Multiplicative stomatal resistance (Rsto)

Contents

[3.1.1. Maximum stomatal conductance () 2](#_Toc49276282)

Mean canopy level stomatal conductance to O3 (Gsto), the inverse of stomatal resistance (Rsto), is calculated with the multiplicative model of Emberson et al. (2000a):

Gsto = gmax \* Fphen \* Flight \* max{fmin, (ftemp \* fVPD \* fSWP)}

where gmax is the leaf/needle-level maximum stomatal conductance (mmol O3 m-2 PLA s-1), Fphen is the bulk canopy stomatal conductance relationship with seasonal canopy age, Flight is the whole canopy stomatal conductance relationship with irradiance penetrating within the canopy, fmin is the minimum daylight stomatal conductance, and ftemp, fVPD and fSWP are the stomatal conductance relationships with temperature, vapour pressure deficit and soil water potential respectively. This calculation gives a mean gsto value for all leaves/needles in the canopy. As such, Gsto can be scaled according to LAI to estimate whole canopy stomatal conductance (Gstocanopy).

Leaf level stomatal conductance to O3 (gsto) is calculated again with the multiplicative model of Emberson et al. (2000a) but following the formulations of UNECE (2004) :-

gsto = gmax \* {min (fphen, fO3) \* flight \* {max (fmin, ftemp \* fVPD \* fSWP})

where gmax is the leaf/needle-level maximum stomatal conductance (mmol O3 m-2 PLA s-1), fphen is the leaf/needle level stomatal conductance relationship with leaf/needle age, fO3 is..... (see below), flight is the stomatal conductance relationship with irradiance at the top of the canopy, fmin is the minimum daylight stomatal conductance, and ftemp, fVPD and fSWP are the stomatal conductance relationships with temperature, vapour pressure deficit and soil water potential respectively. This calculation gives a leaf/needle level gsto value for leaves/needles representative of those at the top of the canopy (or in the case of wheat, the flag leaf). As such, gsto can then be used to estimate upper canopy leaf/needle stomatal O3 flux for risk assessment.

The term fO3, which allows for O3 exposure to cause early senescence, is currently only established for wheat and potato and therefore is set equal to 1 for all other cover-types and species.

The flux-effect models developed by Pleijel et al. (2002) and Danielsson et al. (2003) include a function to allow for the influence of ozone concentrations on stomatal conductance (fO3) on wheat and potato via the onset of early senescence. As such this function is used in association with the fphen function to estimate gsto. The fO3 function typically operates over a one-month period and only comes into operation if it has a stronger senescence-promoting effect than normal senescence. The functions are given in Equations 3.21 and 3.22. The ozone function for spring wheat (based on Danielsson et al. (2003) but recalculated for PLA):

fO3 = ((1+(AFst0/11.5)10)-1) [xxx]

where AFst0 is accumulated from Astart

The ozone function for potato (based on Pleijel et al. (2002)):

fO3 = ((1+(AOT0/40)5)-1) [xxx]

where AOT0 is accumulated from Astart

## Maximum stomatal conductance ()

Table 1 lists absolute maximum stomatal conductance values (in mmol O3 m-2 PLA s-1, denoted , where the exponent *m* stands for the median of *gs* values taken from the literature) and *fmin* values (provided as a fraction of ). These values are given for the vegetation cover types (as necessary for regional deposition modelling) and by key species (from which the cover typeand *fmin* values have been derived).

The values for are provided often provided for gases other than O3 (i.e. H2O vapour or CO2), for total or projected leaf/needle areas and in conductance units of e.g. mm s-1 rather than molar units.

For pressure (P) and temperature (T), gmax in m s-1 units is given by:

gmax = *RT/P*

R is here the gas-constant (8.314 J/mol/K). At normal temperature and pressure, gmax ≈ /14000.

