Terms and symbols in the OMI Algorithm Team

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Aim

The aim of this memo is to recommend a common set of terms and symbols in the development of scientific algorithms for OMI and in writing the ATBD. By using one term and one symbol for one quantity, confusion and errors can be avoided. The present document is the result of several "hard choices".

Guidelines

The following guidelines have been used in making recommendations for notation and terminology.

1. Acronyms (like AMF) should never be used as symbols, because they cannot be used in formulae. They can, however, be used in the text.

2. Symbols should always be in italics (e.g. a is a symbol, but a is not).

3. Preferably only subscripts should be used in symbols. Superscripts should be avoided because of confusion with exponents.

4. No curly letters should be used as symbols, because MS Word cannot handle them in formulae.

5. Units should be used according to the SI system. Units are never in italics. Units are given below after the symbol as [unit].

6. Radiative transfer is a field with a long tradition in astronomy and planetary research (see, e.g., R1–R2). Here we try to follow this tradition as much as possible, with additions from reference texts on (atmospheric) radiation (R3–R6).

7. The chosen terms and symbols should not only be useful for the ATBD, but also for later publications from the OMI team. Preferably, the choice made here should form a solid basis for later use.

Main quantities

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preferred terms and symbols for **angles**:

1.1. viewing zenith angle: θ; $|\cos\theta| = \mu$

1.2. solar zenith angle: θ_0; $|\cos\theta_0| = \mu_0$

1.3. azimuth angle difference (viewing direction – solar direction): $\phi - \phi_0$.

Please note that $\phi - \phi_0 = 0^{\circ}$ for forward scattered light in the principal plane, and $\phi - \phi_0 = 180^{\circ}$ for backscattered light in the principal plane.

1.4. scattering angle: Θ

2.1. preferred term: **radiance**

2.2. preferred symbol: I [W/m^2/nm/sr]

2.3. definition: radiance = radiative energy flux in a particular direction

2.4. non-preferred terms: intensity, brightness.

3.1. preferred term: **irradiance**

3.2. preferred symbol: E [W/m^2/nm]

3.3. definition: the irradiance is the integral of the radiance weighted with μ over 2π steradians:

$$E = \int_0^{2\pi}\int_0^1 I(\mu,\phi)\mu d\mu d\phi$$

Specific symbol for the solar irradiance at top-of-atmosphere (TOA) perpendicular to the direction of incident sunlight: E_0.

This means that the solar irradiance at TOA incident on a horizontal surface unit is: $\mu_0 E_0$.

3.4. non-preferred terms: flux

4.1. preferred term: **reflectance**

4.2. preferred symbol: R [sr^{-1}]

4.3. dependencies: $R(\lambda;\mu,\mu_0,\phi-\phi_0)$

4.4. definition: $R = \pi \times$ radiance at TOA / solar irradiance at TOA on a horizontal surface unit:

$$R = \frac{\pi I}{\mu_0 E_0}$$

4.5. non-preferred terms: reflectivity; reflection function; directional albedo; BRDF.

5.1. preferred term: **albedo**

5.2. preferred symbol: A [-]

5.3. definition:

The basic definition of albedo is the ratio: outgoing irradiance / incoming irradiance. This is in contrast to the reflectance which is the ratio: outgoing radiance / incoming irradiance.

The albedo at TOA is defined as:

$$A = \frac{1}{\pi} \int_0^{2\pi} \int_0^1 R(\mu, \mu_0, \phi - \phi_0) \mu d\mu d\phi$$

Note that A depends on μ_0.

5.4: In analogy to the above definition of albedo at TOA, we have the following albedos:
Surface albedo: A_s.
Cloud albedo: A_c.

Here the incoming and outgoing irradiances are at the level of the cloud top and the surface, repectively.

5.5. In the TOMS algorithm, the so-called **Lambertian equivalent reflectivity** (LER) plays an important role. In fact, this reflectivity is the albedo of a Lambertian surface which is added to the atmosphere to yield the same modelled reflectance at TOA as is measured by the satellite. The symbol of LER is chosen to be A_{LER}. Because a real surface is not Lambertian, the retrieved LER depends on viewing direction.

5.6. For some applications the **spherical albedo** is needed. The spherical albedo at TOA is obtained by integration of $A(\mu_0)$ over μ_0:

$$S = 2 \int_0^1 A(\mu_0) \mu_0 d\mu_0$$

which is equivalent to:

$$S = \frac{2}{\pi} \int_0^{2\pi} \int_0^1 \int_0^1 R(\mu, \mu_0, \phi - \phi_0) \mu \mu_0 \; d\mu d\mu_0 d\phi$$

6.1. preferred term: **anisotropic factor**

6.2. preferred symbol: f_R [sr^{-1}]

6.3. definition:
The anisotropic factor f_R is the reflectance R normalized to the albedo:

$$f_R = R/A$$

7.1. preferred term: **sun-normalized radiance**

7.2. preferred symbol: I_n [sr^{-1}]

7.3. definition: sun-normalized radiance = π × radiance at TOA / irradiance at TOA perpendicular to the direction of incident sunlight:

$$I_n = \mu_0 R$$

7.4. reason: sometimes I_n is handy, because it is directly proportional to the measured signal.

