

Interfacing near real-time aerosols with radiation schemes

- **Time:** 27/09/2021 - 22/10/2021
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1 INTRODUCTION

To improve forecasts during a wildfire, desert dust intrusion, volcanic eruption and enhanced anthropogenic emission situations, climatological information about aerosol concentrations is not sufficient. For this reason, new code updates are heading towards the implementation of the near real-time aerosol concentrations from the CAMS (Copernicus Atmosphere Monitoring Service) model in the radiation schemes.

The main aim of this stay was to understand the basics of the radiation scheme ACRANEB2, to get introduced to the externalization of ACRANEB2 aerosols and to take part in the preparation of conversion subroutine from CAMS aerosol mass mixing ratios (MMRs) to aerosol optical properties.

Starting point was ACRANEB2 scheme with externalized optical properties of the aerosol mixture, together with the subroutine getting these properties from aerosol optical depths at 550 nm of the six Tegen aerosol types.

2 OLD WAY - Tegen climatological aerosols

In the radiation routine ACRANEB2 four coefficients needed for solving the delta-two stream adding system (for details and explanation, see [2, 3]): α_1 , α_2 , α_3 and α_4 are diagnosed.

Originally, they were calculated from aerosol optical depth at 550 nm (PDAER) of the six Tegen aerosols. The updated ACRANEB2 will instead use aerosol optical depth δ (PAERDEL), asymmetry factor g (PAERASM) and single scattering albedo ω (PAERSSA) of the mixture. Except for averaging over different aerosol types, optical properties have to be spectrally averaged. The temporary subroutine that converts PDAER to PAERDEL, PAERASM and PAERSSA, ACRANEB_AER_550 was written by Ján Mašek.

3 NEW WAY - near real-time aerosols

In the updated version of ACRANEB2, PAERDEL, PAERASM and PAERSSA will be calculated from MMRs and inherent optical properties for each aerosol type and each RRTM spectral interval (14 in the shortwave and 16 in the longwave part) from the NetCDF file. That file will be read in the setup routine SUAERO which will fill the data structure with spectrally averaged aerosol optical properties. From spectrally averaged optical properties and MMRs, subroutine RAD_AER_MMR will calculate aerosol optical properties of a mixture in each target spectral interval.

3.1 Setup routine SUAERO

Three main things will be done in the setup SUAERO:

- reading the NetCDF file with the module from ecRad cy46t2 - easy_netcdf (by Robin Hogan),
- reading the namelist NAMAERO,
- spectral averaging to target intervals.

3.1.1 NetCDF file

Inherent optical properties (IOPs) for 14 shortwave and 16 longwave spectral intervals of 10 hydrophilic and 14 hydrophobic aerosol types are contained in the NetCDF file ([1]). For hydrophilic aerosol types, there are 12 different relative humidity bins.

For example, information about the asymmetry factor (similar for mass extinction coefficient and single scattering albedo) can be found in the variables:

```
asymmetry_lw_hydrophilic(hydrophilic, relative_humidity, band_lw)
asymmetry_lw_hydrophobic(hydrophobic, band_lw)
asymmetry_sw_hydrophilic(hydrophilic, relative_humidity, band_sw)
asymmetry_sw_hydrophobic(hydrophobic, band_sw),
```

where dimensions are:

```
band_lw = 16
```

```
band_sw = 14
```

```
hydrophilic = 10
```

```
hydrophobic = 14
```

```
relative_humidity = 12 .
```

The next step, after reading this NetCDF file is to perform spectral averaging to the required number of output spectral bands. For ACRANE2 this is 2 - single shortwave and single longwave spectral interval, while for ecRad scheme averaging is not needed since the used spectral division is the same as in the NetCDF file.

3.1.2 Spectral weights

The first step of spectral averaging is to prepare spectral weights for the shortwave and the longwave band. They are calculated externally and will be defined in the setup with the possibility to provide them through the namelist.

In the longwave part, weight for a specific interval is obtained by integrating Planck function over that interval:

$$w_\nu = \int_{\Delta\nu} B(\nu) d\nu = \int_{\Delta\nu} \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{k_B T}} - 1} d\nu, \quad (1)$$

where w_ν is spectral weight [W/m²], $B(\nu)$ is Planck function, h Planck constant [Js], c speed of light [m/s], ν frequency [1/s], T temperature [K] and k_B Boltzmann constant [J/K]. The numerical integration method used was rectangular integration, since the function is smooth enough so that the result obtained by using more precise integration methods (e.g. Gaussian quadrature) does not differ much.

