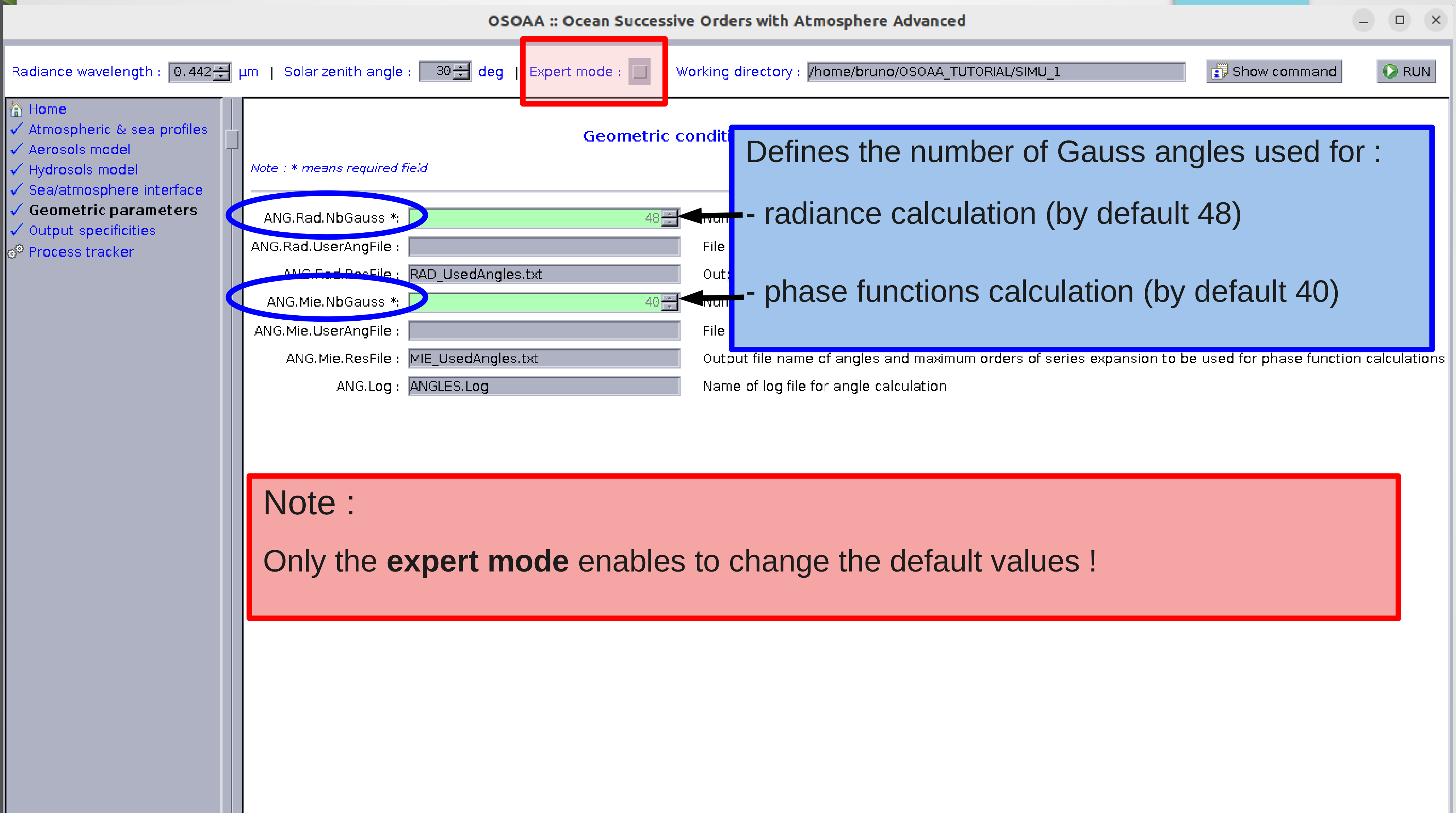
Note :

The higher the number of Gauss angles, the longer the time computations.

The lower the number of Gauss angles, the lower the accuracy of simulations.

It is not recommended to modify the default values.

Defining the number of angles used for calculations



Defines the number of Gauss angles used for :

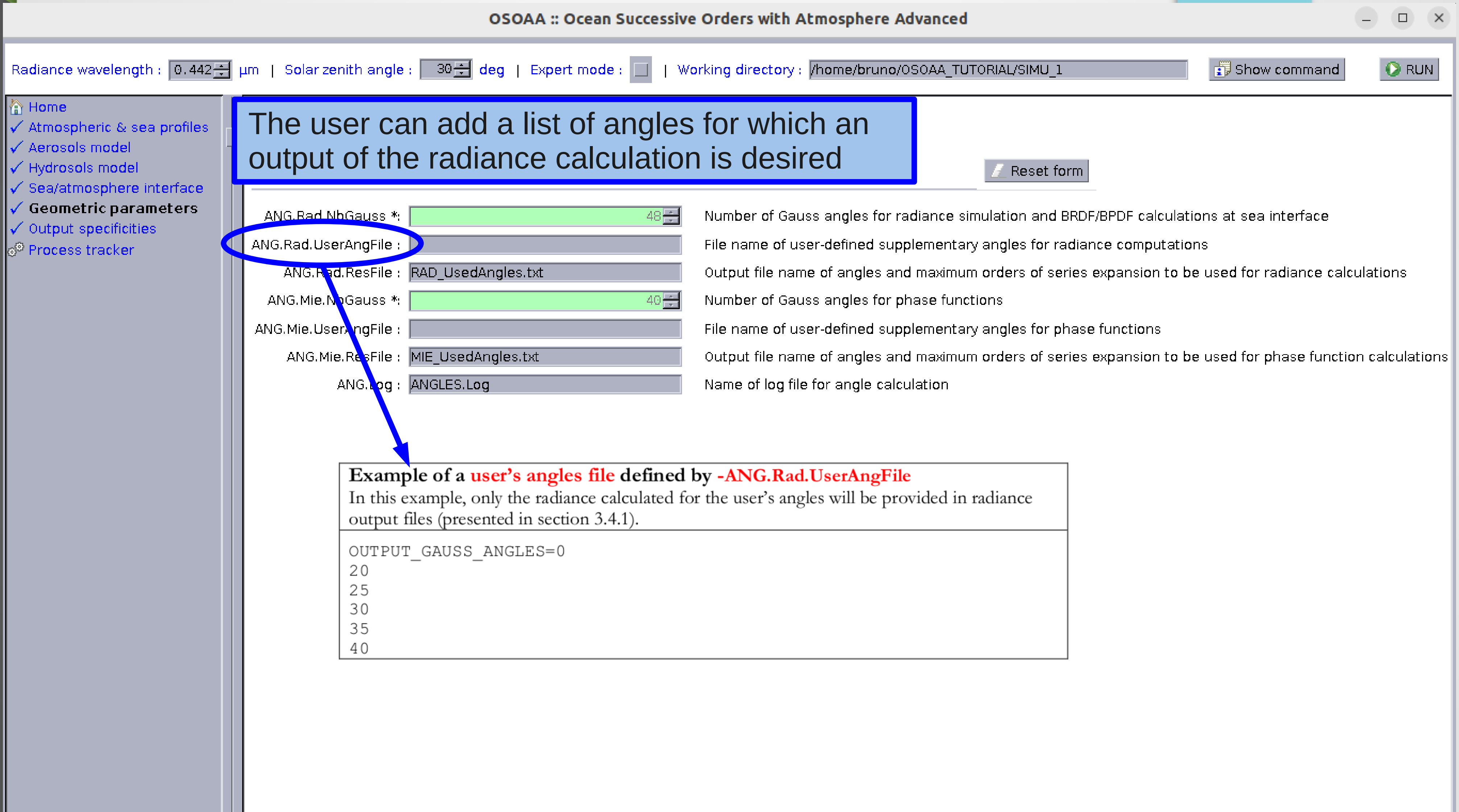
- radiance calculation (by default 48)

- phase functions calculation (by default 40)

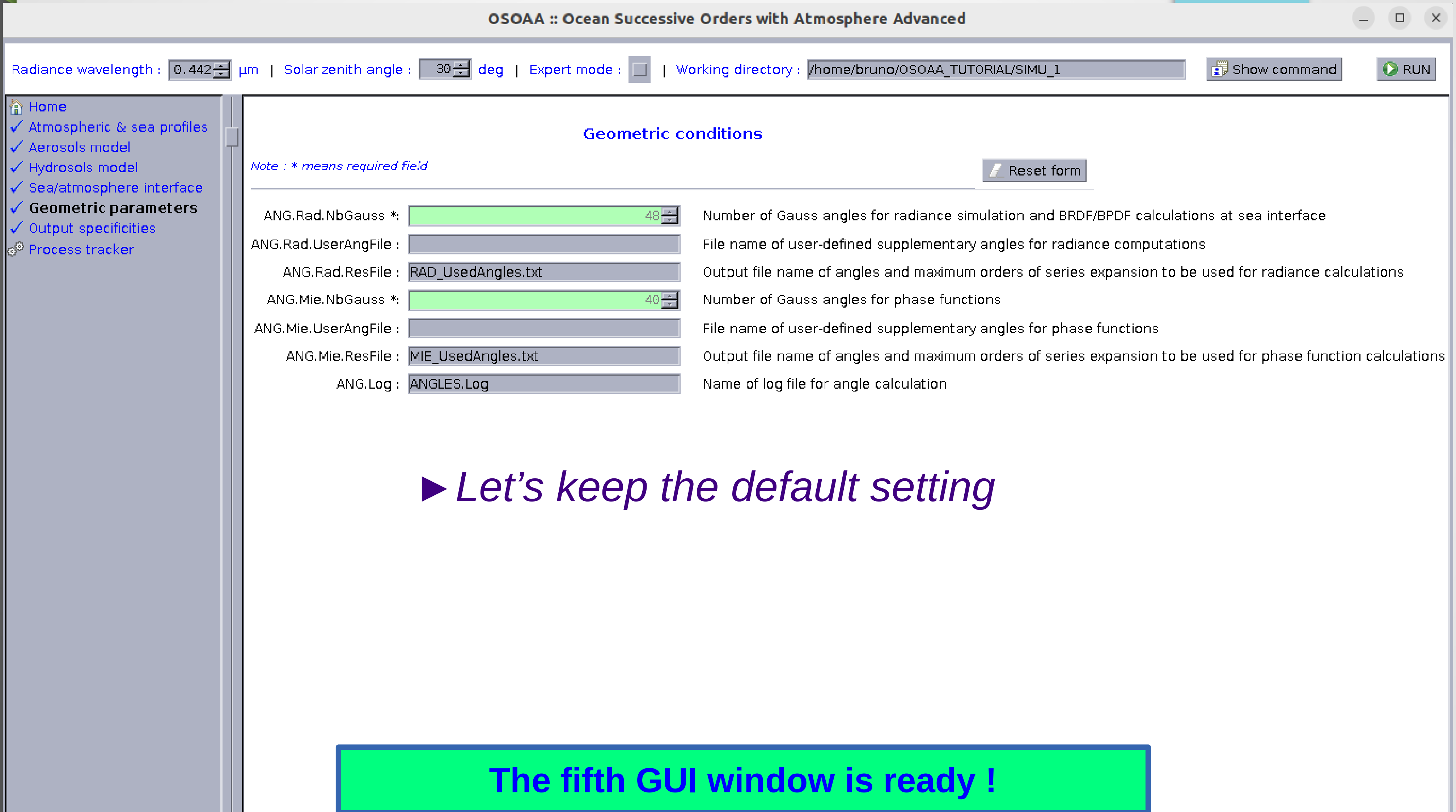
Note :

Only the **expert mode** enables to change the default values !

Defining the number of angles used for calculations



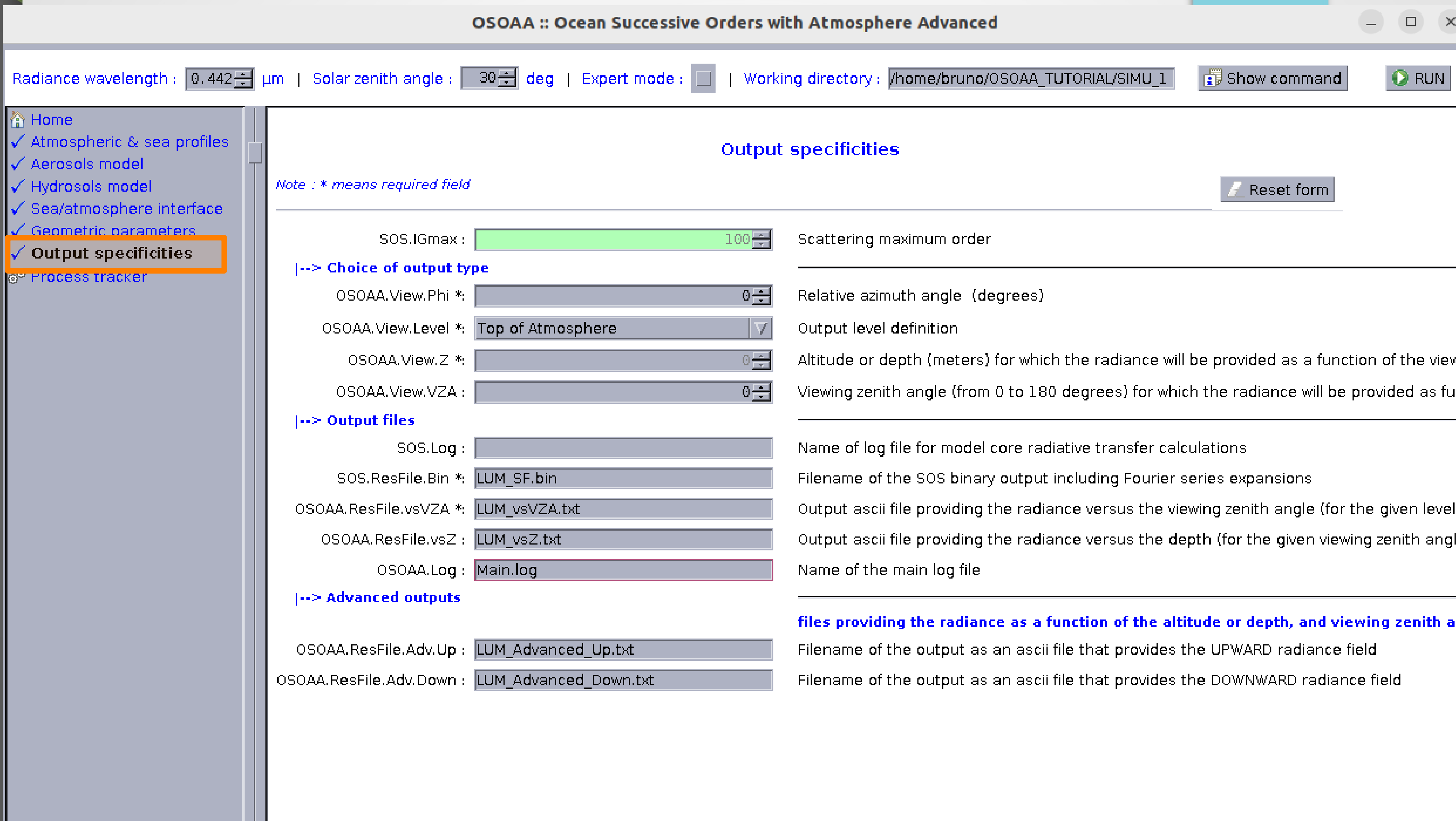
Defining the number of angles used for calculations



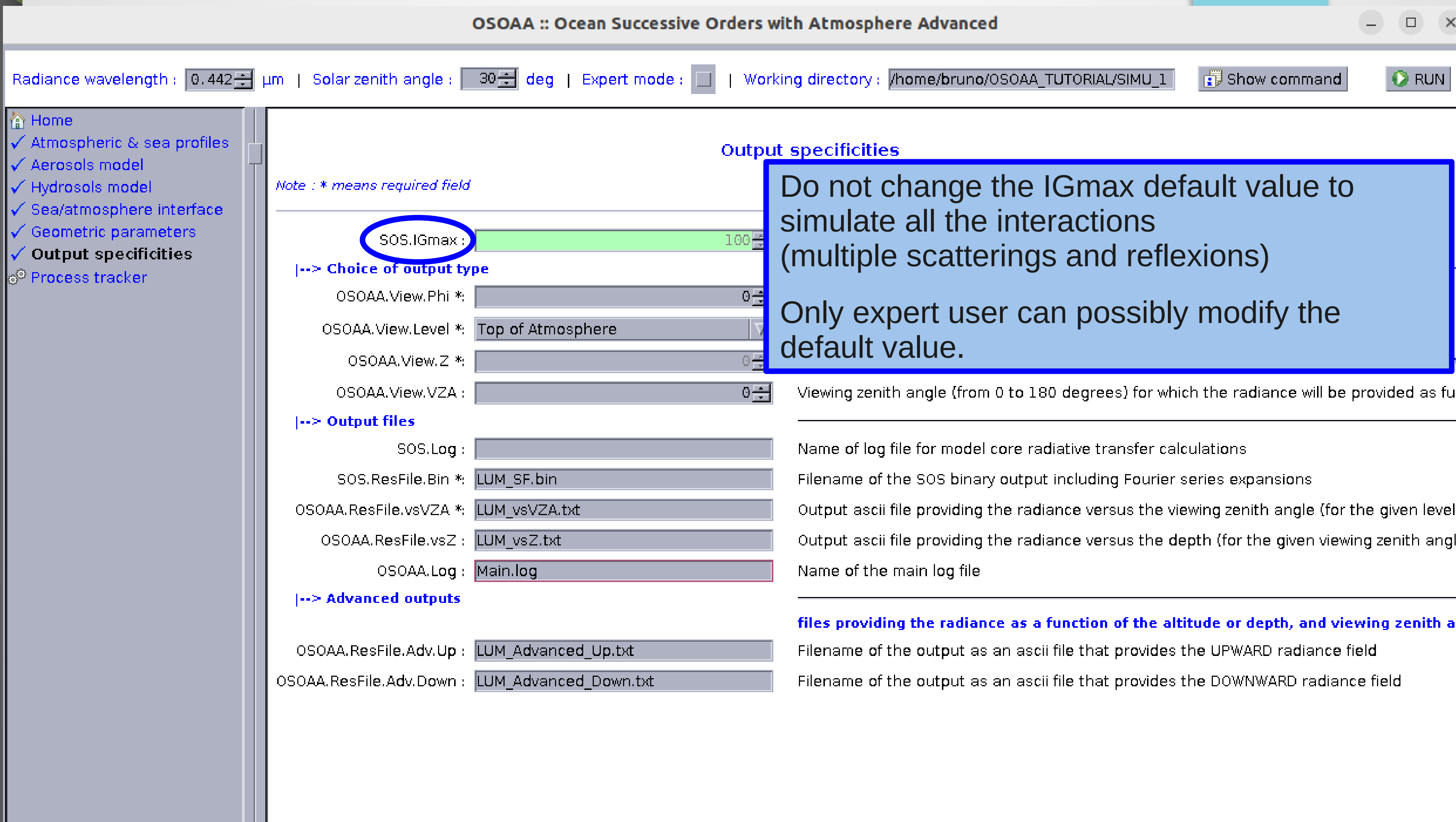
► *Let's keep the default setting*

The fifth GUI window is ready !