Table 1 Default deposition land-cover and species class values for and *fmin* parameters.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Land-cover type & Species** | **Climate region** | ***gmax*** mmol O3 m-2 PLA s-1 | **fmin** | **Reference** |
|  |  |  |  |  |
| **Coniferous Forests (CF)** |  | 160 | 0.1 | Simpson et al. (2003) |
| Norway spruce  (*Picea abies*) | Northern Europe | 112 (111-118(119)) | 0.1 | UNECE (2004); Zimmerman et al. (1988) [112]; Sellin. (2001) [119]; Hansson et al. (in prep) [111] |
| Scots Pine  (*Pinus sylvestris*) | Atlantic Central Europe | 180 (171-188) | 0.1 | UNECE (2004); Whitehead et al. (1984) [188]; Beadle et al. (1985) [175]; Sturm et al. (1998) [171] |
| Norway Spruce  (*Picea abies*) | Continental Central Europe | 125 (87-140) | 0.16 | UNECE (2004) cf. Körner et al. (1979) [87]; Dixon et al. (1995) [121]; Emberson et al. (2000) [130]; Zweifel et al. (2000, 2001, 2002) [140]; Korner. (1979) |
| **Deciduous Forests**  **(DF)** |  | 134 | 0.13 | Simpson et al. (2003) |
| ***Generic Deciduous*** | ***All Europe*** | ***150 (100-180)*** | ***0.1*** | ***UNECE (2004)*** |
| Silver birch  (*Betula pendula*) | Northern Europe | 196 (180-211) | 0.1 | UNECE (2004); Uddling et al. (2005a) [180]; Sellin et al. (2005) [211] |
| Beech  (*Fagus sylvatica*) | Atlantic Central Europe | 150 (100-180) | 0.1 | UNECE (2004); |
| Oak  (*Quercus petraea & robur*) | Atlantic Central Europe | 230 (177-325) | 0.06 | UNECE (2004); Breda et al. (1995) [228]; Epron & Dreyer. (1993) [177]; Breda et al. (1993a) [233]; Breda et al. (1993b) [275]; Q.robur from Epron & Dreyer. (1993) [198]; Dolman & Van den Burg. (1988) [264] |
| Beech  (*Fagus sylvatica*) | Continental Central European | 150 (132-300) | 0.13 | UNECE (2004); Nunn et al. (2005) [147]; Matyssek et al. (2004) [132]; Keel et al. (2007) [180]; Kutsch et al. (2001) [300]; Freeman (1998) cf. Medlyn et al. (2001) [180]; cf. Körner et al. (1979) [150]; Schaub (pers. comm.) [137]; Korner. (1994) |
| Beech  (*Fagus sylvatica*) | Mediterranean Europe | 145 (100-183) | 0.02 | UNECE (2004); Raftoyannis & Radoglou (2002) [156]; cf. Körner et al. (1979) [100; 140]; Nunn et al. (2005) [147]; Matyssek et al. (2004) [132]; Aranda et al. (2000) [183] |
| **Needleleaf Forests**  **(NF)** |  | 180 | 0.13 | Simpson et al. (2003) |
| Aleppo Pine  *(Pinus halepensis)* | Mediterranean Europe | 215 | 0.15 | UNECE (2004); Elvira et al (2007) [215] |
| **Broadleaf Forests**  **(BF)** |  | 200 | 0.03 | Simpson et al. (2003) |
| ***Generic Evergreen Mediterranean*** | ***All Europe*** | ***175 (70-365)*** | ***0.02*** | ***UNECE (2004)*** |
| Holm Oak  (*Quercus ilex*) | Mediterranean Europe | 180 (134-365) | 0.02 | Rhizopoulos & Mitrakos (1990) [250]; Manes et al. (1997) [366]; Filho et al. (1998) [225]; Tognetti et al. (1998) [195]; Sala & Tenhunen (1994) [165]; Alonso et al. (2007) [183, 191]; Infante et al. (1999) [323]; Castell et al. (1994) [177]; Damesin et al. (1998) [171]; Mediavilla & Escudero (2003) [122]; Corcuera et al. (2005) [134]; Gratani et al. (2000) [159]; Bussotti & Ferretti (2007) [166, 188, 156] |
