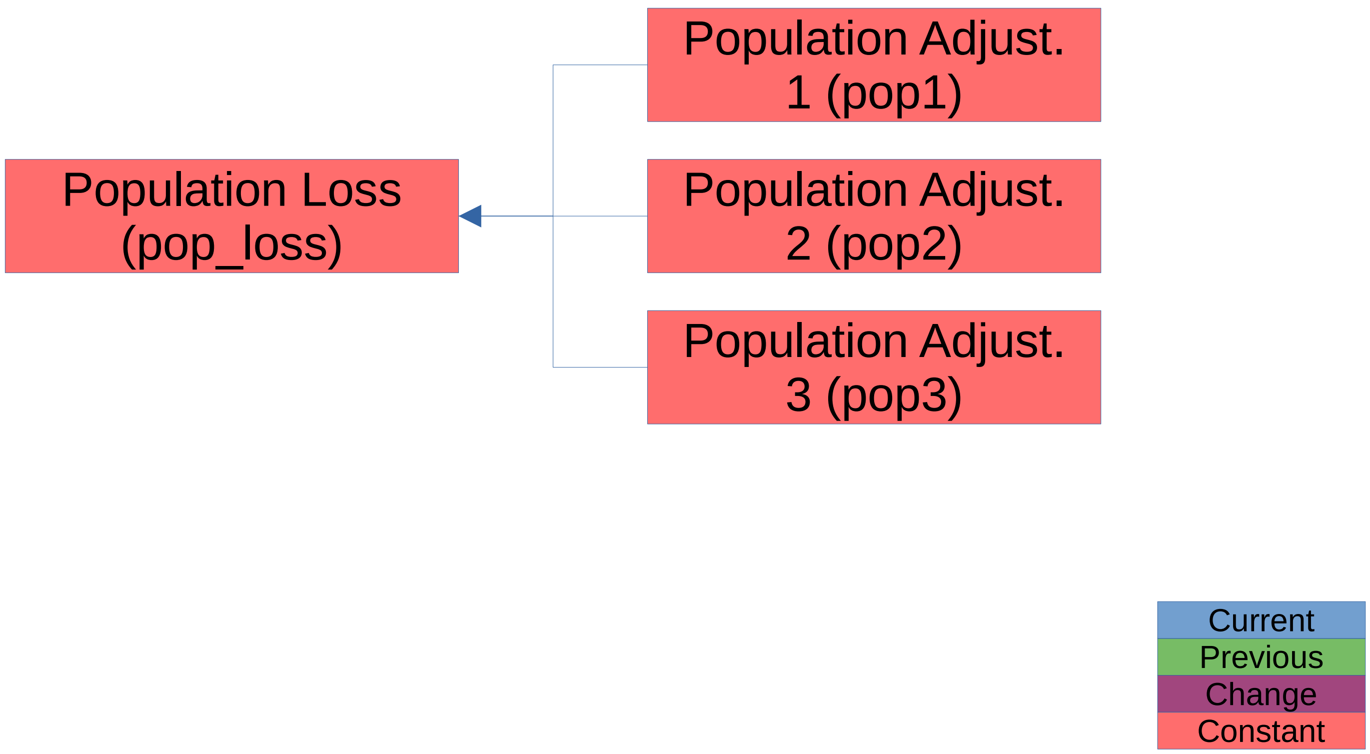
# CONSTANTS

Plant Population Loss (pop_loss)

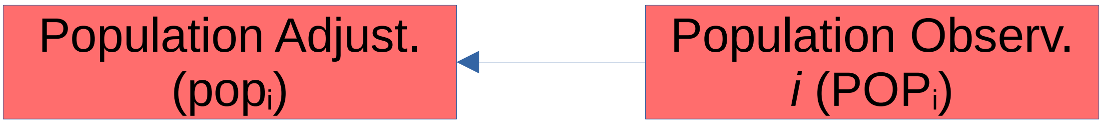


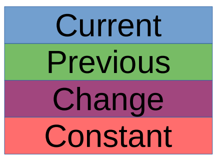

$$\mathrm{pop\_loss} = \frac{1}{3}\left(\sum_{i=1}^{3} pop_i\right)$$

Plant Population Adjustments (pop#)

A model for the loss of potential yeild based on plant population.