Definition of outputs



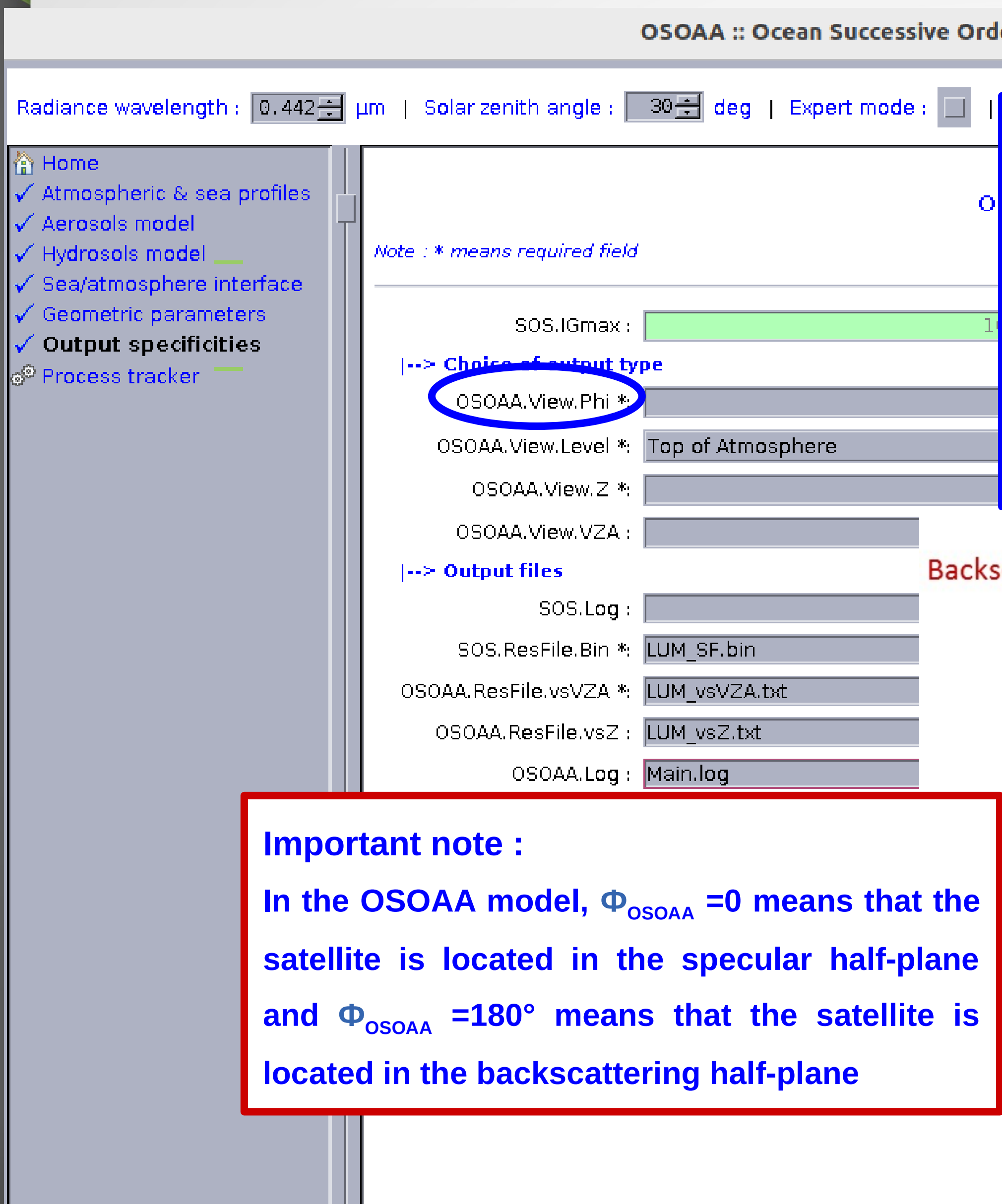
Definition of outputs



Do not change the IGmax default value to simulate all the interactions (multiple scatterings and reflexions)

Only expert user can possibly modify the default value.

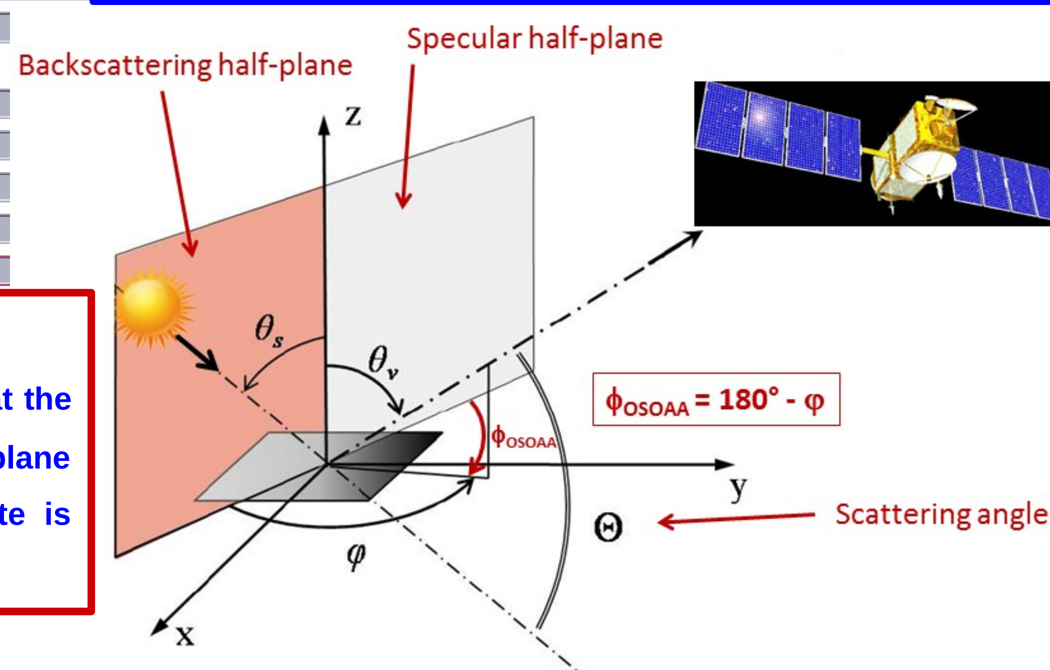
Definition of outputs



Outputs of the radiometric quantities (radiance, degree of polarization, ...) are provided for a relative azimuth plane « Φ_{OSOAA} » (OSOAA.View.Phi)

$\Rightarrow L(\theta,\phi)$

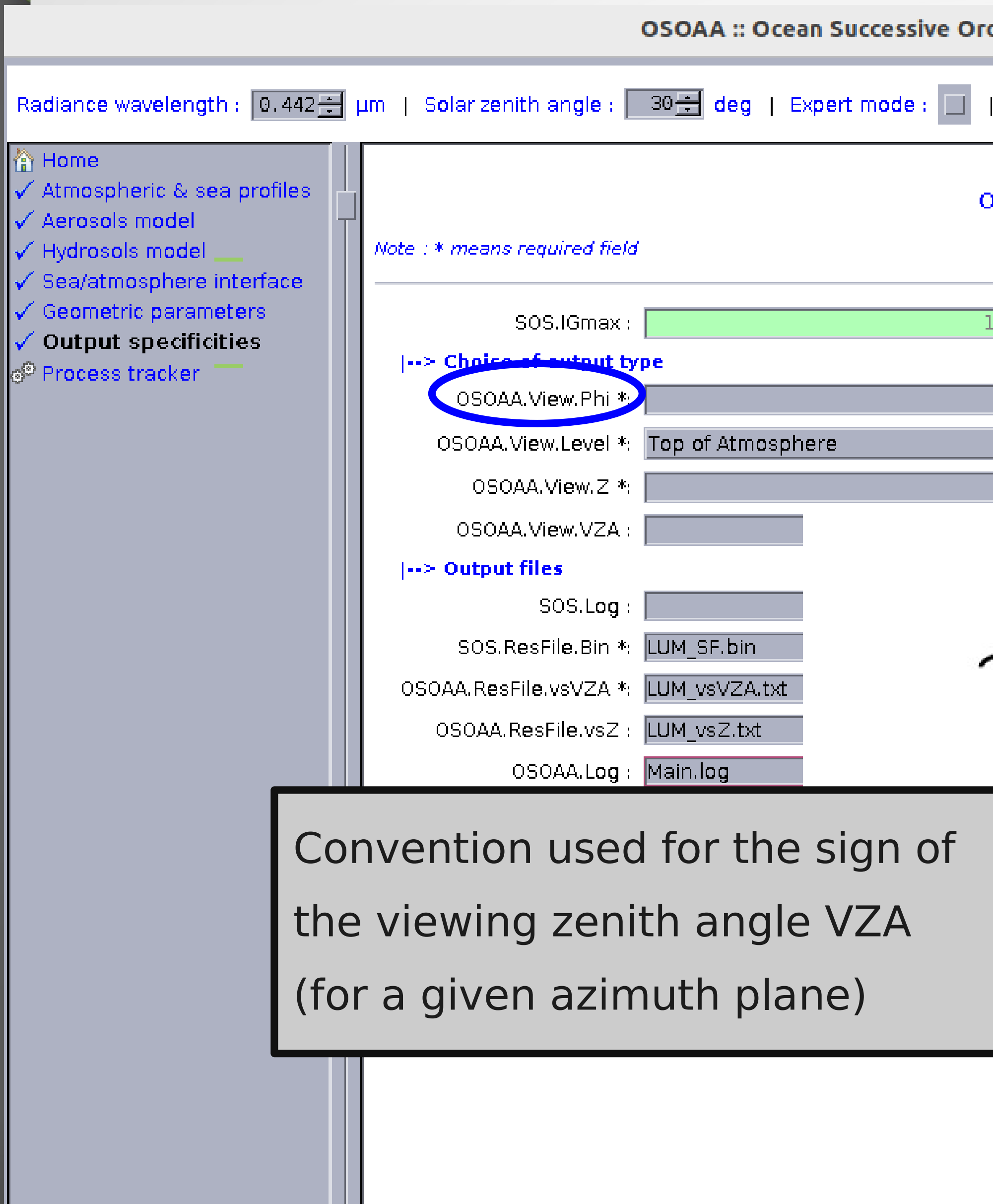
Outputs are given for Viewing Zenith Angle (VZA=θ) in the range [-88° , +88°]



Important note :

In the OSOAA model, Φ_{OSOAA} =0 means that the satellite is located in the specular half-plane and Φ_{OSOAA} =180° means that the satellite is located in the backscattering half-plane

Definition of outputs

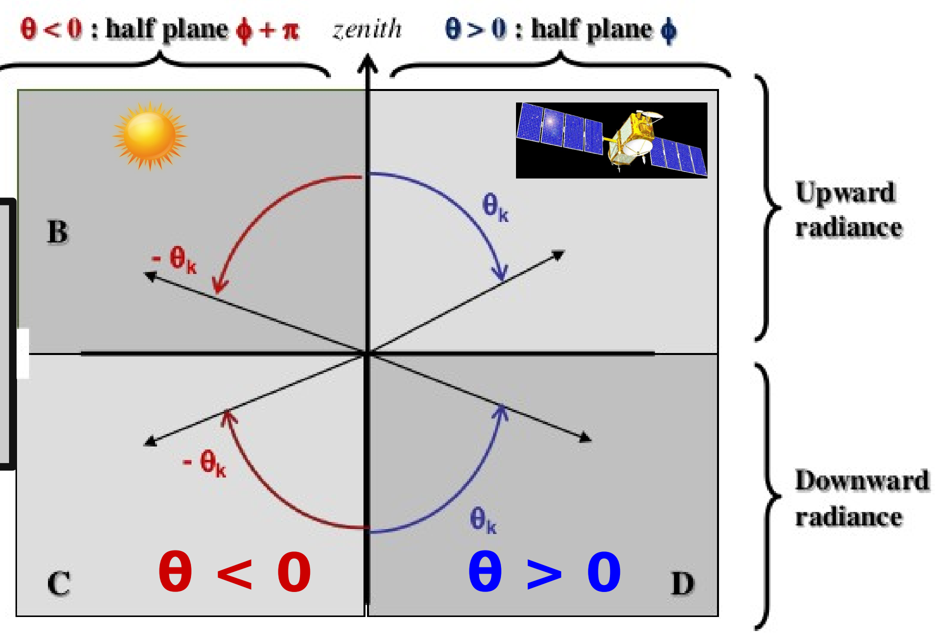


Outputs of the radiometric quantities (radiance, degree of polarization, ...) are provided for a relative azimuth plane « Φ_{OSOAA} » (OSOAA.View.Phi)