| **Temperate crops**  **(TC)** |  | 300 | 0.01 | Simpson et al. (2003) |
| ***Generic crop*** | ***All Europe*** | ***450*** | ***0.01*** | ***UNECE (2004)*** |
| Wheat  (*Triticum aestivum*) | All Europe | 450 | 0.01 | UNECE (2004); Araus et al. (1989) ; Ali et al. (1999) ; Gruters et al. (1995);  Korner et al. (1979); Danielsson et al. (2003); De la Torre (2004): |
| **Mediterranean crops**  **(MC)** |  | 156 | 0.019 | Simpson et al. (2003) |
| Maize  *(Zea mays)* | All Europe | 305 (27 s.d.) | 0.05 | ICP Vegetation contract report (2006); Körner et al. (1979) [315]; Sinclair et al. (1975) [355]; Stigter & Lammers (1974) [295]; Tardieu et al. (1991); Ozier-Lafontein et al. (1998) [300] |
| Sunflower  *(Helianthus annuus)* | All Europe | 370 (230 s.d.) | 0.05 | ICP Vegetation contract report (2006); Ward & Bunce (1986) [390]; Connor & Jones (1985) [325]; Wookey et al. (1991) [153]; Schurr et al. (1992) [397]; Rivelli et al. (2002) [586]; Hirasawa et al. (1995) [473]; Wample & Thornton (1984) [233]; Fay & Knapp (1996) [1104]; Steduto et al. (2000) [732]; Turner et al. (1984) [323]; Turner et al. (1985) [372]; Quick et al. (1992) [350]; Körner et al. (1979) [385; 355; 355] |
| Tomato  *(Solanum lycopersicum)* | All Europe | 285 (74 s.d.) | 0.01 | ICP Vegetation contract report (2006); Duniway (1971) [385], Moreshet & Yocum (1972) [200]; Katerji et al. (1998) [216]; Bakker (1991) [283]; Boulard et al. (1991) [208]; Pirker et al. (2003) [307, 384, 288] |
| Grape vine  *(Vitis vinifera)* | All Europe | 215 (51 s.d.) | 0.01 | ICP Vegetation contract report (2006); Schultz (2003) [225], Naor & Wample (1995) [210]; Schultz (2003a) [134, 150], Medrano et al. (2003) [279, 204]; Patakas et al. (2003) [211, 216, 201]; Winkel & Rambal (1993) [267, 193]; Winkel & Rambal (1990) [264, 336, 216]; Correia et al. (1995) [276]; Jacobs et al. (1996) [188]; Massman et al. (1994) [315] |
| **Root crops**  **(RC)** |  | 360 | 0.02 | Simpson et al. (2003) |
| Potato  (*Solanuum tuberosum*) | All Europe | 750 | 0.01 | UNECE (2004); Jeffries (1994); Vos & Groenwald (1989); Marshall & Vos (1991); Pleijel et al. (2002); Danielsson (2003) |
| **Semi-Natural / Moorland**  **(SNL)** |  | 60 | 0.01 | Simpson et al. (2003) |
| **Grassland**  **(GR)** |  | 270 | 0.01 | Simpson et al. (2003) |
| Perennial rye grass  (*Lolium perenne*) | All Europe | 295 | 0.02 | ICP Vegetation contract report (2009); Sheehy et al. (1975); Gay (1986); Nijs et al. (1989); Ferris et al. (1996); Jones et al. (1996) ; Coyle (personal communication); Mills & Hayes (pers. comm.) |
| Clover  (Trifolium repens) | All Europe | 360 | 0.02 | ICP Vegetation contract report (2009); Degl'Innocenti et al. (2003); Nussbaum, and Fuhrer (2000) |
| **Mediterranean scrub** |  | 213 | 0.014 | Simpson et al. (2003) |