For the shortwave part of the spectrum, weights are values of solar spectral irradiance for air mass 1.5 (surface spectrum at standardized atmospheric conditions, Figure 1), averaged over the interval. For calculating the weights, global total spectral irradiance in the clearsky conditions has been used. The spectra have been modelled using the SMARTS2 (version 2.9.2) Simple Model for Atmospheric Radiative Transmission of Sunshine of Gueymard. More information about the data can be found on <https://www.nrel.gov/grid/solar-resource/spectra-am1.5.html>.

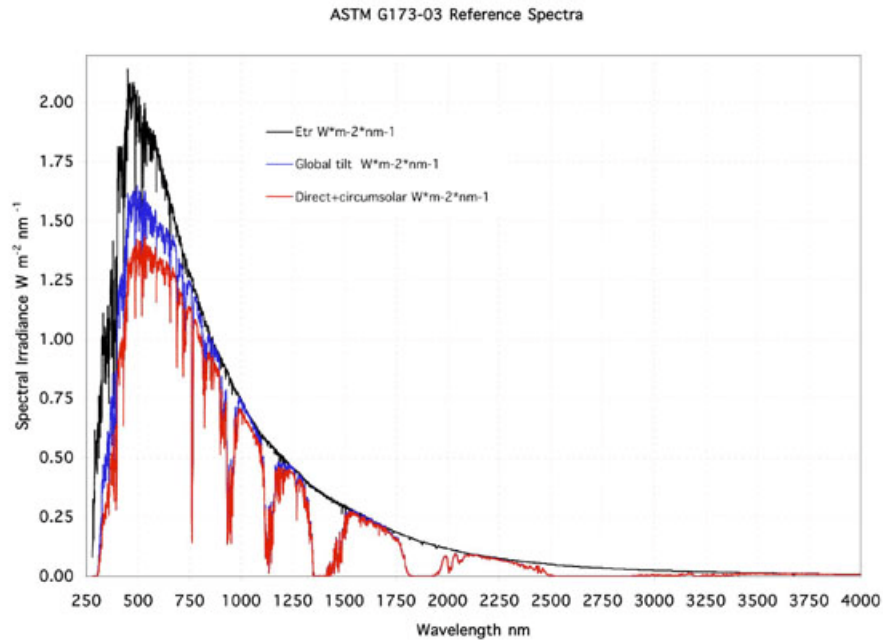


Figure 1: Extraterrestrial spectral irradiance (black), global total spectral irradiance on the 37° sun-facing tilted surface (used for calculating the weights; blue) and direct normal spectral irradiance (red)

3.1.3 Type structure

Aerosol optical properties will be used from the structure defined in TYPE_AERO. This type contains two main structures: TAERO_FILE in which will be stored data from the NetCDF file and TAERO_AVG which will be filled with spectrally averaged optical properties in the setup routine SUAERO. Content of the two type structures is shown in Table 1 and Table 2.

Table 1: TYPE TAERO_FILE

NAERO		
	NBAND_IN	
	RWEIGHT (:)	
	RMASK (:,:)	
SW	PHOBIC	REXT(:,:)
		RSSA(:,:)
		RASM(:,:)
PHILIC	REXT(:,,:)	
	RSSA(:,,:)	
	RASM(:,,:)	
	NBAND_IN	
	RWEIGHT (:)	
	RMASK (:,:)	
LW	PHOBIC	REXT(:,:)
		RSSA(:,:)
		RASM(:,:)
PHILIC	REXT(:,,:)	
	RSSA(:,,:)	
	RASM(:,,:)	

Table 2: TYPE TAERO_AVG

NHUM		
RHUM(:)		
NBAND_OUT		
SW	PHOBIC	REXT(:,:)
		RSSA(:,:)
		RASM(:,:)
PHILIC	REXT(:,,:)	
	RSSA(:,,:)	
	RASM(:,,:)	
	NBAND_OUT	
LW	PHOBIC	REXT(:,:)
		RSSA(:,:)
		RASM(:,:)
PHILIC	REXT(:,,:)	
	RSSA(:,,:)	
	RASM(:,,:)	

NAERO - number of aerosol types

NHUM - number of relative humidity bins

RHUM (:) - lower bounds of relative humidity bins

NBAND_IN - number of input bands (NetCDF file)

NBAND_OUT - number of output bands (radiation scheme)

RWEIGHT (:) - spectral weights for input bands

RMASK (:,:) - masks defining output bands, where indexes are (input band, output band)

REXT* - mass extinction coefficient [m^2/kg]

RSSA* - single scattering albedo

RASM* - asymmetry factor

* For REXT, RSSA and RASM, indexes are as follows:

- for philic (aerosol_type, relative_humidity, spectral_band)

- for phobic (aerosol_type, spectral_band)

3.2 Namelist NAMAERO

The user will be able to define through the namelist:

- CFAERO - NetCDF file name with aerosol optical properties (if path is not given, it is taken from the working directory)
- RAERO_WEIGHT_SW - shortwave spectral weights
- RAERO_WEIGHT_LW - longwave spectral weights
- RAERO_MASK_SW - masks defining output shortwave bands
- RAERO_MASK_LW - masks defining output longwave bands
- MAP_AERO_GFL - aerosol mapping, array with maximum 25 elements containing aerosols to be used: if 0 - aerosol type will not be used, if > 0, this is hydrophobic aerosol type and if < 0, hydrophilic.