$\Rightarrow L(\theta,\phi)$

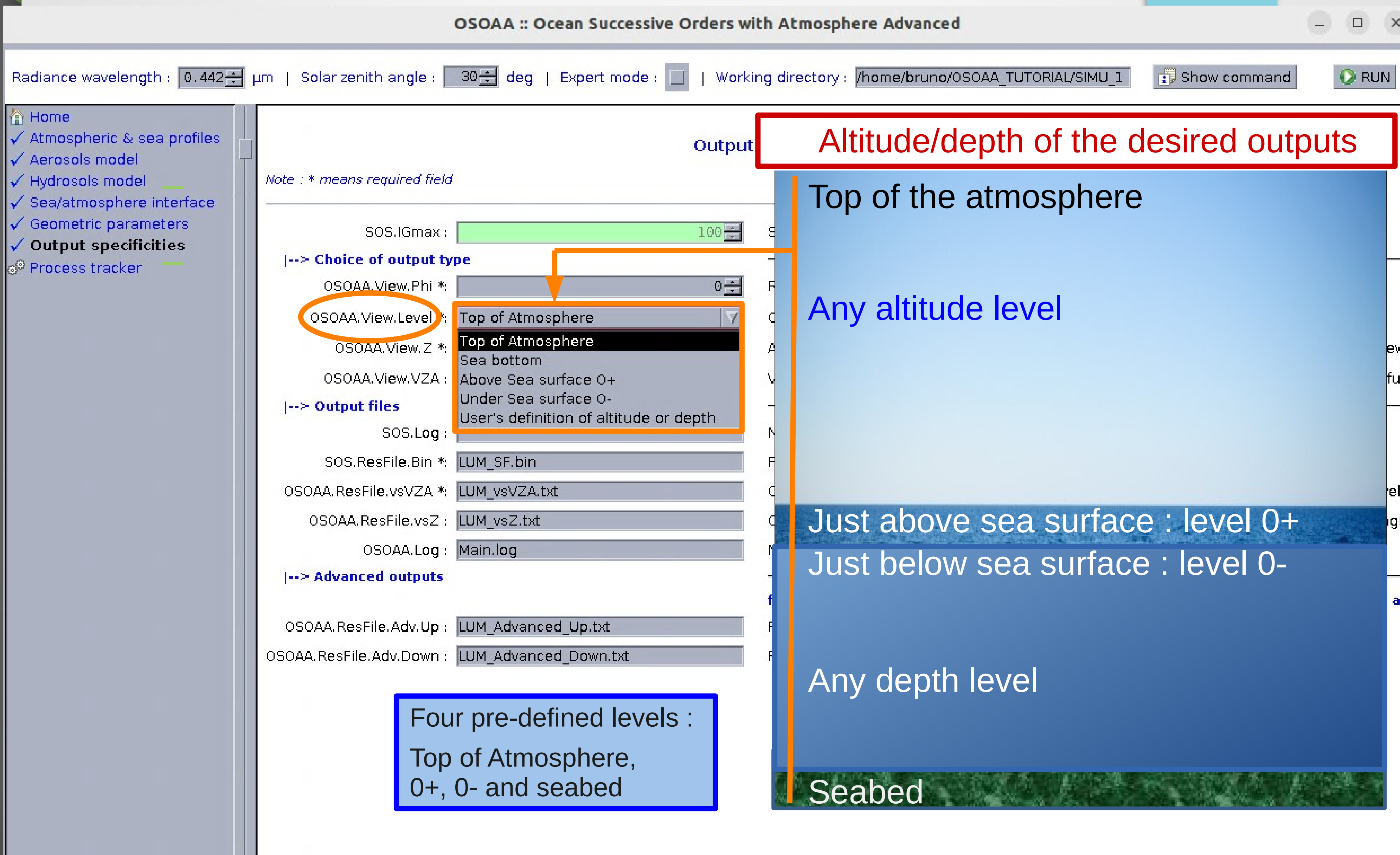
Outputs are given for Viewing Zenith Angle (VZA=θ) in the range [-88° , +88°]

Azimuth plane

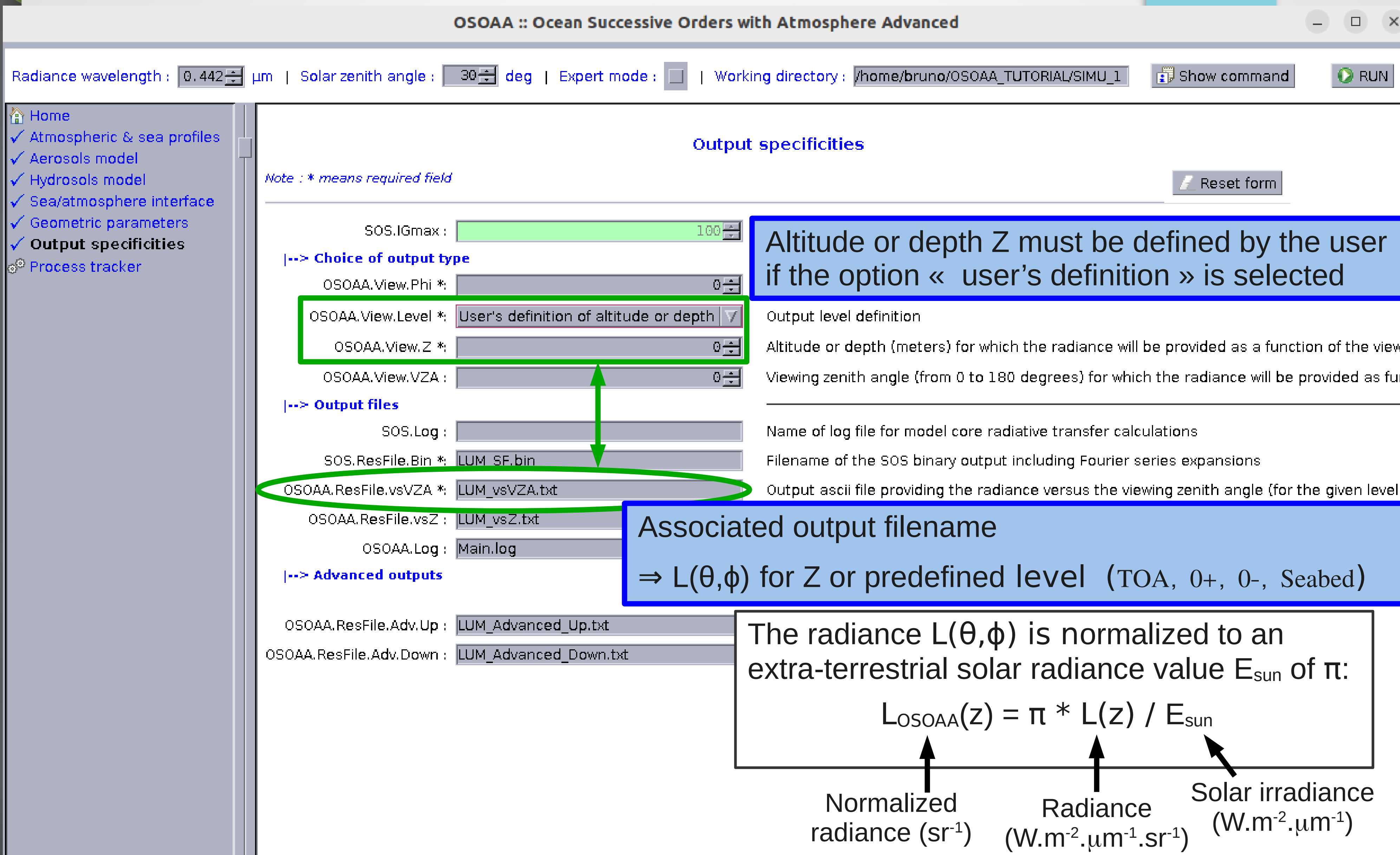


Convention used for the sign of the viewing zenith angle VZA (for a given azimuth plane)

Definition of outputs



Definition of outputs



Altitude or depth Z must be defined by the user if the option « user's definition » is selected

Associated output filename

⇒ L(θ,ϕ) for Z or predefined level (TOA, 0+, 0-, Seabed)

The radiance L(θ,ϕ) is normalized to an extra-terrestrial solar radiance value E_{sun} of π:

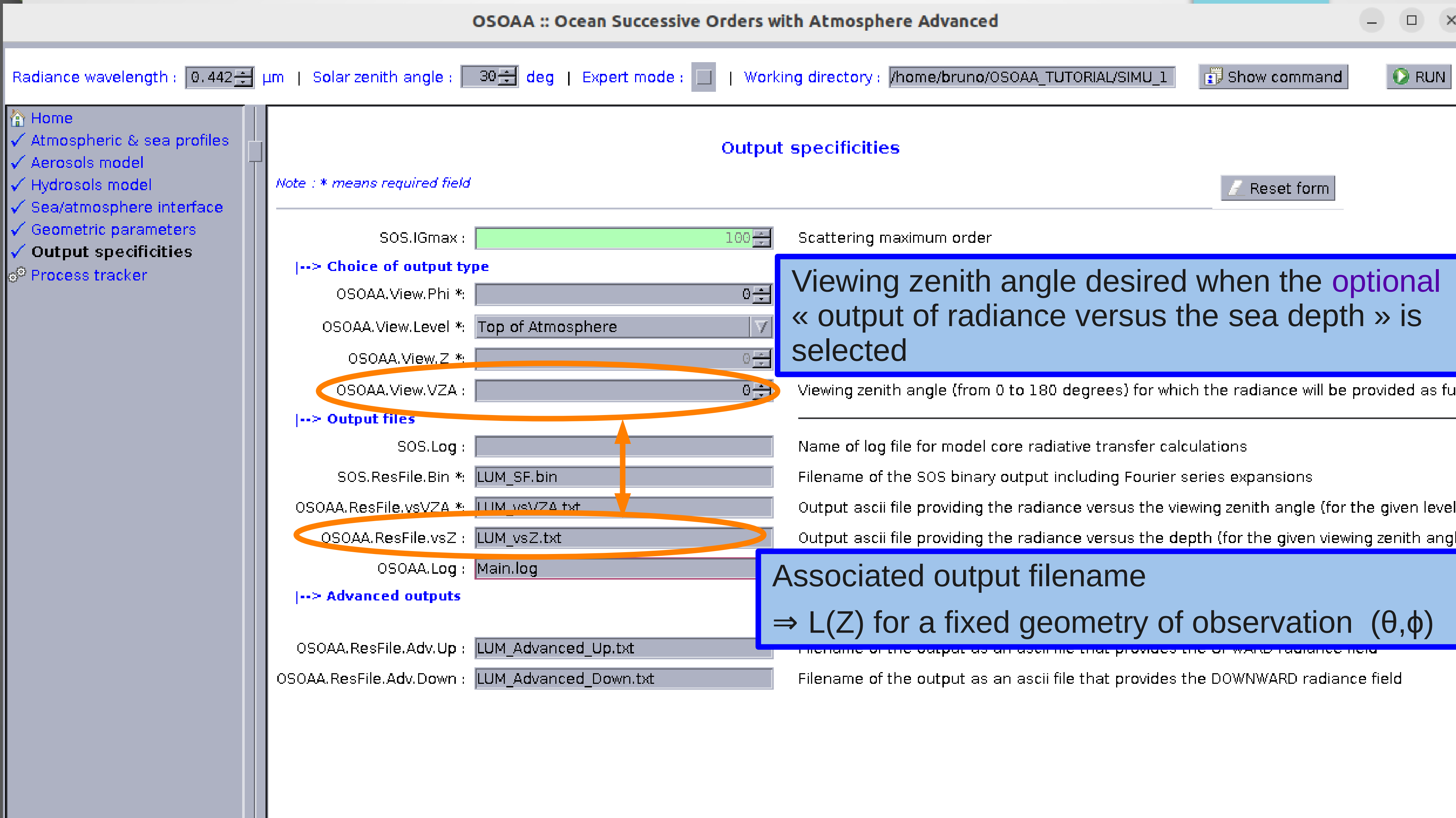
$$L_{OSOAA}(z) = \pi * L(z) / E_{sun}$$

Normalized radiance (sr^{-1})

Radiance ($W.m^{-2}.\mu m^{-1}.sr^{-1}$)

Solar irradiance ($W.m^{-2}.\mu m^{-1}$)

Definition of outputs

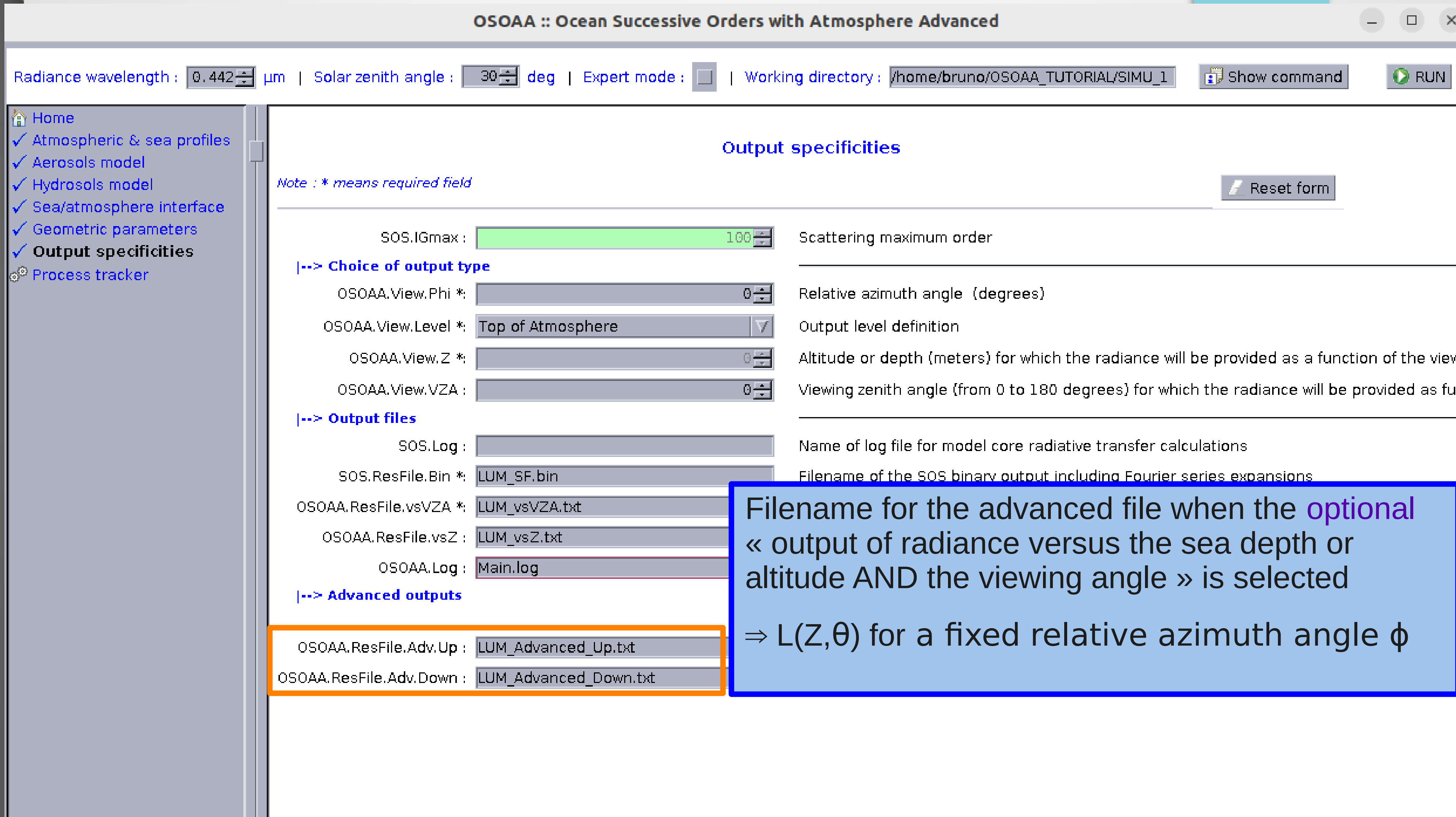


Viewing zenith angle desired when the optional « output of radiance versus the sea depth » is selected

Associated output filename

⇒ L(Z) for a fixed geometry of observation (θ,ϕ)

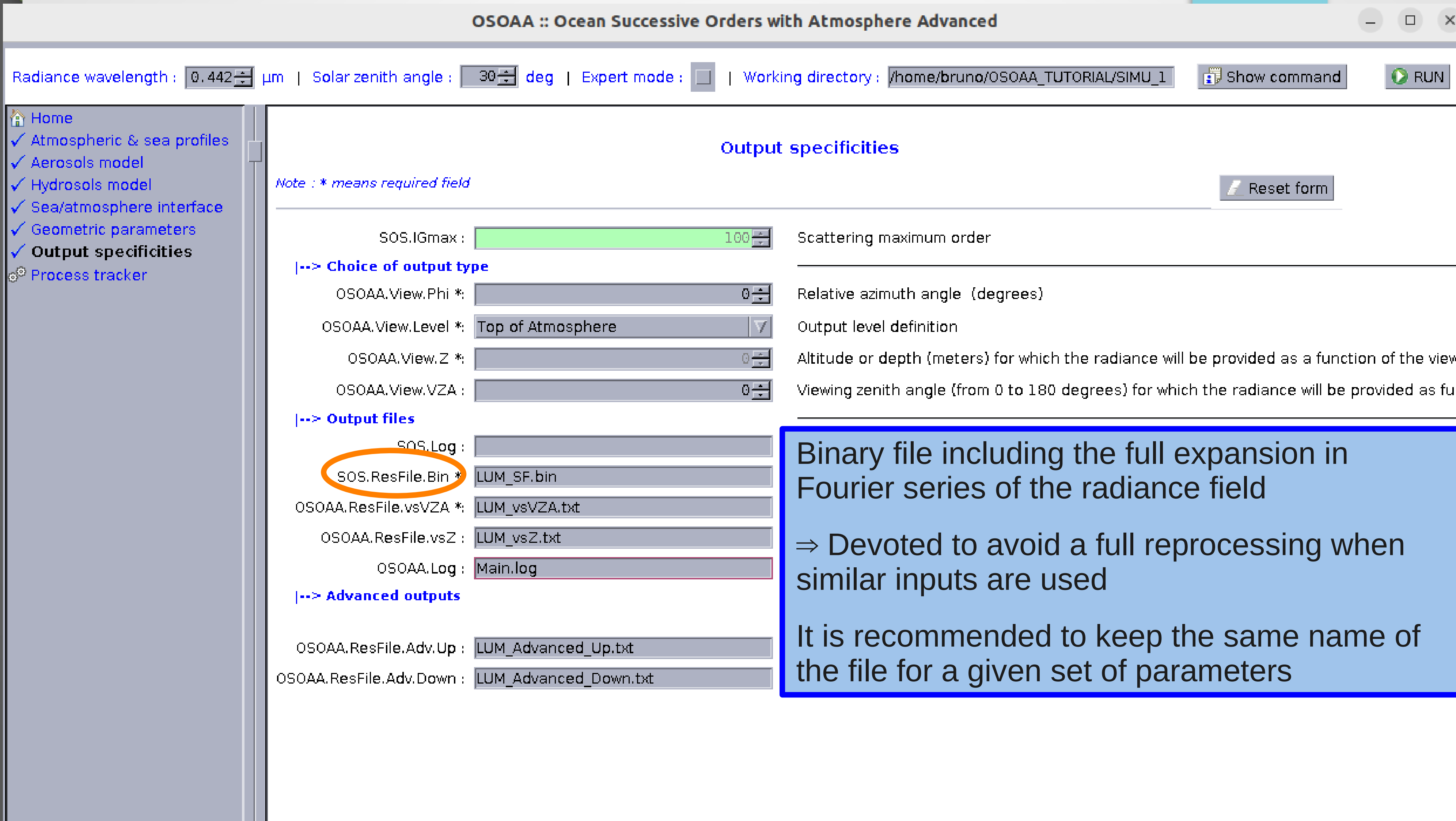
Definition of outputs



Filename for the advanced file when the optional « output of radiance versus the sea depth or altitude AND the viewing angle » is selected