# ∈ (1,2,3)

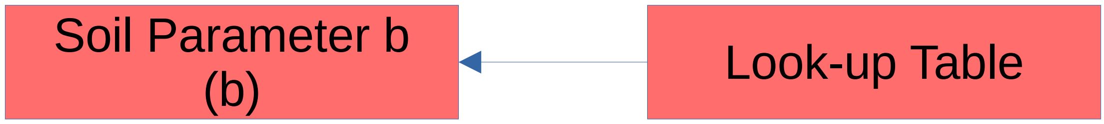


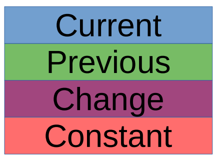




$$pop_i = if\left(POP_i < 90000, -0.0003 \times \left(\frac{POP_i}{1000}\right)^2 + 0.0456 \times \left(\frac{POP_i}{1000}\right) - 1.0246\right)$$

Soil Parameter b (b)

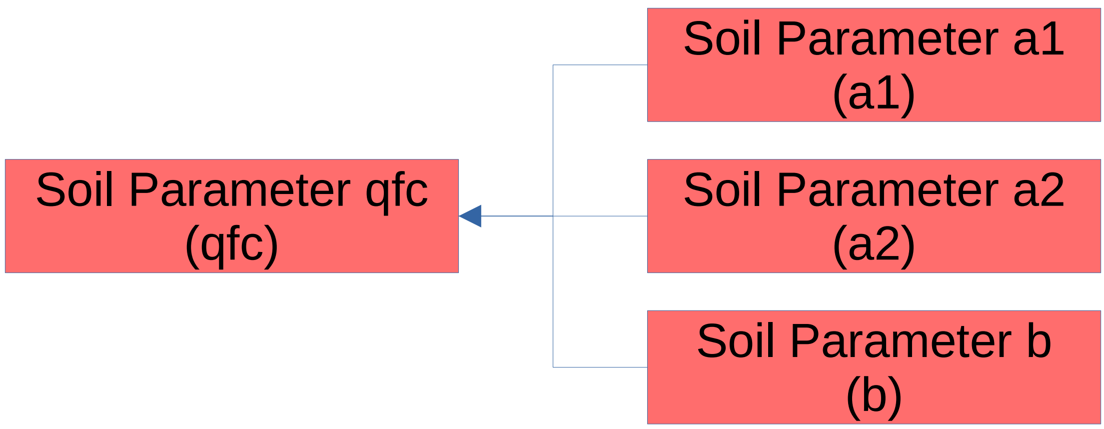
Comes from a look-up table

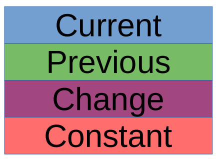



$$if\,(b<1)\,b=2.1$$

Soil Parameter qfc (qfc)

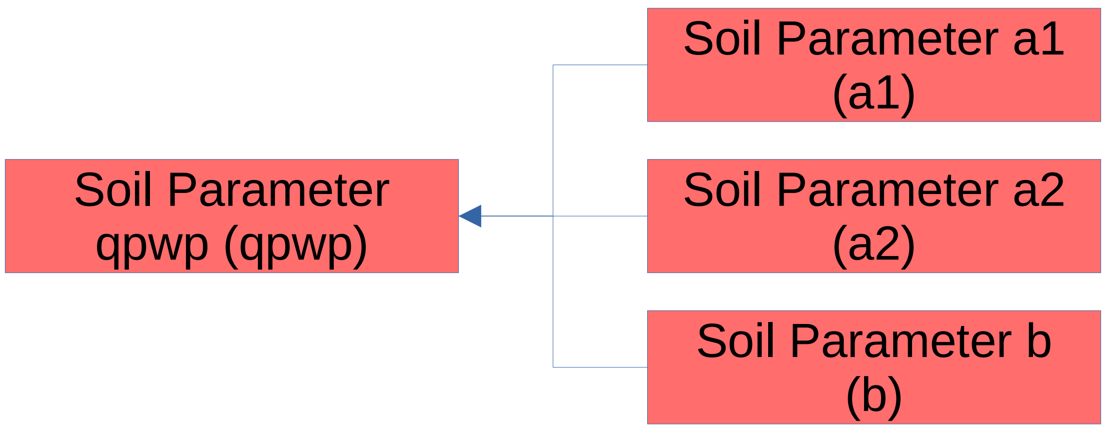


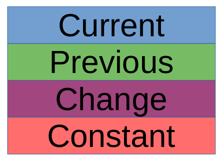




$$qfc=\left(\frac{\mathrm{a2}\times\mathrm{a1}}{5}\right)^{\frac{1}{b}}$$

Soil Parameter qpwp (qpwp)