8.1. preferred term: **vertical column density**

8.2. preferred symbol: N_v [molecules/cm^2]

8.3. definition: N_v is the total number of molecules in a vertical column of the atmosphere:

$$N_v = \int_0^\infty n(z)dz$$

Here $n(z)$ is the trace gas number concentration in [molecules/m^3].

8.4. reason: the symbol N_v (and formulae with N_v in it) can be used for any gas. For gas i the vertical column density is $N_{v,i}$.

9.1. preferred term: **slant column density**

9.2. preferred symbol: N_s [molecules/cm^2]

9.3. definition: N_s is defined as a column amount of absorbing gas molecules along the photon path, in the context of DOAS fitting of $\ln R$ with the absorption cross-section spectrum of the gas.

9.4. reason: the symbol N_s is analogous to N_v.

10.1. preferred term: **absorption cross-section**

10.2. preferred symbol: σ [cm^2/molecule]

10.3. definition: σ = optical thickness / N_v

11.1. preferred term: **optical thickness**

11.2. preferred symbol: τ_0

11.3. definition: the optical thickness is the total vertical extinction (= attenuation due to scattering and absorption) of the atmosphere:

$$\tau_0 = \int_0^\infty k_{\mathrm{ext}}(z)dz$$

Here k_{ext} is the volume extinction coefficient [m^{-1}].

12.1. preferred term: **optical depth**

12.2. preferred symbol: τ

12.3. definition: the optical depth is the vertical extinction *variable* in the atmosphere. At altitude z the optical depth is:

$$\tau = \int_z^\infty k_{\mathrm{ext}}(z)dz$$

Please note that τ becomes τ_0 at the bottom of the atmosphere.

12.4. reason:
Optical thickness and optical depth are often mixed. Here it is proposed to have one symbol, τ, but with different subscripts to indicate its specific meaning:
- τ for the optical depth (the variable in the radiative transfer equation)
- τ_0 for the optical thickness of the atmosphere (the value of τ at the surface)
- τ_n for the optical thickness of atmospheric layer n
- τ_0^i for the optical thickness of the atmosphere due to gas i.

13.1. preferred term: **single scattering albedo**

13.2. preferred symbol: ω [-]

13.3. definition:

$$\omega = \frac{k_{\mathrm{sca}}}{k_{\mathrm{ext}}}$$

Here k_{sca} is the volume scattering coefficient [m^{-1}].

14.1. preferred term: **air mass factor**

14.2. preferred symbol: M [-]

14.3. definition:

$$M = \frac{N_s}{N_v}$$

14.4. Computation of the air mass factor.

The classical computational formula for the air mass factor is:

$$M = (\ln R_0 - \ln R)/\tau_0^i$$

where gas i is the relevant absorber. Here R_0 is the reflectance *without* gas i in the atmosphere, and R is the reflectance *with* gas i added to the atmosphere. R and R_0 are calculated at some representative wavelength for the DOAS fit window. This computational formula only holds for optically thin gases. An improved version, developed by Stammes and Koelemeijer, which also holds for optically thick gases, is:

$$M = -\frac{d \ln R}{d\tau_0^i}.$$

Another approach to compute the air mass factor is the empirical or DOAS-simulated method, developed by Veefkind and De Haan. In this method the DOAS technique of determining the slant column is applied to a simulated spectrum at TOA for the atmospheric scenario which most closely resembles the measured case. Then M is calculated by dividing this slant column by the vertical column which is known from the model.

14.5. reason: a capital symbol is preferred. The air mass factor M of the entire atmosphere can be regarded as the integral of the altitude-dependent air mass factor $m(z)$:

$$M = \int_0^\infty m(z) dz$$

Other quantities

15. phase function: $P(\Theta)$ [sr^{-1}]

16. asymmetry parameter: g [-]; allowed alternative: $< \cos\Theta >$

17. frequency: ν [Hz]

18. wavelength: λ [nm]; λ should be given in vacuum.

19. wavenumber: ν/c_l [cm^{-1}], with c_l the speed of light in vacuum; note that $\nu/c_l = 10^4/\lambda$, with λ in nm.

20. temperature: T [K]

21. pressure: p [hPa]

22. altitude: z [m]

23. cloud fraction: c [-]

24. cloud pressure: p_c [hPa]

25. surface pressure: p_s [hPa]

26. polynomials: P_n.

27. Ring effect (expressed as a cross-section): σ_{Ring}.

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