⇒ $L(Z,\theta)$ for a fixed relative azimuth angle ϕ

Definition of outputs



Binary file including the full expansion in Fourier series of the radiance field

⇒ Devoted to avoid a full reprocessing when similar inputs are used

It is recommended to keep the same name of the file for a given set of parameters

Definition of outputs

- Setting for the example #1 : SIMU_1

  ► *Let’s define an observation in the solar principal plane : Relative azimuth angle Φ = 0°*

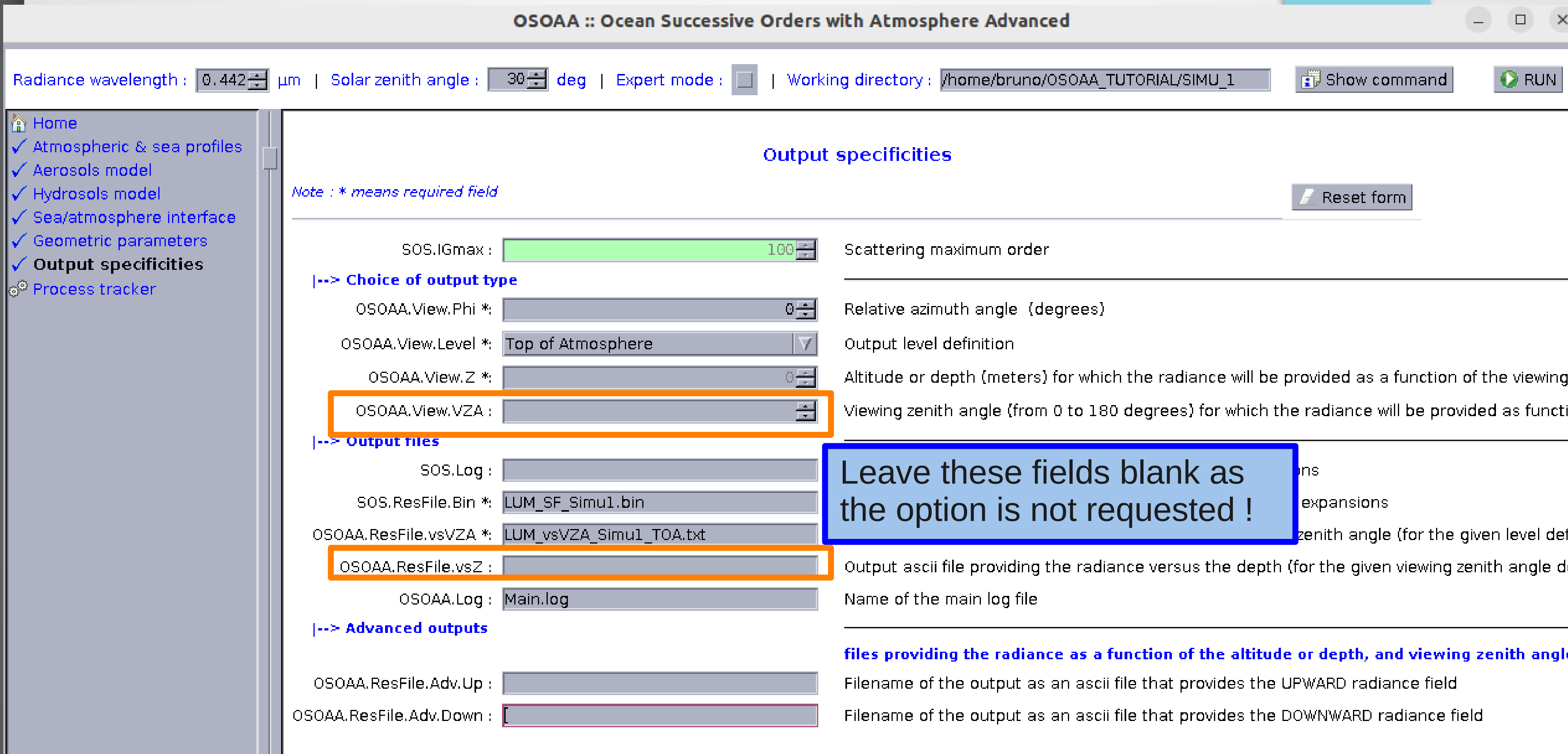
  ► *Output (i.e., radiance, reflectance, degree of polarization) for Top Of Atmosphere*

  ► *Output versus the viewing angle*
  Let’s call the output file : LUMvzVZA_Simu1_TOA.txt

  ► *No Advanced output files*

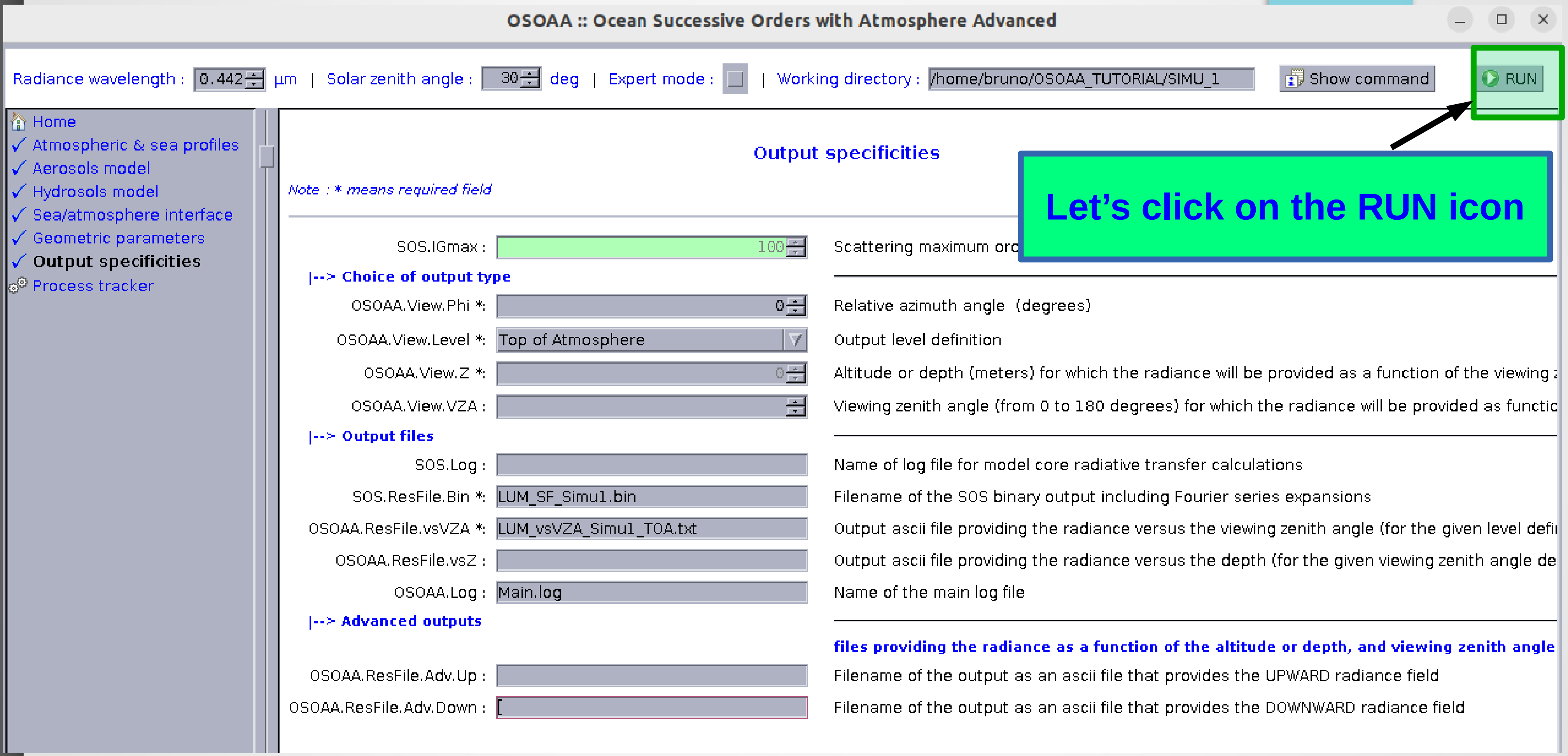
  ► *Let’s call the binary file : LUM_SF_Simu1.bin*

Definition of outputs

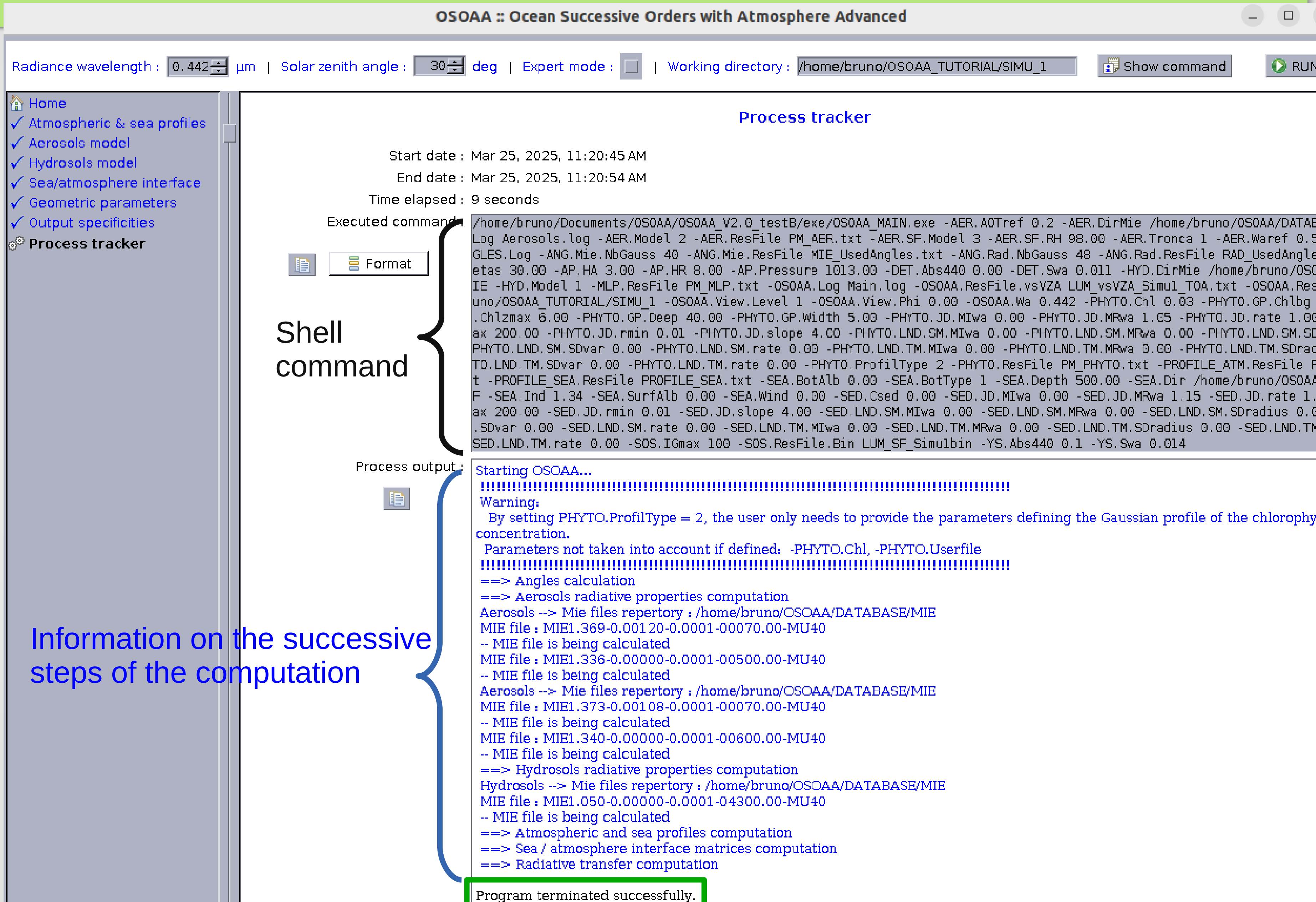


The last GUI window is ready !
We are now ready to perform a run !

Definition of outputs



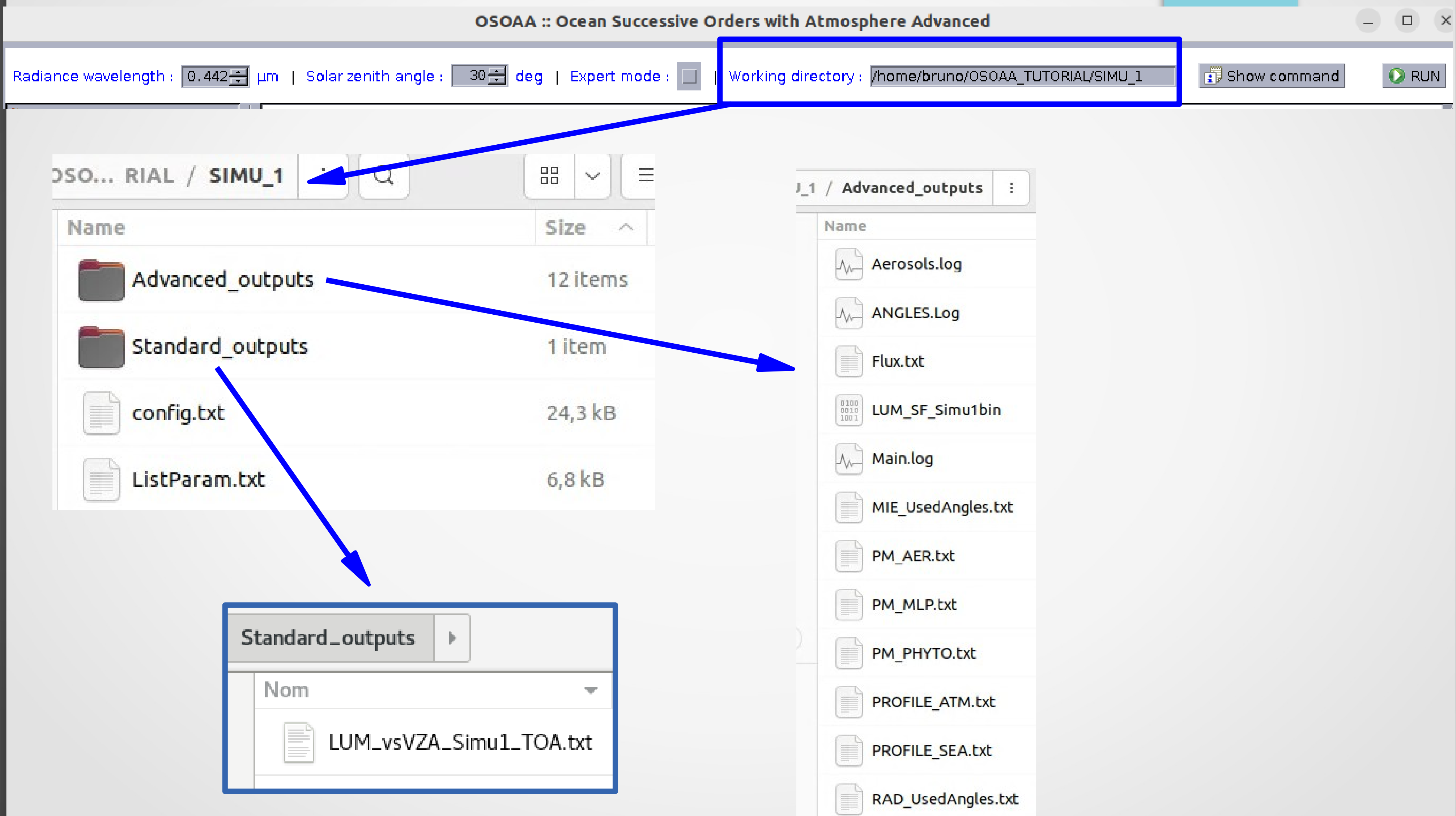
Running OSOAA



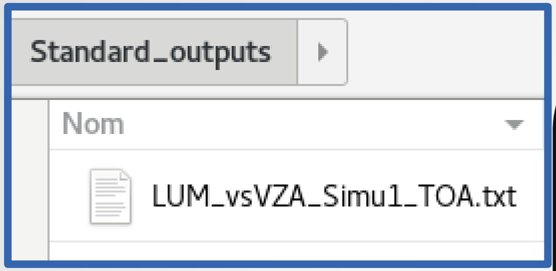
Shell command

Information on the successive steps of the computation

Output files



Output files



Header of the output file

```
STANDARD RESULTS :
  UPWARD RADIANCE FIELD VERSUS THE VIEWING ZENITH ANGLE
  (RELATIVE AZIMUTH AND ALTITUDE/DEPTH ARE FIXED)
--------------------------------------------------------------------------------------------------
Relative azimuth (degrees) :

   Relative azimuth convention :
       180 degrees <-> Satellite and Sun in the same half-plane
         0 degree  <-> Satellite and Sun in opposite half-planes with respect to the zenith direction

   Simulated relative azimuth (degrees) :
       for VZA < 0 (sign convention):    180.000000000000
       for VZA > 0 (sign convention):    0.000000000000000

TOA level - Altitude (km) :   300.000000000000

Columns parameters :
  VZA      :  Viewing Zenith Angle (deg)
  SCA_ANG  :  Scattering angle (deg)
  I        :  Stokes parameter at output level Z (in sr-1)
              normalized to the extraterrestrial solar irradiance (PI * L(z) / Esun)
  REFL     :  Reflectance at output level Z (PI * L(z) / Ed(z))
  POL_RATE:  Degree of polarization (%)
  LPOL     :  Polarized intensity at output level Z (in sr-1)
              normalized to the extraterrestrial solar irradiance (PI * Lpol(z) / Esun)
  REFL_POL:  Polarized reflectance at output level Z (PI * Lpol(z) / Ed(z))
--------------------------------------------------------------------------------------------------
```