This parameter is currently not employed in the code




$$qpwp = \left(\frac{a2 \times a1}{1500}\right)^{\frac{1}{b}}$$

# Constants: soil type dependent

| | $b \leq 20$ | $b > 20$ |
|---|---|---|
| Kappa ($\kappa$) | 0.0027 | 0.0008 |
| Gamma ($\gamma$) | 0.00014 | 0.00002701 |
| w_stressA | 2 | 5 |
| w_stressB | 0.6 | 0.8 |
| w_stressC | 300 | 200 |
| RUEZero1 | RUEZero | 2.1 |

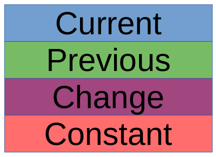
# Constants: Constant

| Parameter | Value | Calculation of | Comment |
|---|---|---|---|
| a1 | 0,4 | qfc, qpwp | |
| a2 | 0,6 | qfc, qpwp | |
| beta0 | 0,00935 | root_depth | |
| c1 | 378,8 | rsum | |
| c2 | 8 | rsum | |
| CSrad_k | -0,64 | na | |
| CSrad_S | 1,27 | na | |
| delta | 0,002715 | root_depth | |
| DiseaseModel | 0 | na | |
| DiseaseProgress | 0 | na | |
| Dsowing | 0,02 | root_depth | |
| Extinction | 0,7 | na | |
| fZero | 0,000015 | f | |
| gamma2 | 0,00007 | na | |
| Gsc | 0,082 | na | |
| kappa2 | 0,00148 | na | |
| Ky | 0,42 | na | |
| LAImu | 1150 | na | |
| LAIsigma1 | 381 | na | |
| LAIsigma2 | 700 | na | |
| LAIzero | 3200 | na | |
| length0 | 0,0491 | root_depth | |
| muMin02 | -0,00017 | na | |
| muZero | 0,06556 | na | |
| nuZero | 0,005866 | na | |
| psiCrop | -1500 | esoil | |
| RUEZero | 1,95 | RUEZero1 | |
| Tbase | 3 | ΔT | |
| Tzero | 90 | root_depth, bbch | |
| Albedo | 0,23 | na | |
| Sbconstant | 4,90E-09 | na | |

# INITIAL CALCULATIONS (COLUMN-WISE)

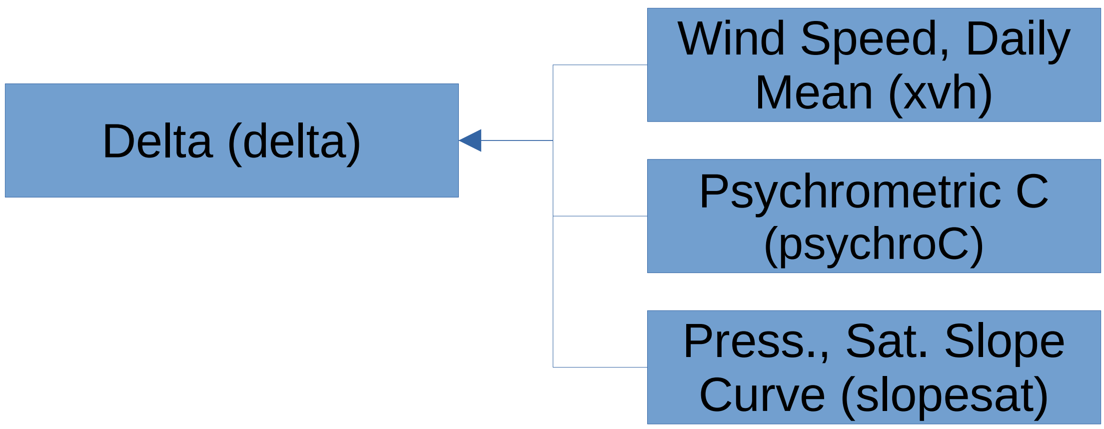
Day Of Year (doy) [integer series]

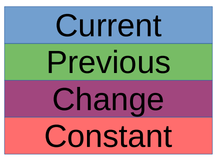
Leap years are basically ignored, i.e. in leap year, 29 Feb = doy 60, in non-leap year 1 March = doy 60.