Spectrally averaged optical properties, saved in type TAERO_AVG are imported through the module YOMAERO to the subroutine RAD_AER_MMR.

3.3 Subroutine RAD_AER_MMR

This new subroutine will be called at every model timestep, getting actual aerosol MMRs and relative humidity. It will do two things:

- binning for hydrophilic aerosols with respect to relative humidity
- computation of the optical properties (PAERDEL, PAERASM, PAERSSA) of the mixture from the mass mixing ratios of the individual CAMS aerosol types - averaging over aerosol types.

3.3.1 Averaging over aerosol types

From the shape of the delta-two stream system it follows that in a case of incoherent scattering, averaging of the optical properties of several radiatively active species goes via coefficients α'_{1-4i} , weighted by layer optical thicknesses $\Delta\delta'_i$ (see equation (13) of [3]):

$$\overline{\alpha'_{1-4}} = \frac{\sum_i \alpha'_{1-4i} \Delta\delta'_i}{\sum_i \Delta\delta'_i}, \quad \overline{\Delta\delta'} = \sum_i \Delta\delta'_i. \quad (2)$$

This way of averaging is indeed used in ACRANE2 scheme, where it is applied on δ -scaled quantities (indicated by prime). For modularity reasons, however, it is more convenient to specify aerosol mixture via its layer optical thickness $\overline{\Delta\delta}$, single scattering albedo $\overline{\omega}$, and asymmetry factor \overline{g} , all δ -unscaled. This is because various radiation schemes can use different shape of coefficients α'_{1-4} , or different strength of forward scattering via Dirac δ -peak.

Order of δ -scaling and averaging over aerosol species matters. In order to guarantee reproducibility of old ACRANE2 results, externalized optical properties of the mixture of Tegen aerosols have to be calculated in the following way (subroutine ACRANE2_AER.550):

- averaging of δ -scaled aerosol coefficients α'_{1i} and α'_{2i} of 6 Tegen aerosol types using equation (2);
- conversion from $(\overline{\alpha'_1}, \overline{\alpha'_2})$ to $(\overline{\omega'}, \overline{g'})$;
- δ -unscaled of $(\overline{\omega'}, \overline{g'}, \overline{\Delta\delta'})$ to $(\overline{\omega}, \overline{g}, \overline{\Delta\delta})$.

In ACRANE2, operations are done in reversed order, in order to ensure reproducibility of original result (2):

- δ -scaling of $(\overline{\omega}, \overline{g}, \overline{\Delta\delta})$ back to $(\overline{\omega'}, \overline{g'}, \overline{\Delta\delta'})$;
- conversion from $(\overline{\omega'}, \overline{g'})$ back to $(\overline{\alpha'_1}, \overline{\alpha'_2})$;
- $(\overline{\alpha'_3}, \overline{\alpha'_4})$ are calculated from $(\overline{\omega'}, \overline{g'}, \overline{\Delta\delta'})$ as in (5) and (6) from [3].

When using near real time aerosols, ACRANE2 scheme will get on input $(\overline{\omega}, \overline{g}, \overline{\Delta\delta})$ of the aerosol mixture, diagnosed from optical properties and MMRs of individual aerosol species. The question arises, how the averaging over aerosol species should be done. Here we show that as long as the backscatter fraction β depends linearly on asymmetry factor g , optical thickness weighted averaging of coefficients $(\alpha_{1i}, \alpha_{2i})$ is equivalent to averaging of (ω_i, g_i) with weights proportional to $(r_i k_i^{\text{ext}}, r_i k_i^{\text{ext}} \omega_i)$, where r_i are aerosol MMRs and k_i^{ext} are their mass extinction coefficients.