VZA	SCA_ANG	I	REFL	POL_RATE	LPOL	REFL_POL
-89.07	120.93	0.319458E+00	0.368878E+00	46.34	0.148049E+00	0.170952E+00
-87.20	122.80	0.313348E+00	0.361823E+00	42.39	0.132835E+00	0.153385E+00
-85.34	124.66	0.304782E+00	0.351932E+00	39.30	0.119786E+00	0.138317E+00
-83.47	126.53	0.294714E+00	0.340307E+00	36.87	0.108659E+00	0.125468E+00
-81.61	128.39	0.283251E+00	0.327070E+00	34.84	0.986768E-01	0.113942E+00
-79.74	130.26	0.271018E+00	0.312944E+00	33.01	0.894733E-01	0.103315E+00
-77.88	132.12	0.258639E+00	0.298651E+00	31.26	0.808569E-01	0.933655E-01

Viewing Zenith Angle (VZA)

Scattering angle

Normalized radiance

Reflectance

Degree of polarization

Polarized normalized radiance

Polarized reflectance

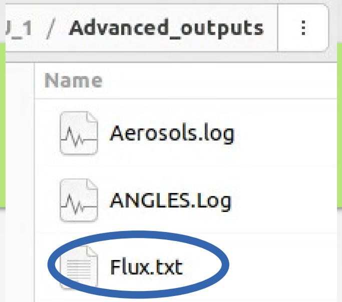
Normalized radiance is defined as:

$$L_{OSOAA} = \pi * L(z) / E_{sun}$$

The radiance in geophysical units ($W.m^{-2}.sr^{-1}$) is :

$$L_{geophys} = E_{sun} * L_{OSOAA} / \pi$$

Output files



- Advanced_Outputs/Flux.txt

Profile of downward and upward fluxes from TOA to the sea bottom
for a solar extra-terrestrial irradiance at TOA equals to PI .

	Level	Z(m)	Direct_Down	Diffuse_Down	Total_Down	Direct_Up	Diffuse_Up	Total_Up	Total_Up/Total_Down
TOA	0	300000.00000	0.272070E+001	0.000000E+000	0.272070E+001	0.256128E-001	0.404820E+000	0.430433E+000	0.158207E+000
	1	21067.00000	0.266862E+001	0.339498E-001	0.270257E+001	0.261126E-001	0.386517E+000	0.412630E+000	0.152680E+000
	2	15700.00000	0.261845E+001	0.660302E-001	0.268448E+001	0.266129E-001	0.368208E+000	0.394821E+000	0.147075E+000
	3	12681.00000	0.257018E+001	0.966905E-001	0.266687E+001	0.271128E-001	0.350364E+000	0.377477E+000	0.141543E+000
	4	10630.00000	0.252376E+001	0.126170E+000	0.264993E+001	0.276115E-001	0.333180E+000	0.360791E+000	0.136151E+000
	5	9105.00000	0.247907E+001	0.154625E+000	0.263369E+001	0.281092E-001	0.316705E+000	0.344814E+000	0.130924E+000
	6	7908.00000	0.243592E+001	0.182210E+000	0.261813E+001	0.286072E-001	0.300893E+000	0.329500E+000	0.125853E+000
	7	6934.00000	0.239421E+001	0.208975E+000	0.260319E+001	0.291055E-001	0.285707E+000	0.314813E+000	0.120934E+000
	*								
	*								
	*								
	24	362.00000	0.182631E+001	0.573796E+000	0.240011E+001	0.381560E-001	0.777433E-001	0.115899E+000	0.482892E-001
	25	177.00000	0.179878E+001	0.590868E+000	0.238965E+001	0.387400E-001	0.669443E-001	0.105684E+000	0.442259E-001
Level 0+	26	0.00000	0.177177E+001	0.607498E+000	0.237927E+001	0.393306E-001	0.564370E-001	0.957676E-001	0.402509E-001
Level 0-	27	-0.00000	0.173244E+001	0.575489E+000	0.230793E+001	0.000000E+000	0.210157E-001	0.210157E-001	0.910588E-002
	28	-0.00000	0.173231E+001	0.575472E+000	0.230778E+001	0.000000E+000	0.210144E-001	0.210144E-001	0.910591E-002
	29	-1.80400	0.130621E+001	0.508931E+000	0.181514E+001	0.000000E+000	0.166171E-001	0.166171E-001	0.915473E-002
	30	-3.60800	0.984920E+000	0.440888E+000	0.142581E+001	0.000000E+000	0.130973E-001	0.130973E-001	0.918590E-002
	31	-5.41200	0.742658E+000	0.376310E+000	0.111897E+001	0.000000E+000	0.103050E-001	0.103050E-001	0.920936E-002
	32	-7.21600	0.559986E+000	0.317575E+000	0.877561E+000	0.000000E+000	0.809873E-002	0.809873E-002	0.922868E-002
	33	-9.02000	0.422245E+000	0.265619E+000	0.687864E+000	0.000000E+000	0.636010E-002	0.636010E-002	0.924615E-002
	*								
	*								
	*								
	103	-51.52900	0.597642E-006	0.928106E-004	0.934082E-004	0.000000E+000	0.918747E-006	0.918747E-006	0.983582E-002
	104	-52.58800	0.473425E-006	0.770871E-004	0.775605E-004	0.000000E+000	0.677501E-006	0.677501E-006	0.873513E-002
	105	-53.84400	0.369093E-006	0.626283E-004	0.629974E-004	0.000000E+000	0.454464E-006	0.454464E-006	0.721402E-002
	106	-55.31400	0.283311E-006	0.497645E-004	0.500478E-004	0.000000E+000	0.238391E-006	0.238391E-006	0.476327E-002
Seabed	107	-56.96200	0.215144E-006	0.389111E-004	0.391262E-004	0.000000E+000	0.000000E+000	0.000000E+000	0.000000E+000

or depth for which the maximum allowed value of the optical depth is reached (τ_{max}= 30 for OSOAA)

Additional simulations

- Additional simulations for the example #1 : SIMU_1

Modifications of the output conditions

▶ *Let's perform the same simulation for :*

- *Just above the sea surface : Level 0+*
  →*Output file : LUMvzVZA_Simu1_Level0p.txt*
- *Just below the sea surface : Level 0-*
  →*Output file : LUMvzVZA_Simu1_Level0m.txt*

- New setting : example #2 (SIMU_2)

Modifications of the surface conditions

▶ *Same conditions as SIMU_1 but for a surface wind speed of 5 m/s*

▶ *Outputs for the levels : TOA, 0+ and 0-*

- New setting : example #3 (SIMU_3)

▶ *Same conditions as SIMU_1 but for a surface wind speed of 10 m/s*

▶ *Outputs for the levels : TOA, 0+ and 0-*

Additional simulations

- A few comments :
  - Running the same simulation to get radiances for another level is very fast

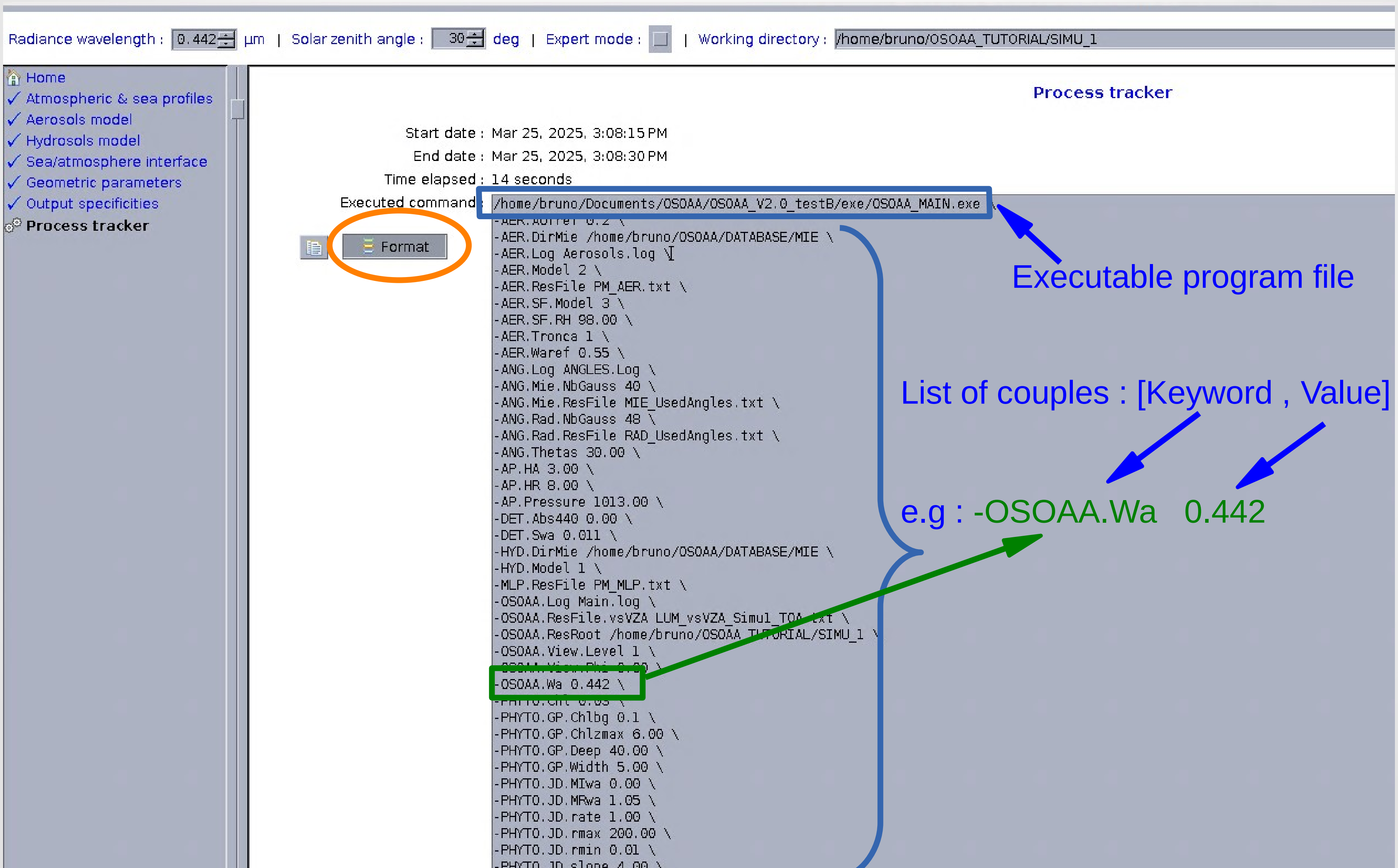
    ⇒ Re-use of the previous result file (SOS.ResFile.Bin) including all the radiance fields, over all the maritime and atmospheric profiles

  - Running simulations by introducing a new value of surface wind speed induces an additional calculation of sea/atmosphere interface matrices

```
==> Sea / atmosphere interface matrices computation
Surface matrices repertory : /home/bruno/OSOAA/DATABASE/SURF
Matrix RAA : RAA-1.340-05.0-RadMU48-NB80-SZA30.000-TSZA21.909
-- RAA Matrix file is being calculated
Matrix TAW : TAW-1.340-05.0-RadMU48-NB80-SZA30.000-TSZA21.909
-- TAW Matrix file is being calculated
Matrix RWW : RWW-1.340-05.0-RadMU48-NB80-SZA30.000-TSZA21.909
-- RWW Matrix file is being calculated
Matrix TWA : TWA-1.340-05.0-RadMU48-NB80-SZA30.000-TSZA21.909
-- TWA Matrix file is being calculated
==> Radiative transfer computation
```

Performing a simulation using the command line mode

- The GUI generates and executes a command line



Performing a simulation using the command line mode

- Use of shell scripts can help for :
  - single simulation
  - many simulations using a single script file
  - Look-Up Tables calculations