 is given in mmol O3 m-2 PLA s-1. PLA is projected leaf area (m2). Species gmax is the median of all values rounded to the nearest 5 mmol O3 m-2 PLA s-1. A/H describes whether the stomata are found over the entire leaf or (A=amphistomatous) or one side (H=hypostomatous). The conversion of total to projected leaf area for needles uses a factor of 2.6. The median of species**** values are rounded to the nearest multiple of 5; values given in square brackets are the study specific maximum gs values in mmol O3 m-2 PLA s-1. The mean cover type ****values are rounded to the nearest multiple of 10. \*gs data given for the flag leaf. † Q. ilex is chosen to represent the climax vegetation type of this broad cover type. Cover type *f*min values are assigned according to the lowest species *f*min value within that group, key reference used to establish this value is provided though other references may exist that support the value selected.

### Irradiance (flight)

The ‘big leaf’ DO3SE model uses a one-layer “two big-leaf” approach to calculate the stomatal conductance. This assumes that the canopy can be represented as a single ‘big-leaf’ leaf split into shaded and sun lit fractions. This model follows the accepted principle that radiation attenuation through canopies follows Beer’s law and that such radiation penetration must separately consider direct and diffuse radiation, due to their different attenuation through canopies, and visible and near infra-red wavelengths due to differential absorptance by leaves (Goudriaan, 1977). The DO3SE model uses the radiation attenuation method of Weiss & Norman (1985) to estimate the quantity and quality of radiation distribution through the canopy. Application of this model requires that the Photosynthetically Active Radiation (PAR), which has a wavelength of 400 to 700 nm, reaching the top of the canopy has to be differentiated into direct and diffuse irradiance. This is dependent upon transmission through the atmosphere which is a function of optical air mass (*om*), atmospheric pressure, (*P*) and hence altitude. If atmospheric pressure is not recorded, it can be estimated according to eq. 6.

6

where *Po* is the atmospheric pressure at sea level (101.325 kPa), *g* is the acceleration due to gravity (9.81 m s-2), *hsite* is the site altitude in m and *H*atm is the atmospheric scale height which is equal to 7400 m.

The value of *om* can be calculated according to Weiss & Norman, (1985) as in eq. 7

7

where *sinβ* is the solar elevation. This parameter varies over the course of the day as a function of latitude and day length as described in eq. 8, this eq. and the other solar geometry equations required for its calculation are taken from Campbell & Norman, (1998).

8

where *β* is the solar elevation above the horizontal, *λ* is the latitude, *δ* is the angle between the sun’s rays and the equatorial plane of the earth (solar declination), *hr* is the hour angle of the sun and is given by where *t* is time and *to* is the time at solar noon.

The solar declination (*δ*) is calculated according to eq. 9.

9

where *td* is the year day.

The time, *t* is in hours (standard local time), ranging from 0 to 23. Solar noon (*to*) varies during the year by an amount that is given by the equation of time (*e*, in min) and calculated by:-

10

where *LC* is the longitude correction. *LC* is + 4 or –4 minutes for each degree you are either east or west of the standard meridian. *e* is a 15 to 20 minute correction which depends on year day according to eq. 11.

11

where *f* = 279.575 + 0.9856 *td* in degrees.

It is also necessary to calculate the day length so that the hour angle of the sun can be calculated throughout the day. Day length is defined as the number of hours that the sun is above the horizon and requires the hour angle of the sun, *hr*, at sunrise or sunset to be calculated with eq. 12.

12

so that day length in hours equals 2*hr*/15.

The formulations of Weiss & Norman, (1985) can then be used to estimate the potential direct (*pPARdir*) (eq. 13) and diffuse (*pPARdiff*) (eq. 14) irradiances in W/m2 which are necessary to estimate irradiance penetration and quality (whether direct or diffuse) into the canopy.