We define averaging as:

$$\overline{\alpha_1} = \frac{\sum_i w_i \alpha_{1i}}{\sum_i w_i}, \quad (3)$$

$$\overline{\alpha_2} = \frac{\sum_i w_i \alpha_{2i}}{\sum_i w_i}, \quad (4)$$

Starting from equations:

$$\beta_i = \frac{1}{2} - \frac{3}{8}g_i \quad (5)$$

$$\alpha_{2i} = 2\omega_i\beta_i, \quad (6)$$

we get:

$$\alpha_{2i} = 2\omega_i\left(\frac{1}{2} - \frac{3}{8}g_i\right) \quad / \cdot w_i \quad (7)$$

$$\alpha_{2i}w_i = \omega_iw_i - \frac{3}{4}g_iw_i\omega_i \quad / \sum_i \quad (8)$$

$$\sum_i \alpha_{2i}w_i = \sum_i \omega_iw_i - \frac{3}{4} \sum_i g_iw_i\omega_i \quad / : \sum_i w_i \quad (9)$$

$$\frac{\sum_i \alpha_{2i}w_i}{\sum_i w_i} = \frac{\sum_i \omega_iw_i}{\sum_i w_i} - \frac{3}{4} \frac{\sum_i g_iw_i\omega_i}{\sum_i w_i} \quad (10)$$

On the left hand side we recognize $\bar{\alpha}_2$. First term on the right hand side is trivial to show that it is $\bar{\omega}$. Then we have:

$$\bar{\alpha}_2 = \bar{\omega} - \frac{3}{4} \frac{\sum_i g_iw_i\omega_i}{\sum_i w_i} \quad / \cdot \frac{\sum_i \omega_iw_i}{\sum_i \omega_iw_i} \quad (11)$$

$$\bar{\alpha}_2 = \bar{\omega} - \frac{3}{4} \frac{\sum_i g_iw_i\omega_i}{\sum_i \omega_iw_i} \cdot \frac{\sum_i \omega_iw_i}{\sum_i w_i} \quad (12)$$

$$\bar{\alpha}_2 = \bar{\omega} - \frac{3}{4} \frac{\sum_i g_iw_i\omega_i}{\sum_i \omega_iw_i} \cdot \bar{\omega} \quad (13)$$

$$\bar{\alpha}_2 = \bar{\omega} \left(1 - \frac{3}{4} \frac{\sum_i g_iw_i\omega_i}{\sum_i \omega_iw_i}\right), \quad (14)$$

which gives us the averaging rule for the asymmetry factor:

$$\bar{g} = \frac{\sum_i w_i\omega_i g_i}{\sum_i w_i\omega_i}, \quad (15)$$

as long as β is linear in g .

This is valid for some general weight w_i , while our intention is to use layer optical thickness as weight, i.e. $w_i = \Delta\delta_i$.

Since $\Delta\delta_i = \tilde{k}_i^{ext} r_i(1 - q_v)\Delta p$, optical properties are calculated as follows:

$$\bar{\Delta\delta} = \left(\sum_i \tilde{k}_i^{ext} r_i\right)(1 - q_v)\Delta p \quad (16)$$

$$\bar{\omega} = \frac{\sum_i \omega_i r_i \tilde{k}_i^{ext}}{\sum_i r_i \tilde{k}_i^{ext}} \quad (17)$$

$$\bar{g} = \frac{\sum_i g_i \omega_i r_i \tilde{k}_i^{ext}}{\sum_i \omega_i r_i \tilde{k}_i^{ext}} \quad (18)$$

where r_i is dry air mass mixing ratio of the i^{th} aerosol type, q_v specific humidity, \tilde{k}_i^{ext} extinction coefficient in [1/Pa] and $\bar{\Delta\delta}$ layer optical depth of the mixture. $\bar{\omega}$ and \bar{g} are single scattering albedo and asymmetry factor of the aerosol mixture.

The same averaging rules are valid for spectral averaging, where i is not aerosol type but spectral interval and spectral weights are not $\Delta\delta_i$ but instead calculated as described in 3.1.2.

For hydrophilic types, binnig with respect to relative humidity will be made.

4 Conclusion and further work

The main (technical) difference between the old ACRANEB2 version and the new drafted one is that input to ACRANEB2 was PDAER for six Tegen aerosol types and in the new version input will be PAERDEL, PAERSSA and PAERASM for the mixture of CAMS aerosol types (up to 25 types). These optical properties will be spectrally averaged in the new setup routine SUAERO. The new subroutine RAD_AER_MMR converts aerosol load given as mass mixing ratios of individual CAMS aerosol types to aerosol SW and LW broadband optical properties (δ , g and ω) of the mixture.

Subroutines are not yet finished, and there is still some work to be done:

- binning procedure of relative humidity for hydrophilic aerosols
- we will use the narrowband model to convert extraterrestrial weights from Kurucz (Kurucz, R. L. (2005), The Solar Irradiance by Computation) to weights characterizing surface radiation for the short-wave band
- compilation and testing.

Acknowledgement: I would like to thank Ján Mašek for all the help, answers and patience during the stay, ONPP department for hosting me and RC-LACE for funding this stay.

References

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