- A demonstration script is available in $OSOAA_ROOT/exe

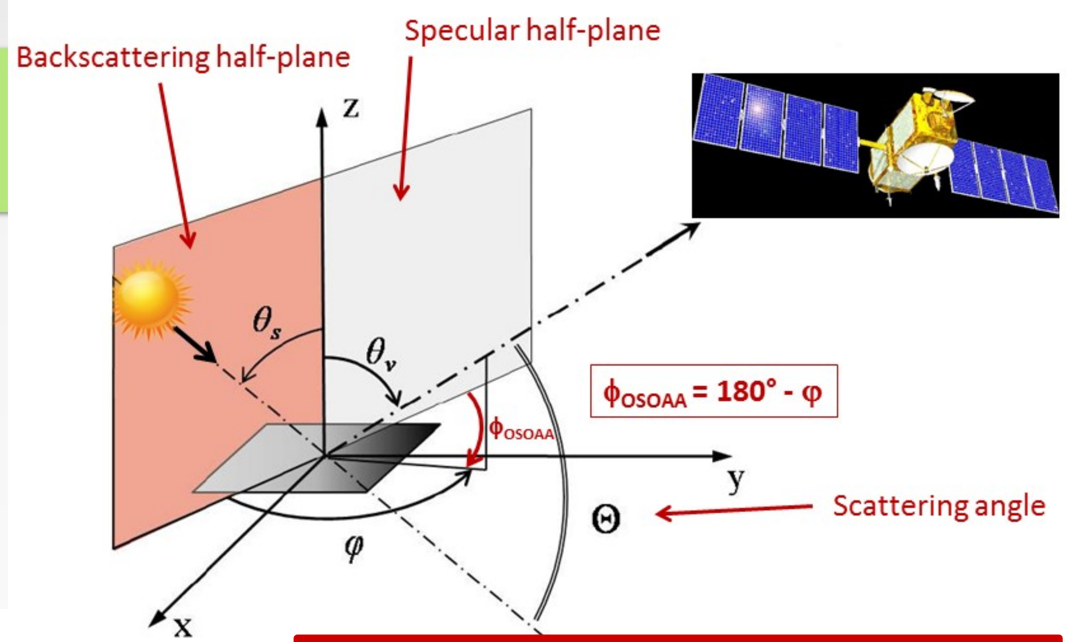
  . ./run_OSOAA_demo.ksh

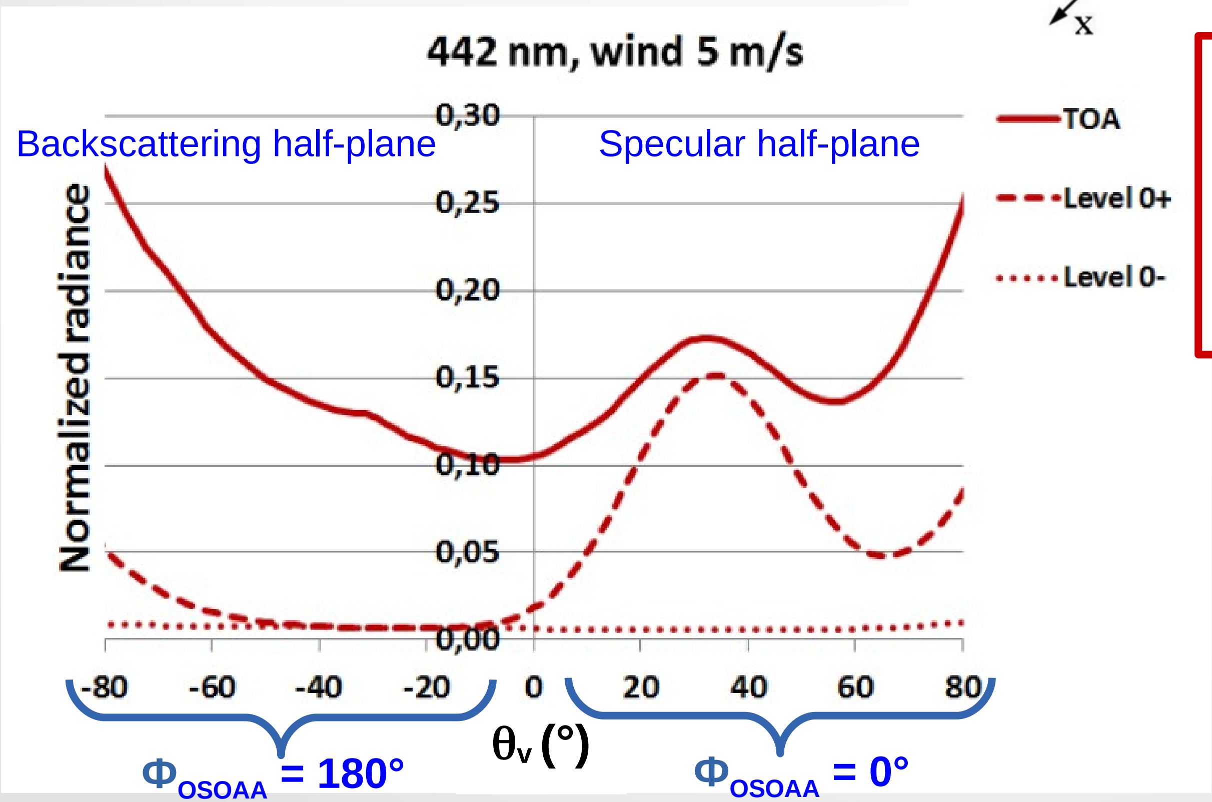
```
dirRESULTS=${OSOAA_ROOT}/OSOAA_RESULTS_DEMO

dirMIE_AER=${OSOAA_ROOT}/DATABASE/MIE_AER  && mkdir -p ${dirMIE_AER}
dirMIE_HYD=${OSOAA_ROOT}/DATABASE/MIE_HYD  && mkdir -p ${dirMIE_HYD}
dirSURF=${OSOAA_ROOT}/DATABASE/SURF_MATR   && mkdir -p ${dirSURF}


${OSOAA_ROOT}/exe/OSOAA_MAIN.exe \
          -OSOAA.ResRoot ${dirRESULTS} \
          -OSOAA.Log Main.Log \
          -OSOAA.Wa 0.440 \
          -ANG.Thetas 30. \
          -AP.Pressure 1013.0  -AP.HR 8.0 -AP.HA 2.0 \
          -AER.Waref 0.550 -AER.AOTref 0.1  \
          -AER.DirMie ${dirMIE_AER} \
          -AER.Model 2 \
          -AER.SF.Model 3 -AER.SF.RH 98.  \
          -PHYTO.Chl 0.2 \
          -SED.Csed  0.0 -PHYTO.ProfilType 1 \
          -YS.Abs440 0.00  -DET.Abs440 0.00 \
          -SEA.Depth 15.000 \
          -HYD.DirMie ${dirMIE_HYD}  \
          -HYD.Model 1 \
          -PHYTO.JD.slope 4.0 -PHYTO.JD.rmin 0.01 -PHYTO.JD.rmax 200. \
          -PHYTO.JD.MRwa 1.05 -PHYTO.JD.MIwa -0.000 -PHYTO.JD.rate 1.0 \
          -SEA.Dir ${dirSURF} -SEA.Ind 1.34  -SEA.Wind 7   \
          -SEA.SurfAlb 0.0  -SEA.BotType 1 -SEA.BotAlb 0.30 \
          -OSOAA.View.Phi 0.0 \
          -OSOAA.View.Level 5\
          -OSOAA.View.Z -10.0   -OSOAA.ResFile.vsVZA RESLUM_vsVZA.txt \
          -OSOAA.View.VZA 0.0   -OSOAA.ResFile.vsZ RESLUM_vsZ.txt \
          -OSOAA.ResFile.Adv.Up   RESLUM_Advanced_UP.txt \
          -OSOAA.ResFile.Adv.Down RESLUM_Advanced_DOWN.txt
```

Example of results

Data from directory ***Standard_Outputs/***

- LUM_vsVZA_Simu2_TOA.txt
- LUM_vsVZA_Simu2_Level0p.txt
- LUM_vsVZA_Simu2_Level0m.txt





Important note :

In the OSOAA model, Φ_{OSOAA} =0 means that the satellite is located in the specular half-plane and Φ_{OSOAA} =180° means that the satellite is located in the backscattering half-plane

Illustration of the normalized radiance in the Solar Principal Plan (Φ_{OSOAA} = 0° & 180°)

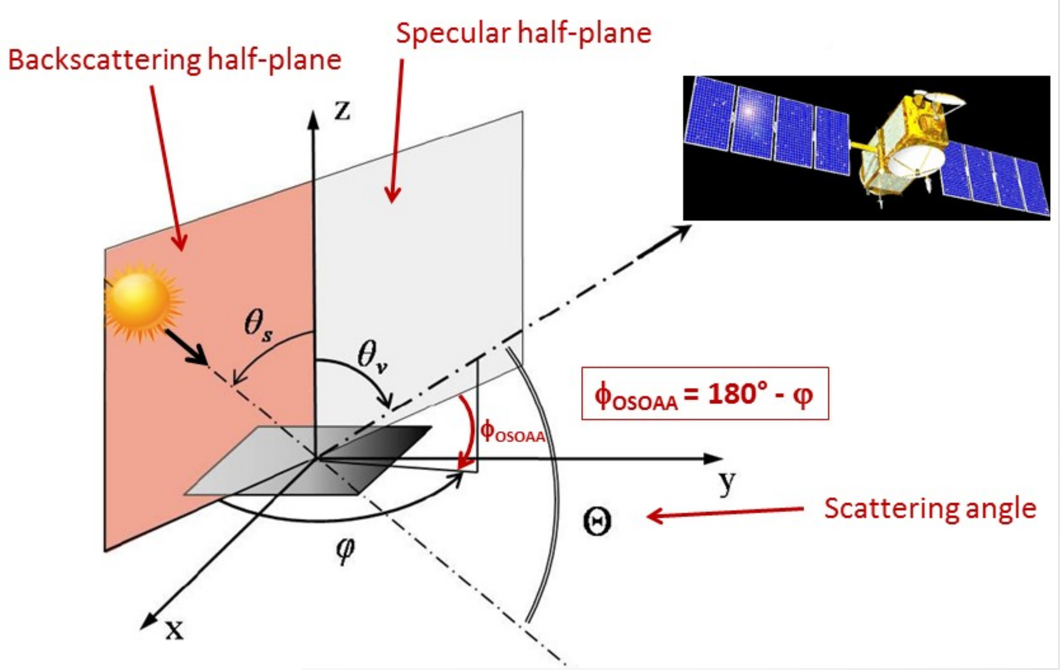
Normalized radiance is defined as:

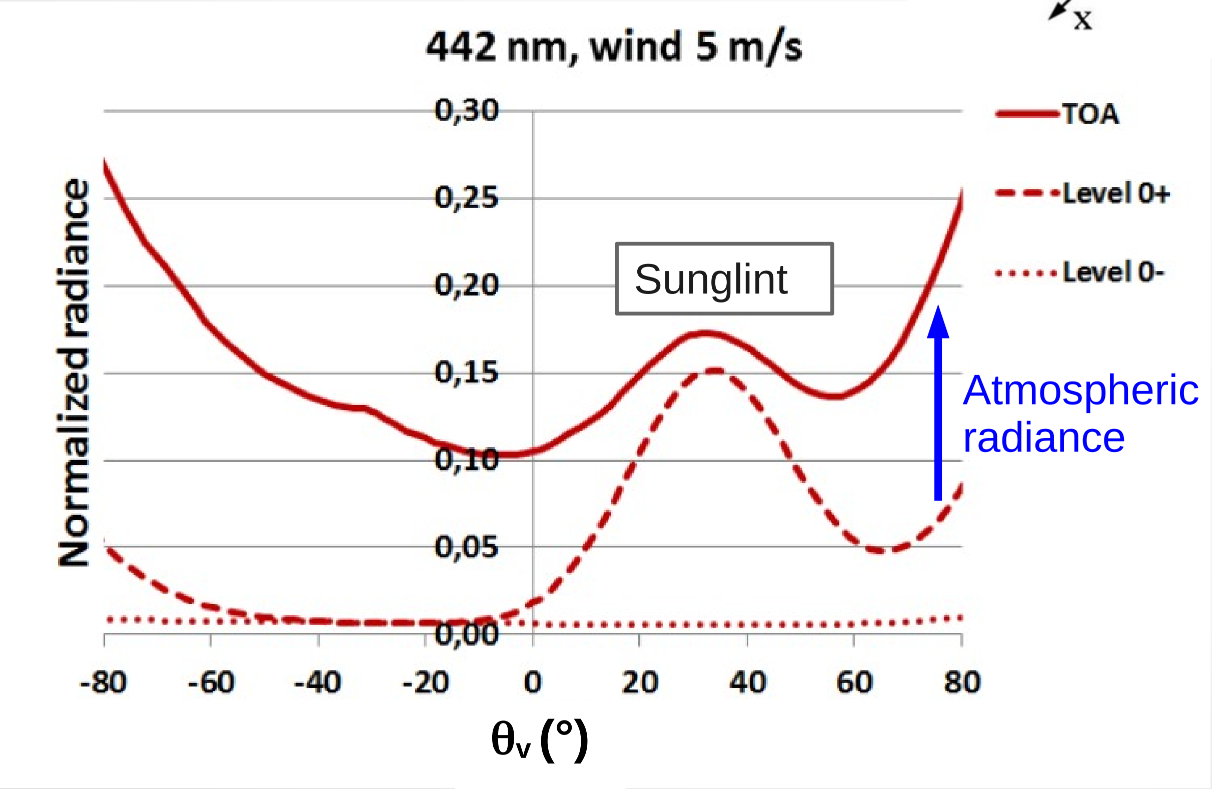
$\pi * L(z) / E_{sun}$

Example of results

Data from directory ***Standard_Outputs/***

- LUM_vsVZA_Simu2_TOA.txt
- LUM_vsVZA_Simu2_Level0p.txt
- LUM_vsVZA_Simu2_Level0m.txt



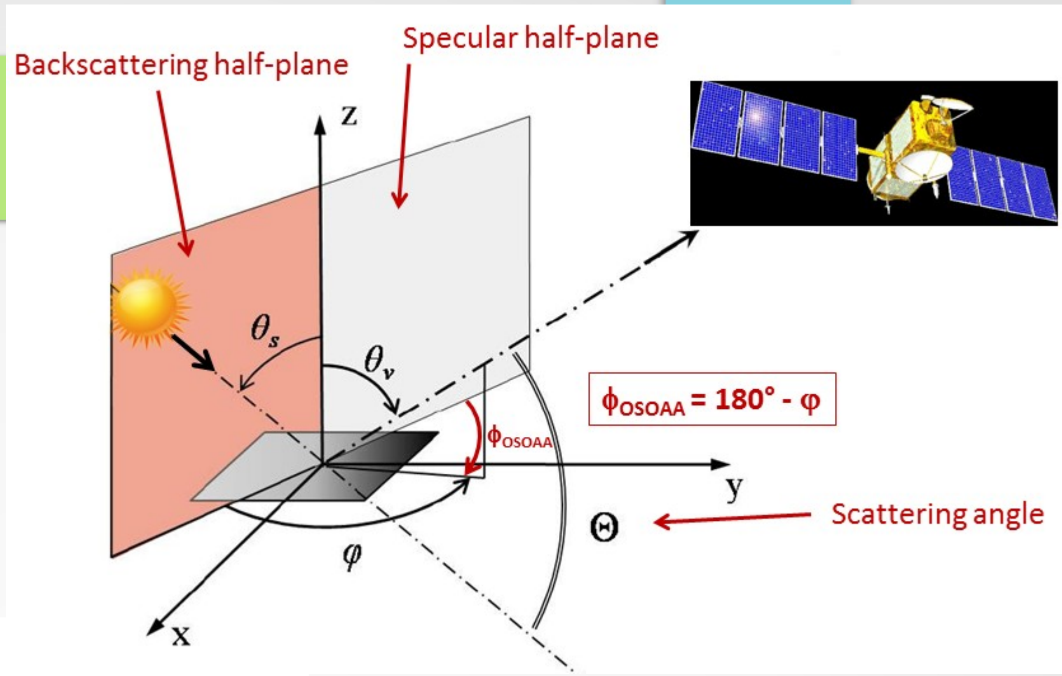


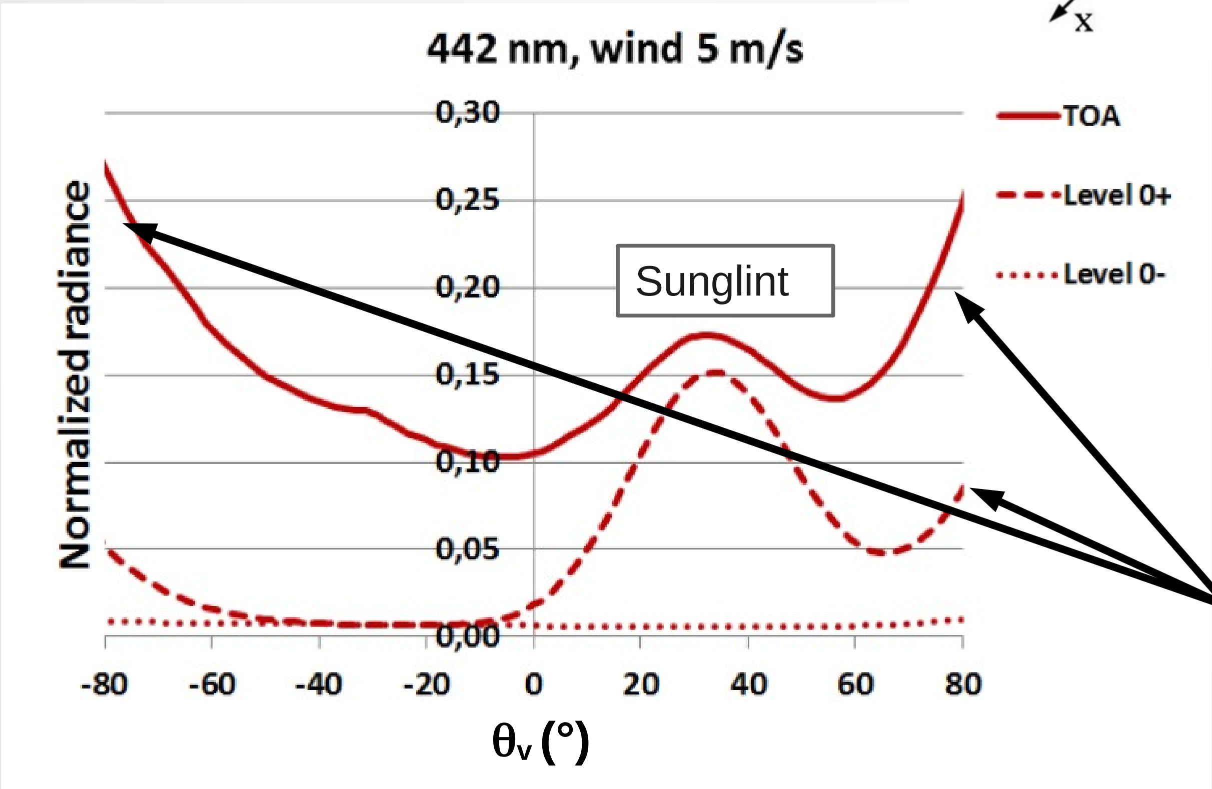
Sunglint in the specular direction

Example of results

Data from directory ***Standard_Outputs/***

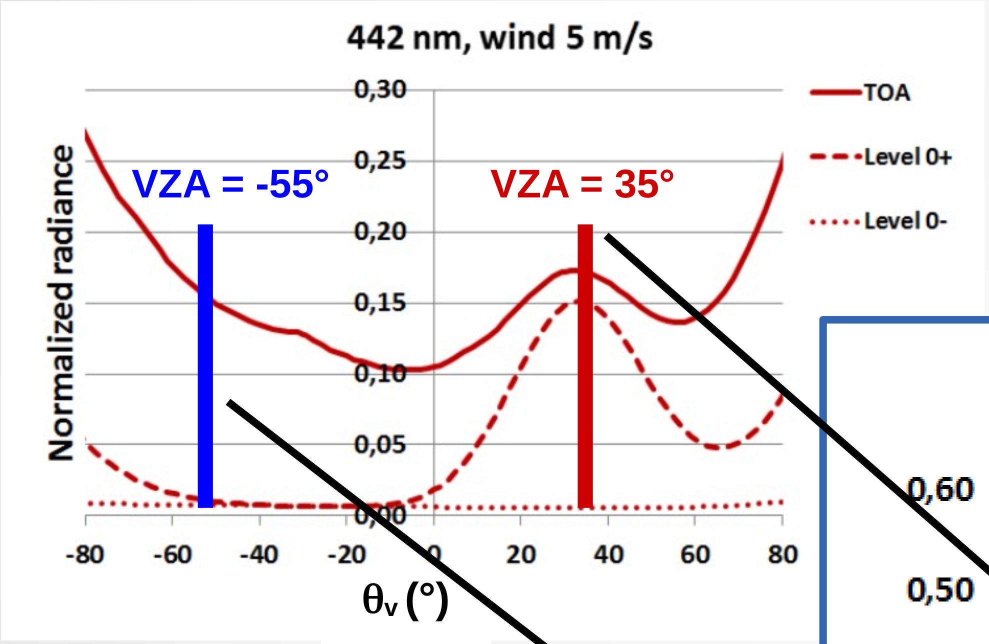
- LUM_vsVZA_Simu2_TOA.txt
- LUM_vsVZA_Simu2_Level0p.txt
- LUM_vsVZA_Simu2_Level0m.txt