13

where the 600 (W m-2) represents the average amount of *PAR* radiation available at the top of the atmosphere, estimated according to the solar constant (1320 W m-2), of which 0.45 is the PAR fraction (Jones, 1992) and 0.185 represents the extinction coefficient.

14

where the term in brackets represents the total available *PAR* diffuse radiation. 0.4 is the fraction of intercepted *PAR* beam radiation that is converted to downward diffuse radiation at the surface. The potential total *PAR* beam radiation (*pPARtotal*) is then the sum of *pPARdir* and *pPARdiff*. The actual total *PAR* (*PARtotal*) is measured at each site (or provided as modelled values). To allow for variability in the calibration of the measurement apparatus or modelled data we estimate the sky transmissivity (*ST*) during the daylight period as in eq.15 where the *pPARtotal* is not allowed to exceed the *PARtotal*.

15

*ST* is confined within 0.9 and 0.21 to deal with situations when the zenith angle may be greater than 80o (i.e. at sunrise and sunset). Estimation of this value allows the fraction of the direct and diffuse components of the radiation beam to be defined during the daylight periods using eqs. 16 and 17.

16

17

The actual *PARdir* and *PARdiff*can then simply be calculated by multiplying the respective *fPAR* with the actual total *PAR* (*PARtotal*).

Estimations of the diffuse and direct irradiance fractions are necessary to calculate the *PAR* incident on the sunlit (*LAIsun*) (see eq. 18) and shaded (*LAIshade*) (see eq. 19) portions of the canopy.

18

19

*PARsun*, which is dependent on the mean angle between leaves and the sun, is calculated using a modified “big leaf” version of the canopy radiation transfer model of (Zhang et al., 2001) where the flux density of *PAR* on sunlit leaves is calculated as described in eq. 20

20

Where *PARdir* is the actual direct *PAR* above the canopy (as calculated previously) and *θ* is the angle between a leaf and the sun. For these calculations it is assumed that the canopy has a spherical leaf inclination distribution (*θ*) constant at 60 degrees.

*PARshade* is calculated semi-empirically using eq. 21

21

where *PARdiff* is the actual diffuse *PAR* above the canopy.

These values are then used to estimate the mean canopy relative stomatal conductance (*Flight*) as a function of irradiance using the *flight* function in eq. 22 according to the proportions of sunlit and shaded leaf area.

22

Where *PPFD* represents the photosynthetic photon flux density in units of μmol m-2 s-1 (conversion from *PAR* in units of W m-2 to *PPFD* in units of μmol m-2 s-1 can be achieved using a conversion factor of 4.57 after Jones (1992), this provides estimates of PPFDsun and PPFDshade from values provided in eqs. 20 and 21 respectively. The above calculations give estimates of *flight* for individual leaves or needles at the top of the canopy.

To estimate canopy *Gsto*, it is necessary to allow for the variable penetration of irradiance into the canopy which can be achieved by scaling *flight* according to the sunlit and shaded *LAI* fractions of the canopy (see eqs 23 and 24). Sunlit (*flightsun*) and shaded (*flightshade*) leaves are then weighted according to the fraction of sunlit and shaded *LAI* and summed to give the total irradiance-dependant canopy conductance (*Flight*) as described in eq. 25. This method has been simplified so that rather than integrating *Flight* over the canopy, a “big leaf” approach has been employed. This means that *Flight* will be underestimated since the model does not allow for the variability in direct and diffuse irradiance within the canopy. However, since these parameters vary only slightly the model under-estimations are relatively small.

23

24

*Flight* is calculated as : -

25

This mean canopy *Flight* value is used to estimate mean canopy leaf/needle *Gsto*. The canopy *Gsto* is then calculated in equation using the cover-type specific *LAI* to upscale from the leaf/needle to the canopy level.

