Boundary Layer Resistance (Rb and rb)

The boundary layer of a plant surface can be defined as the layer of air surrounding the surface within which O3 transfer is reduced from that which would occur in the atmosphere due to friction imparted by the plant surface.

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# Model Flow

TODO

# Boundary layer resistance (Rb & rb)

The boundary layer of a plant surface can be defined as the layer of air surrounding the surface within which O3 transfer is reduced from that which would occur in the atmosphere due to friction imparted by the plant surface. The processes which determine transfer across canopy and leaf boundary layers occur due both to mechanical forcing (imparted by the momentum of the atmosphere) and molecular diffusion, with the latter becoming more important closer to the leaf surface as the momentum is reduced due to surface friction. The boundary layer resistance is commonly termed quasi-laminar since it comprises turbulent air movement occurring in the direction of laminar flow. The calculation of total O3 deposition requires that the whole **canopy** boundary layer resistance (Rb) be estimated. In contrast, to estimate stomatal O3 deposition to representative leaves of the upper canopy, **leaf** boundary layer resistances (rb) need to be calculated. Explain what is of relevance for interface

## Canopy level quasi-laminar boundary layer resistance (Rb)

Whole canopy boundary layer resistance is approximated according to the following formulation presented by Hicks et al (1987)

Rb = 

where Sc is the Schmidt number equal to *v*/*Di*, with *v* being the kinematic viscosity of air (0.15 cm-2 s-1 at 20°C), *Di* being the molecular diffusivity (for O3 this is 0.15 cm-2 s-1 and for H2O this is 0.25 cm-2 s-1 at 20oC) and Pr being the Prandtl number (0.72).

[Include Rb for CO2, H2O, O3 and heat]

## Leaf level quasi-laminar boundary layer resistance (rb)

Consistency of the quasi-laminar boundary layer is harder to achieve, so a leaf-level *rb* term (McNaughton and van der Hurk, 1995) is used. This incorporates the cross-wind leaf dimension *L* (given in m) and *u*(*h*) (the wind speed at the top of the canopy given in m/s). According to Campbell & Norman (1998), *rb* for heat (for forced convection) can be calculated according to eq. 3 giving values in s/m (these formulations take into account both sides of the leaf and therefore provide *rb* for PLA).

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The approximate value of 150 (as used in the UNECE Mapping Manual (LRTAP Convention, 2010)) is arrived at using the value of 0.135 which is a constant for heat conductance in mol m-2 s-1 for a single leaf surface and is converted to a resistance term (s/m). This is achieved using 41 to convert from mol m-2 s-1 to m/s, 2 from single surface to PLA and by dividing by 1 to give a resistance (i.e. 1/(0.135\*2)/41 which gives 151.85 and is then rounded down to 150).

For the gases - water vapour, carbon dioxide and ozone, the values of 0.147, 0.110 and 0.105 are the constants used for used for conductance in mol m-2 s-1 for a single leaf surface (i.e. these replace the 0.135 constant for heat). These are equivalent to 139, 186 and 195 when used in the equations giving units in s/m (similar to eq 3).

N.B. Some boundary layer models also make a distinction between free (or natural) convection and forced convection. Free (natural) convection occurs due to temperature differences which affect the density, and thus relative buoyancy, of the fluid (e.g. water vapour). In forced convection, sometimes also called heat convection, fluid movement results from external surface forces such as expansion of air due to heat. Free (or natural) convection is not currently used in the DO3SE model. However, we describe the method to estimate free (or natural) convection below in case this might be introduced in subsequent model versions.

For the definition of the criteria for free *vs*. forced convection, a ratio term is necessary which is calculated as in eq. 4.

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ratio     = (9.81\*abs(Tleaf\_K-Tair\_K))/((u\*\*2)\*((Tleaf\_K+Tair\_K)/2)) – these brackets aren’t correct and what does ‘abs’ stand for.

If ratio ≤ 0.1, then forced convection dominates (see above). Else if the ratio is > 0.1 then free convention is occurring which is estimated according to Campbell & Norman (1998) as described in eq. 5 in units of s/m.

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