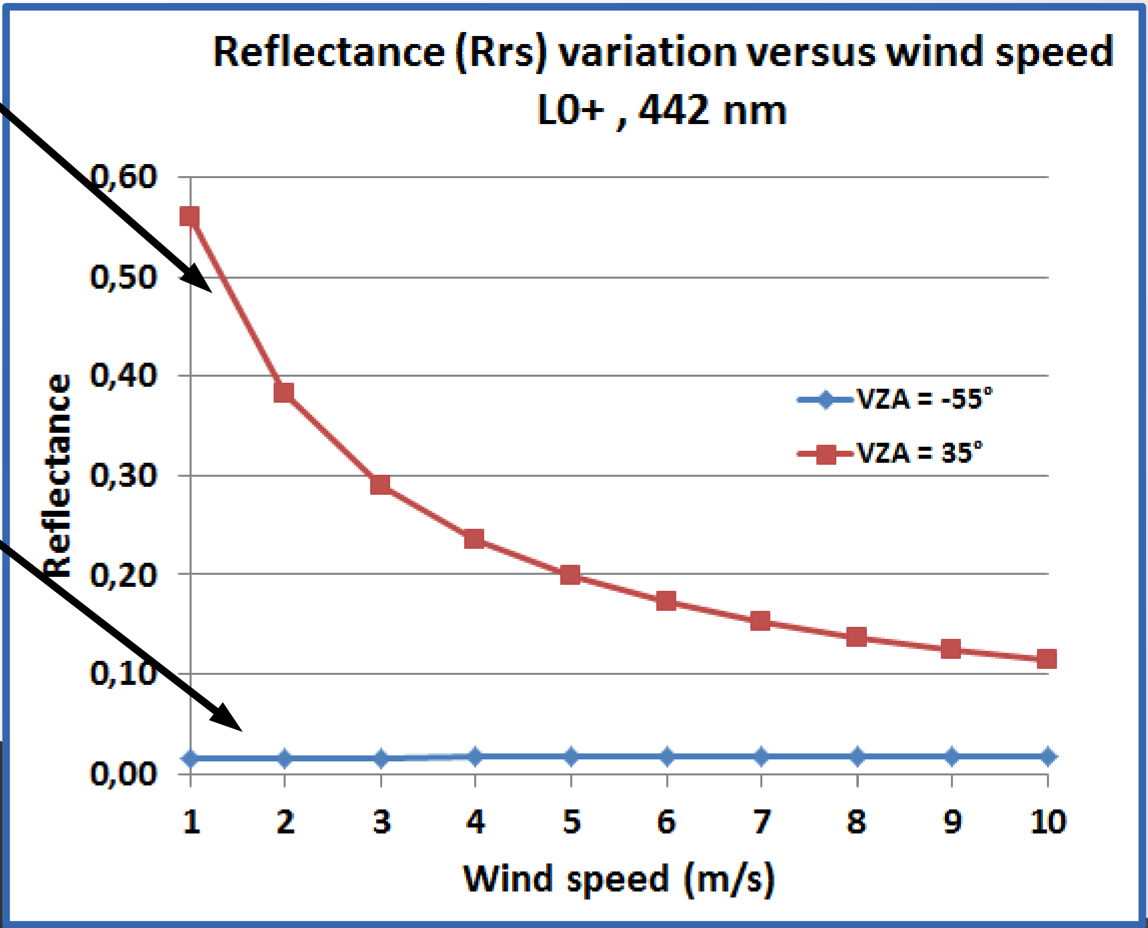


Increase of the radiance towards limb (high viewing zenith angles VZA)

Example of results



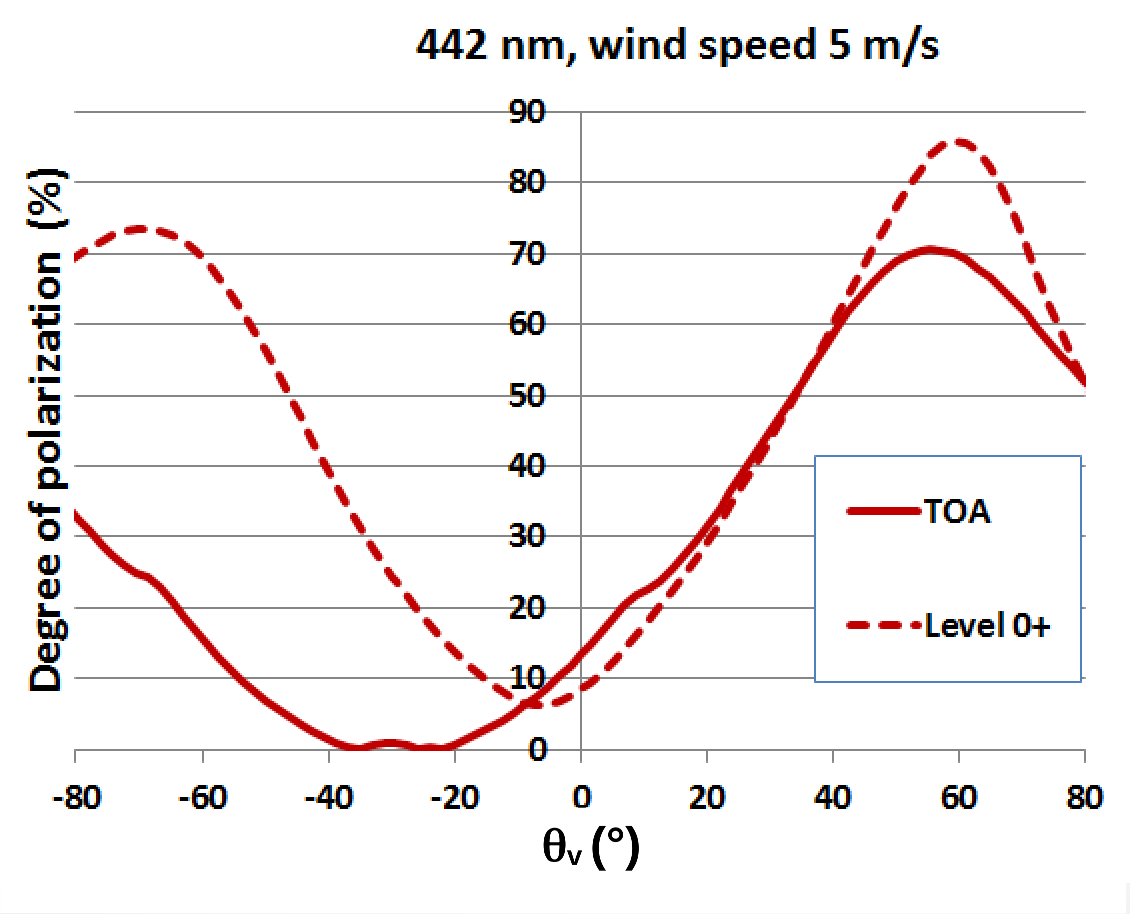
Sensitivity of the surface reflectance Rsr(0+) to the wind speed



Data from ***Standard_Outputs.***
Calculations for a wind speed from 1 to 10 m/s by step of 1m/s (loop on command lines + data extraction)

Example of results

Angular variation of the degree of polarization



The atmospheric scattering induces a depolarization of the radiation from 0+ to TOA

Data from ***Standard_Outputs***

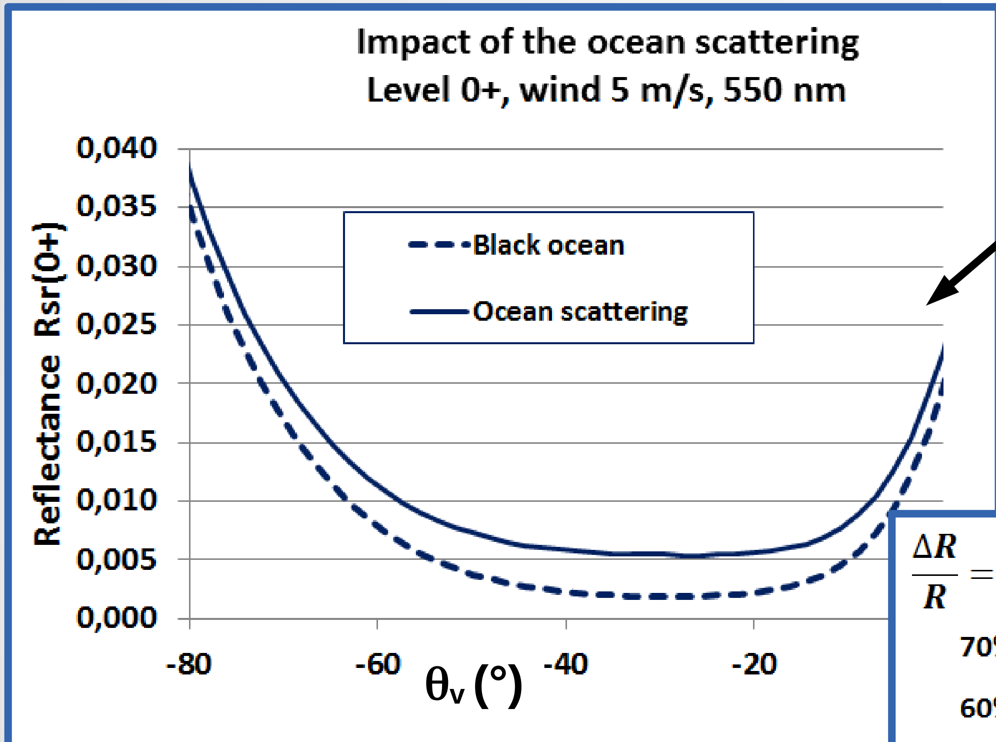
Example of results

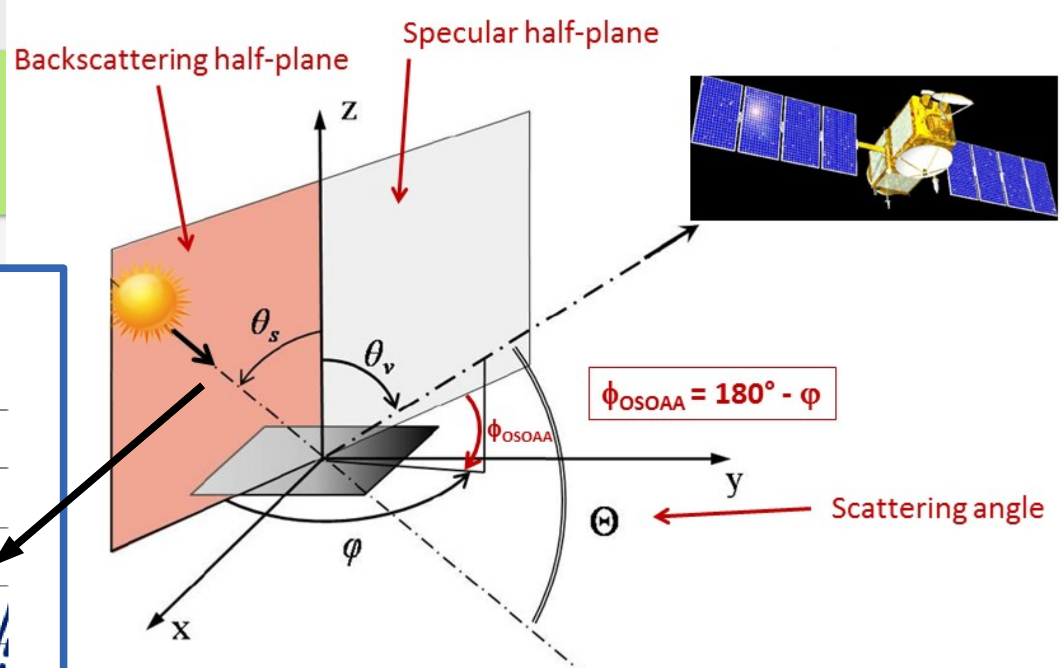
- Procedure to simulate a « Black Ocean »
  - Open the source code src / ***OSOAA_SOS_CORE.F***
  - To cancel the ocean scattering, set the expert parameter EXPERT_MODE_FORCED_FSEA_NULL as « .TRUE. »

```
C    EXPERT_MODE_FORCED_FATM_NULL : Constant devoted to expert analyses
C         ==> Force the atmospheric source function to be null if TRUE
C    EXPERT_MODE_FORCED_FSEA_NULL : Constant devoted to expert analyses
C         ==> Force the sea source function to be null if TRUE
C--------------------------------------------------------------------------
#include "OSOAA.h"
#define INCTE_IDLOG_SOS 99
#define INCTE_PI DACOS(-1.D+00)

#define EXPERT_MODE_FORCED_FATM_NULL .FALSE.
#define EXPERT_MODE_FORCED_FSEA_NULL .FALSE.
```

  - Make a new compilation : gen/Makefile_OSOAA.gfortran
  - If the seabed depth is weak (i.e., shallow waters), ensure to set the seabed albedo to the value of zero

Example of results

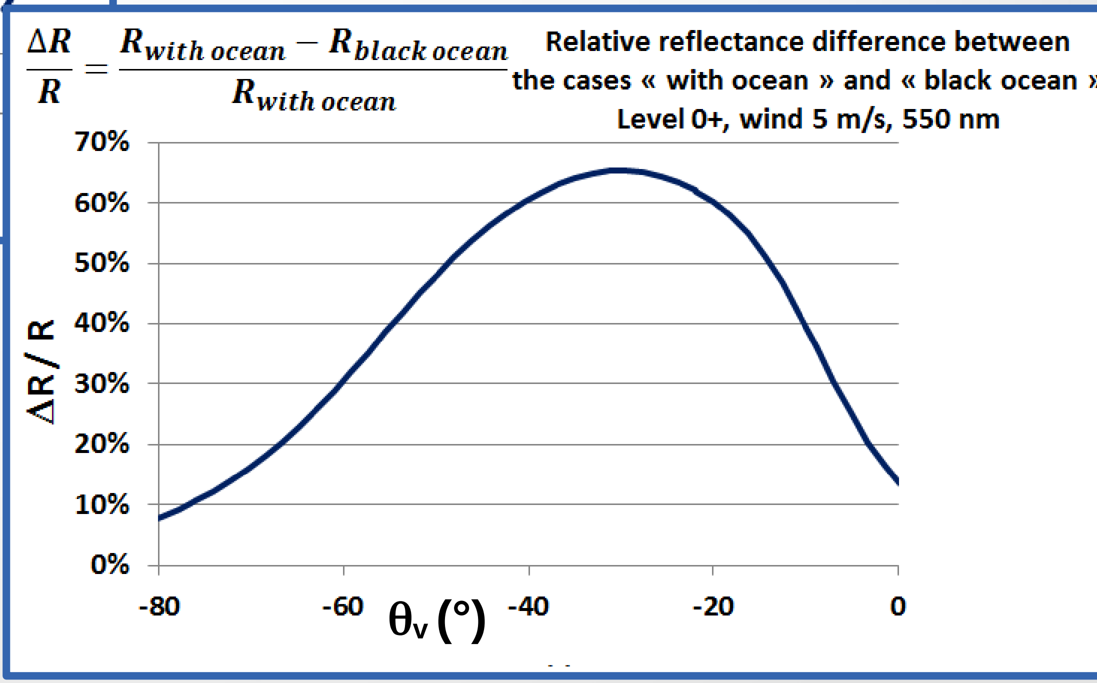




550 nm ⇒ Phytoplankton scattering

Sensitivity of the surface reflectance Rsr(0+) to the ocean scattering.