### Temperature (ftemp)

Add text

fT = max{fmin, (T-Tmin) / (Topt – Tmin)\*[(Tmax-T) / (Tmax-Topt)]bt}

where bt = (Tmax-Topt)/(Topt-Tmin)

**Table (x) Default deposition land-cover and species class parameters for flight (α) and ftemp (Tmin, Topt and Tmax) calculations.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Land-cover type & Species** | **Climate region** | **Flight factor (α)** | **Tmin** | **Topt** | **Tmax** | **Reference** |
|  |  |  |  |  |  |  |
| **Coniferous Forests (CF)** |  | 0.0083 | 1 | 18 | 36 | Simpson et al. (2003) |
| Norway spruce  (*Picea abies*) | Northern Europe | 0.006 | 0 | 20 | 200\*\* | UNECE (2004); Karlsson et al. (2000); Hansson et al. (in prep) |
| Scots Pine  (*Pinus sylvestris*) | Atlantic Central Europe | 0.006 | 0 | 20 | 36 | UNECE (2004); Beadle et al. (1985); Sturm et al. (1998); Ng. (1979) |
| Norway Spruce  (*Picea abies*) | Continental Central Europe | 0.01 | 0 | 14 | 35 | UNECE (2004); Thoene et al. (1991), Korner et al. (1995), Zweifel et al. (2000, 2001,2002) |
| **Deciduous Forests**  **(DF)** |  | 0.006 | 6 | 20 | 34 | Simpson et al. (2003); |
| ***Generic Deciduous*** | ***All Europe*** | ***0.006*** | ***0*** | ***21*** | ***35*** | ***UNECE (2004)*** |
| Silver birch  (*Betula pendula*) | Northern Europe | 0.0042  (0.006) | 5 | 20 | 200\*\* | UNECE (2004); Uddling et al. (2005a)  Osonubi & Davies. (1980); Oksanen. (pers. comm.) (2003) |
| Beech  (*Fagus sylvatica*) | Atlantic Central Europe | 0.006 | 0 | 21 | 35 | UNECE (2004) |
| Oak  (*Quercus petraea & robur*) | Atlantic Central Europe | 0.003 | 0 | 20 | 35 | UNECE (2004); Breda et al. (1993b); Dolman. (1988) |
| Beech  (*Fagus sylvatica*) | Continental Central European | 0.006 | 5 | 16 | 33 | UNECE (2004); Braun et al. (in prep) |
| Beech  (*Fagus sylvatica*) | Mediterranean Europe | 0.006 | 4 | 21 | 37 | UNECE (2004); Damesin et al. (1998); Rico et al. (1996) |
| **Needleleaf Forests**  **(NF)** |  | 0.013 | 4 | 20 | 37 | Simpson et al. (2003) |
| Aleppo Pine  *(Pinus halepensis)* | Mediterranean Europe | 0.013 | 10 | 27 | 38 | UNECE (2004); Elvira et al. (2007) |
| **Broadleaf Forests**  **(BF)** |  | 0.009 | 4 | 20 | 37 | Simpson et al. (2003) |
| ***Generic Evergreen Mediterranean*** | ***All Europe*** | ***0.009*** | ***2*** | ***23*** | ***38*** | ***UNECE (2004)*** |
| Holm Oak  (*Quercus ilex*) | Mediterranean Europe | 0.012 | 1 | 23 | 39 | These refs are in the hard copy version |
| **Temperate crops**  **(TC)** |  | 0.009 | 12 | 26 | 40 | Simpson et al. (2003) |
| ***Generic crop*** | ***All Europe*** | ***0.0105*** | ***12*** | ***26*** | ***40*** | ***UNECE (2004)*** |
| Wheat  (*Triticum aestivum*) | All Europe | 0.0105 | 12 | 26 | 40 | UNECE (2004); Gruters et al. (1995); Bunce (2000) |
| **Mediterranean crops**  **(MC)** |  | 0.0048 | 0 | 25 | 51 | Simpson et al. (2003) |
| Maize  *(Zea mays)* | All Europe | 0.0048 | 2 | 25 | 48 | ICP Vegetation contract report (2006); Bethenod & Tardieu (1990); Turner & Begg (1973); Rochette et al. (1991); Machado & Lagoa (1994); Guilioni et al. (2000); Olioso et al. (1995); Ozier-Lafontein et al. (1998); Rodriguez & Davies (1982) |
| Sunflower  *(Helianthus annuus)* | All Europe | 0.002 | 2 | 25 | 48 | ICP Vegetation contract report (2006); Turner (1970); Fay & Knapp (1996).  For t\_opt, t\_min and t\_max maize parameterisation used as default |
| Tomato  *(Solanum lycopersicum)* | All Europe | 0.0175 | 0 | 21 | 35 | ICP Vegetation contract report (2006); Boulard et al. (1991); Bakker (1991); Starck et al. (2000). |
| Grape vine  *(Vitis vinifera)* | All Europe | 0.0076 | 9 | 30 | 43 | ICP Vegetation contract report (2006); Schultz (2003a); Winkel & Rambal (1993); Winkel & Rambal (1990); Massman et al. (1994); Jacobs et al. (1996); Correia et al (1995); Flexas et al. (1999); Schultz (2003); Shultz (2003a); Massman et al (2003); Schultz (2003) |
| **Root crops**  **(RC)** |  | 0.0023 | 8 | 24 | 50 | Simpson et al. (2003) |
| Potato  (*Solanuum tuberosum*) | All Europe | 0.005 | 13 | 28 | 39 | UNECE (2004); Ku et al. (1977) ; Dwelle et al (1981) |
| **Semi-Natural / Moorland**  **(SNL)** |  | 0.009 | 1 | 18 | 36 | Simpson et al. (2003) |
| **Grassland**  **(GR)** |  | 0.009 | 12 | 26 | 40 | Simpson et al. (2003) |
| Perennial rye grass  (*Lolium perenne*) | All Europe | 0.007 | 10 | 25 | 40 | ICP Vegetation contract report (2009) |
| Clover  (Trifolium repens) | All Europe | 0.008 | 10 | 27 | 43 | ICP Vegetation contract report (2009) |
| **Mediterranean scrub** |  | 0.012 | 4 | 20 | 37 | Simpson et al. (2003) |

