Atmospheric Resistance (Ra)

The atmospheric resistance (Ra) term describes the resistance to O3 transfer due to mechanical and thermal atmospheric mixing processes between a specific reference height in the atmosphere at which the O3 concentration is modelled or measured (zR) and the top of the plant canopy (z1) for which O3 deposition or uptake is being calculated.

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# Model Flow

TODO:

# Atmospheric resistance (Ra)

We have to explain when Ra is needed and when not (e.g. for leaf-level applications with available ozone data measured at top of plant canopy)

The atmospheric resistance (Ra) term describes the resistance to O3 transfer due to mechanical and thermal atmospheric mixing processes between a specific reference height in the atmosphere at which the O3 concentration is modelled or measured (zR) and the top of the plant canopy (z1) for which O3 deposition or uptake is being calculated.

Ra is estimated using two different methods, the selection of which depends primarily upon the complement of available input data. The more data intensive method incorporates both mechanical and thermal atmospheric mixing processes in the estimation of Ra (here termed Racomp) and requires heat flux data (both sensible and latent) which are often unavailable at site-specific locations. The less data intensive method only incorporates mechanical atmospheric mixing processes (i.e. assumes neutral stability of the atmospheric profile) in the estimation of Ra (here termed Rasimp).

These Ra formulations both incorporate canopy roughness characteristics which will in part determine atmospheric turbulence. The vegetation roughness length (*zo)* and displacement height *(d)* are approximately 10 % and 70 % of the vegetation height (*h*) respectively (references). Default values for *h* used in EMEP DO3SE are given in Table x. Here, z1 is more accurately defined as the top of the quasi-laminar canopy boundary layer (zo+d).

The interfaced version of the DO3SE model uses the Rasimp model formulations.

### Rasimp

Assuming neutral stability, Rasimp and friction velocity (*u\**) can be estimated as follows using standard methods consistent with those described in the UNECE (2004).

Rasimp = 

The friction velocity, *u\** (m s-1) is derived from :-

u\* = 

Where *k* is the von Karman constant (0.41), *u\** is the friction velocity, *u*(*z*) is the windspeed at height *z*, *d* is the displacement height and *zo* is the roughness length.

### Racomp

Where data are available to determine the actual stability profile of the atmosphere, Racomp can be approximated following the procedure given by Garland (1978), using the Monin-Obukhov similarity relations for the dimensionless wind shear and potential temperature gradient suggested by Businger et al. (1971):

Racomp = 

Where *k* is the von Karman constant (0.41), u\* is the friction velocity, *d* is the displacement height, *zo* is the vegetation roughness length and *L* is the Monin-Obukhov length. ψh is the integrated stability function for heat.

According to Arya (1988), integration of simplified forms of the similarity functions with respect to height yields the formulations used for the stability function for heat (ψh) and momentum (ψm)

ψh (ξ) = ψm (ξ) = -5 ξ if ξ ≥ 0 (stable)

ψ*m* (ζ ) = ln if ζ < 0 (unstable)

ψ*h* (ζ ) = 2 ln if ζ < 0 (unstable)

where xm = (1-16 ζ ) 1/4 and xh = (1-16 ζ ) 1/2 and ζ = (z-d)/L or zo/L.

The friction velocity, u\* (m s-1) is derived from :-

u\* = ,

where τ is turbulent surface stress (kg / m / s-2) and *ρ* is surface density of dry air (kg/m3) derived from :-

*ρ* = 

where P is surface air pressure (Pa), *Rmass* is the mass gas constant for dry air (J / Kg / K) and T2 is the surface air temperature (Kelvin).

The Monin-Obukhov length, L, is derived from

L = -

where c*p* is the specific heat capacity of dry air; k is von Karman’s constant (0.41), g is the gravitational acceleration (9.81 m s-2) and H is the surface flux of sensible heat (W m-2).