Rsr(0+) is driven by the skylight reflection onto the sea surface in the case of a black ocean

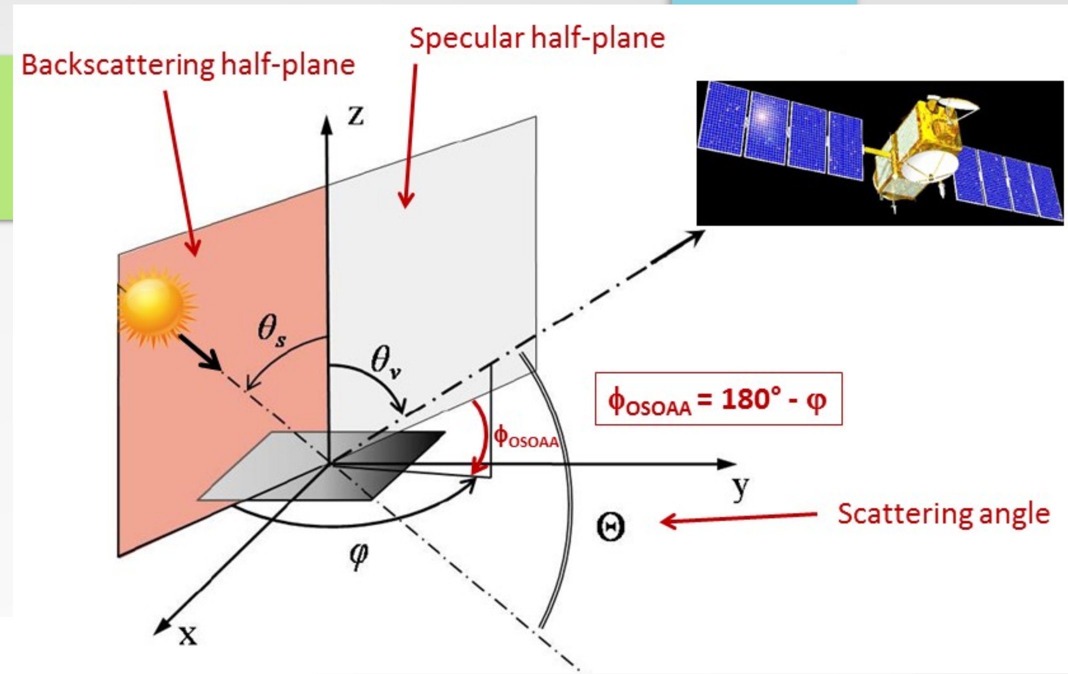


Data from ***Standard_Outputs.***
Calculations for an expert mode

Example of results

Physical explanation of the reason for an increase of the radiance at high viewing zenith angles (VZA)

⇒ Possible with OSOAA by simulating a « Black Sky »



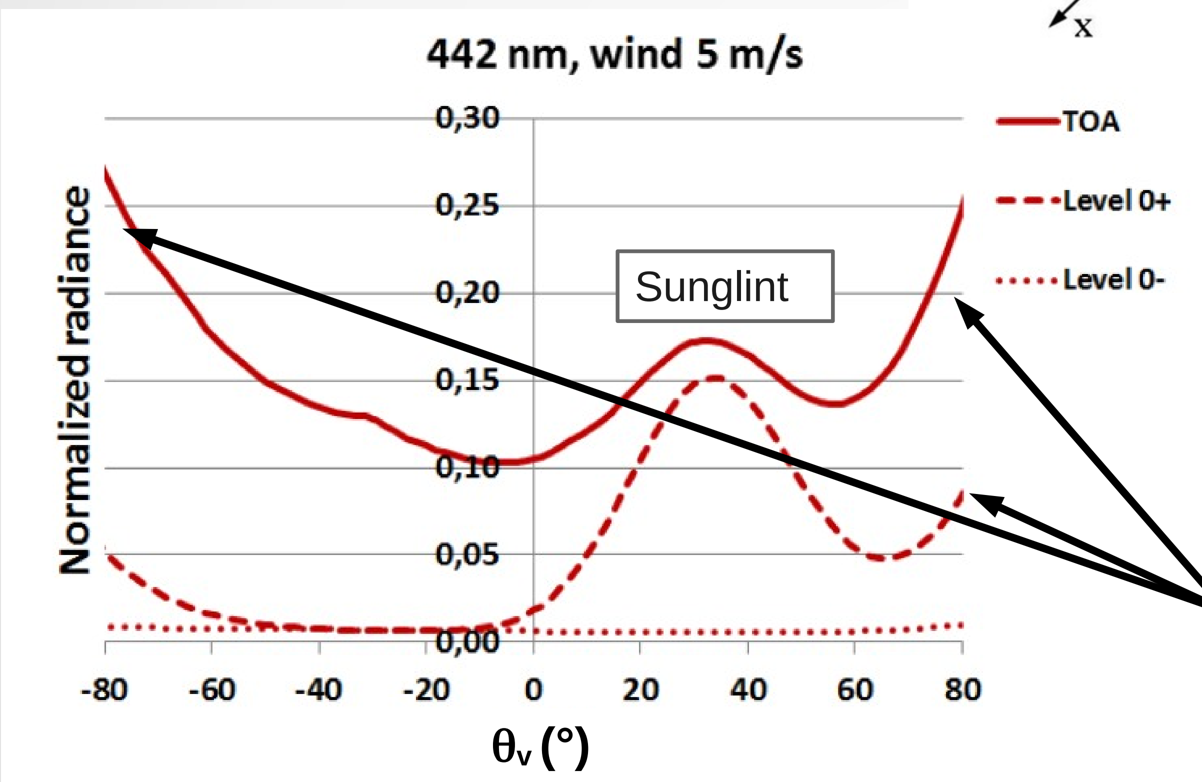


Illustration of the normalized radiance in the Solar Principal Plan (Φ_{OSOAA} = 0° & 180°)

Increase of the radiance towards limb (high viewing zenith angles VZA)

Example of results

- Procedure to simulate a « Black Sky »
  - Code src / ***OSOAA_SOS_CORE.F***
  - Cancel the atmospheric scattering : set the expert parameter EXPERT_MODE_FORCED_FATM_NULL as « .TRUE. »

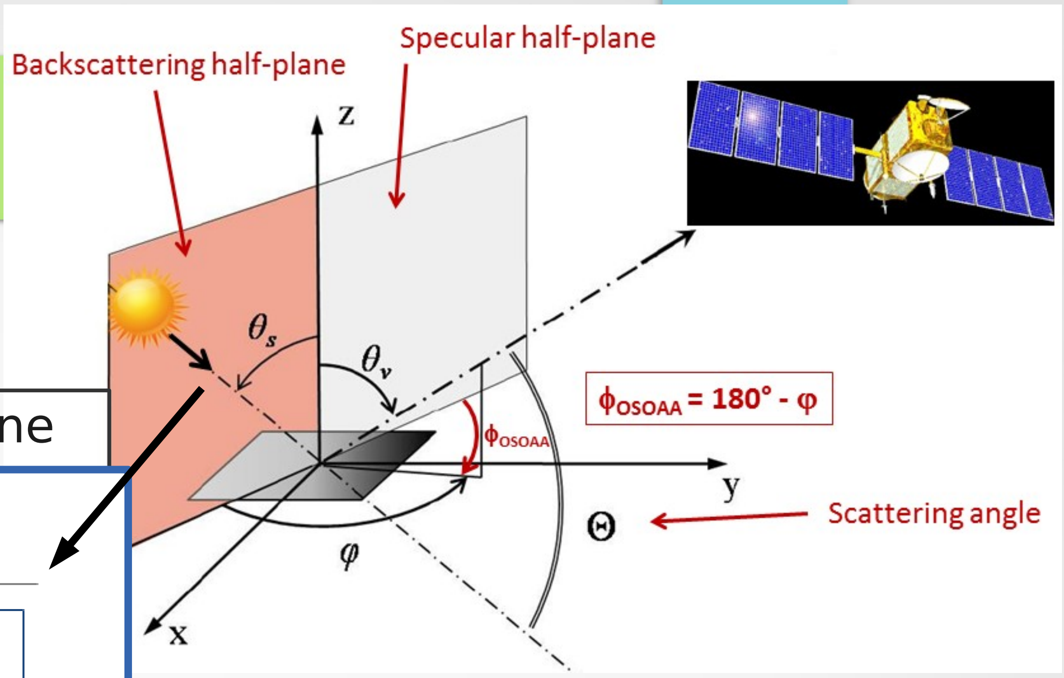
```
C    EXPERT_MODE_FORCED_FATM_NULL : Constant devoted to expert analyses
C         ==> Force the atmospheric source function to be null if TRUE
C    EXPERT_MODE_FORCED_FSEA_NULL : Constant devoted to expert analyses
C         ==> Force the sea source function to be null if TRUE
C--------------------------------------------------------------------------
#include "OSOAA.h"
#define INCTE_IDLOG_SOS 99
#define INCTE_PI DACOS(-1.D+00)

#define EXPERT_MODE_FORCED_FATM_NULL .FALSE.
#define EXPERT_MODE_FORCED_FSEA_NULL .FALSE.
```

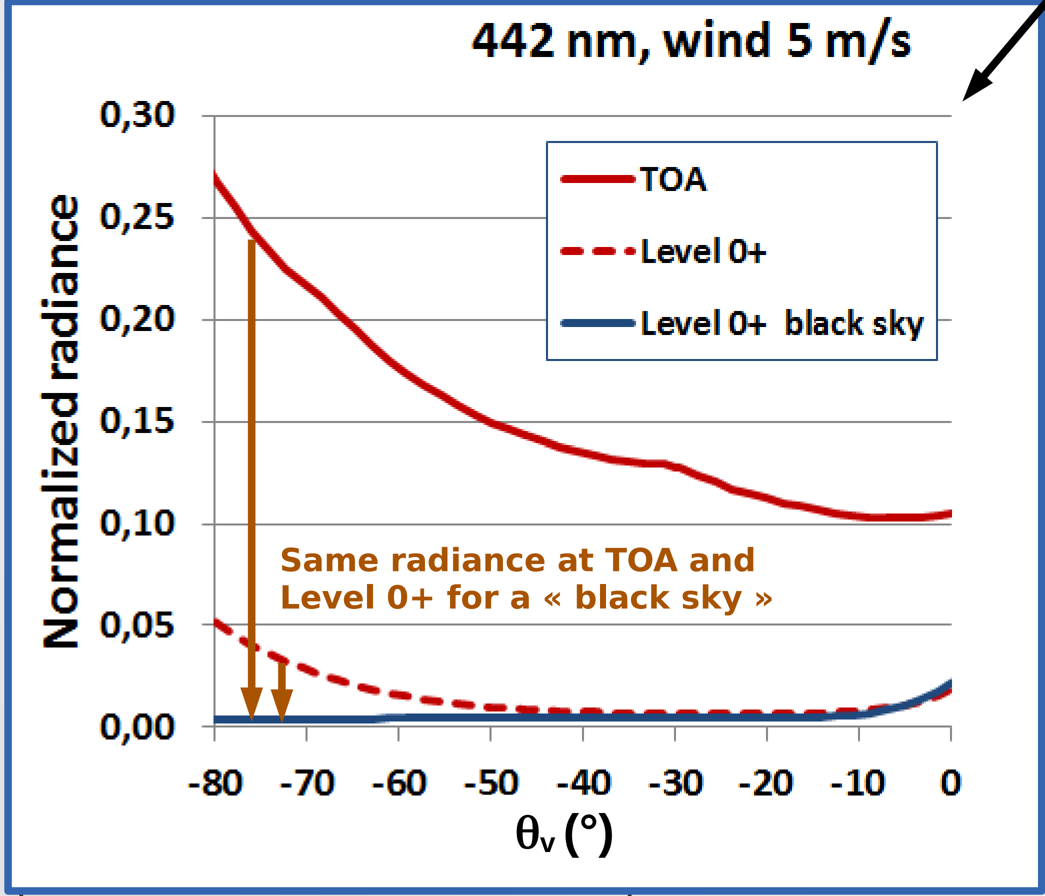
  - Make a new compilation
  - Set the AOT = 0 and a fairly zero molecular optical thickness (≈0.001)

Example of results

Impact of the atmospheric scattering on TOA radiance

Focus on the backscattering half-plane





Increase of the radiance towards high viewing zenith angles (VZA)

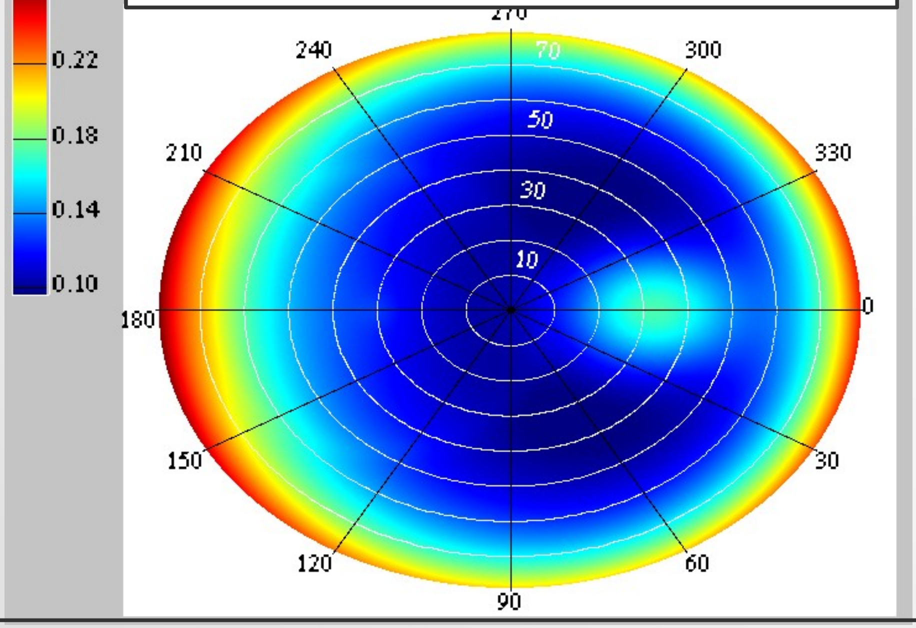
⇒ Caused by the reflexion of the downward atmospheric diffuse light onto the sea surface (i.e., skylight reflexion)

Data from ***Standard_Outputs.***
Calculations for an expert mode

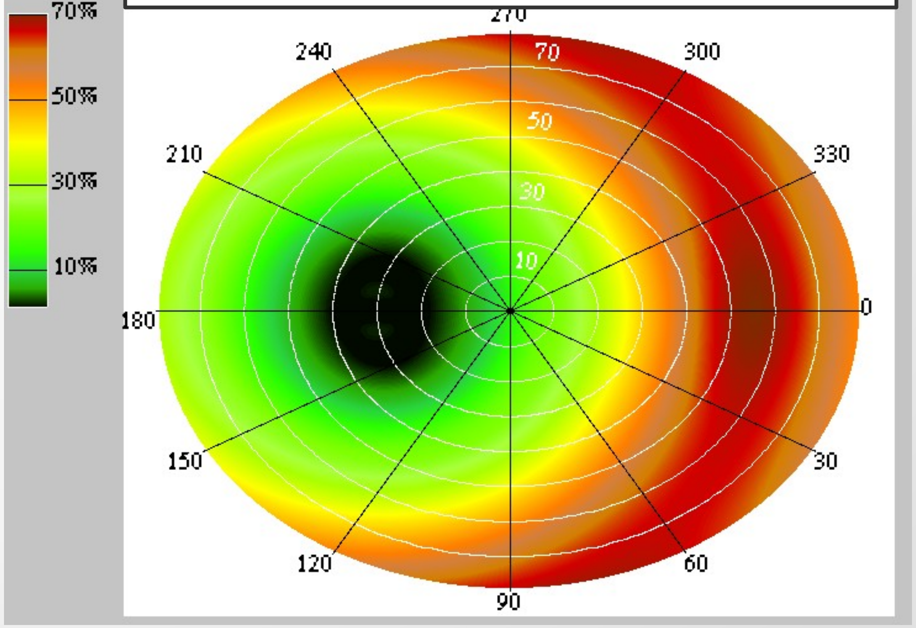
Example of results

- OSOAA simulations cover all geometry of observations (variations in azimuth and zenith angles)
- OSOAA can thus be used for the analysis of satellite ocean color observations

Normalized radiance at TOA
442 nm ; wind speed 5 m/s



Degree of polarization at TOA
442 nm ; wind speed 5 m/s



Data obtained using a loop of simulations over the values of Φ_{OSOAA} from 0 to 180° by step of 2°

Illustrations made using the Mgraph software from Laboratoire d'Optique Atmosphérique (LOA, France)

OSOAA is yours

Enjoy using OSOAA !

https://github.com/CNES/RadiativeTransferCode-OSOAA

Thank you for your attention !