### Vapour pressure deficit (fVPD)

Add text

fVPD=max{fmin, min{1, (1-fmin)\*(VPDmin-VPD)/(VPDmin-VPDmax) + fmin}}

For wheat, potato and the generic crop there is another effect on stomata by water relations which can be modelled using VPD. During the afternoon, the air temperature typically decreases, which is normally, but not always, followed (if the absolute humidity of the air remains constant or increases) by declining VPD. According to the fVPD function this would allow the stomata to re-open if there had been a limitation by fVPD earlier during the day. Most commonly this does not happen. This is related to the fact that during the day the plant loses water through transpiration at a faster rate than it is replaced by root uptake. This results in a reduction of the plant water potential during the course of the day and prevents stomata re-opening in the afternoon. The plant water potential then recovers during the following night when the rate of transpiration is low. A simple way to model the extent of water loss by the plant is to use the sum of hourly VPD values during the daylight hours (as suggested by Uddling et al., 2004). If there is a large sum it is likely to be related to a larger amount of transpiration, and if the accumulated amount of transpiration during the course of the day (as represented by a VPD sum) exceeds a certain value, then stomatal re-opening in the afternoon does not occur. This is represented by the VPDsum function (ΣVPD) which is calculated in the following manner:

If ΣVPD ≥ ΣVPD\_crit, then gsto\_hour\_n+1 ≤ gsto\_hour\_n

Where gsto\_hour\_n and gsto\_hour\_n+1 are the gsto values for hour n and hour n+1 respectively calculated according to the gsto equation.

### Soil Water Potential (fSWP)