*Day of year with base January* 1

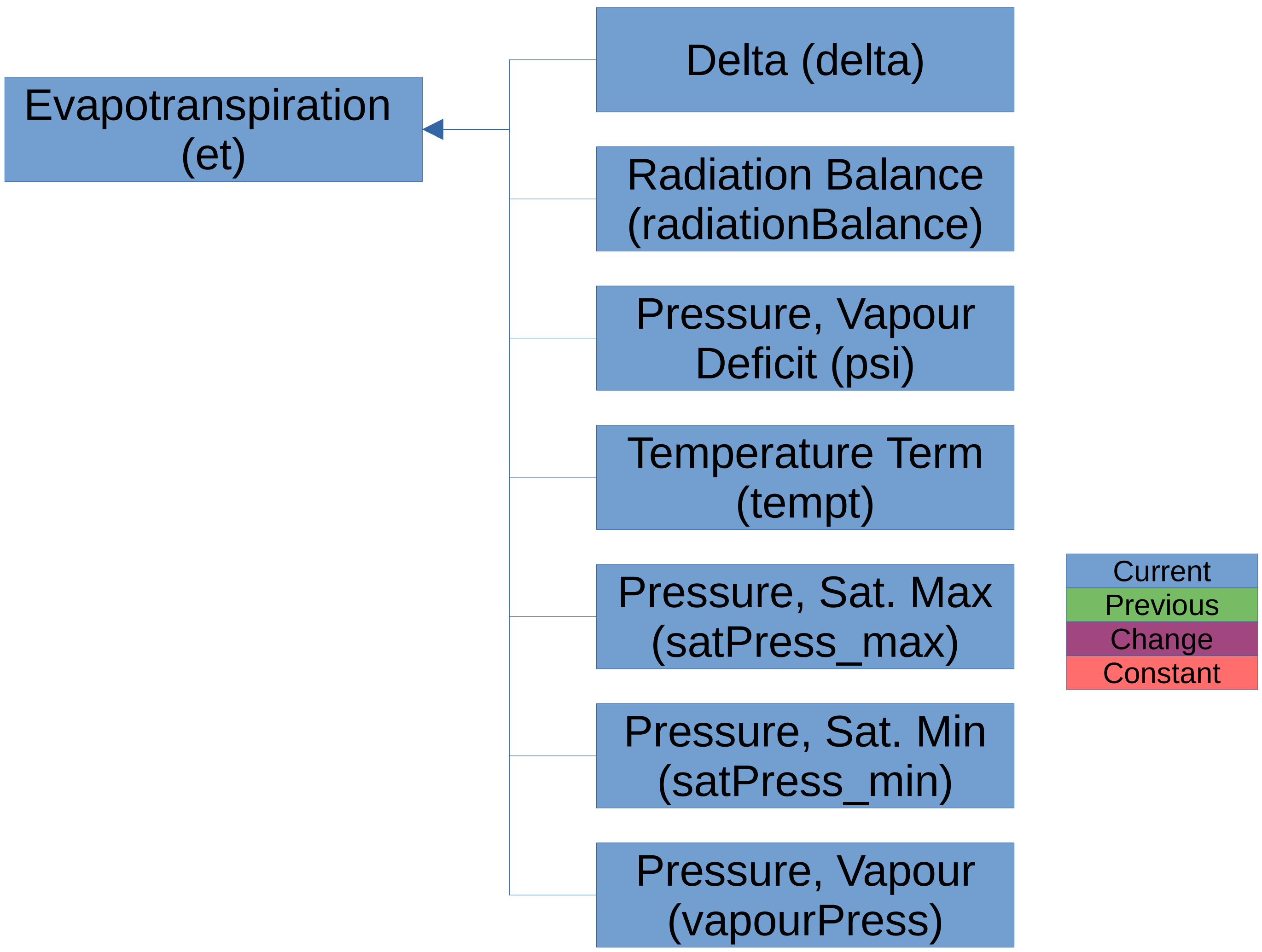
# Delta (delta) []



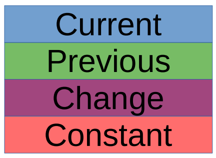

$$delta = \frac{slopesat}{slopesat + psychroC \times (1 + 0.34 \times xvh)}$$

Evapotranspiration (et) [mm/day ?]



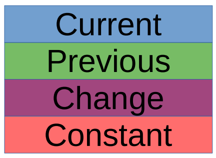

$$et = delta \times radiationBalance + psi \times tempt \times \left(\frac{\mathrm{satPress\_max} + \mathrm{satPress\_min}}{2} - vapourPress\right)$$

# Humidity, Daily Maximum (hhum) [%]

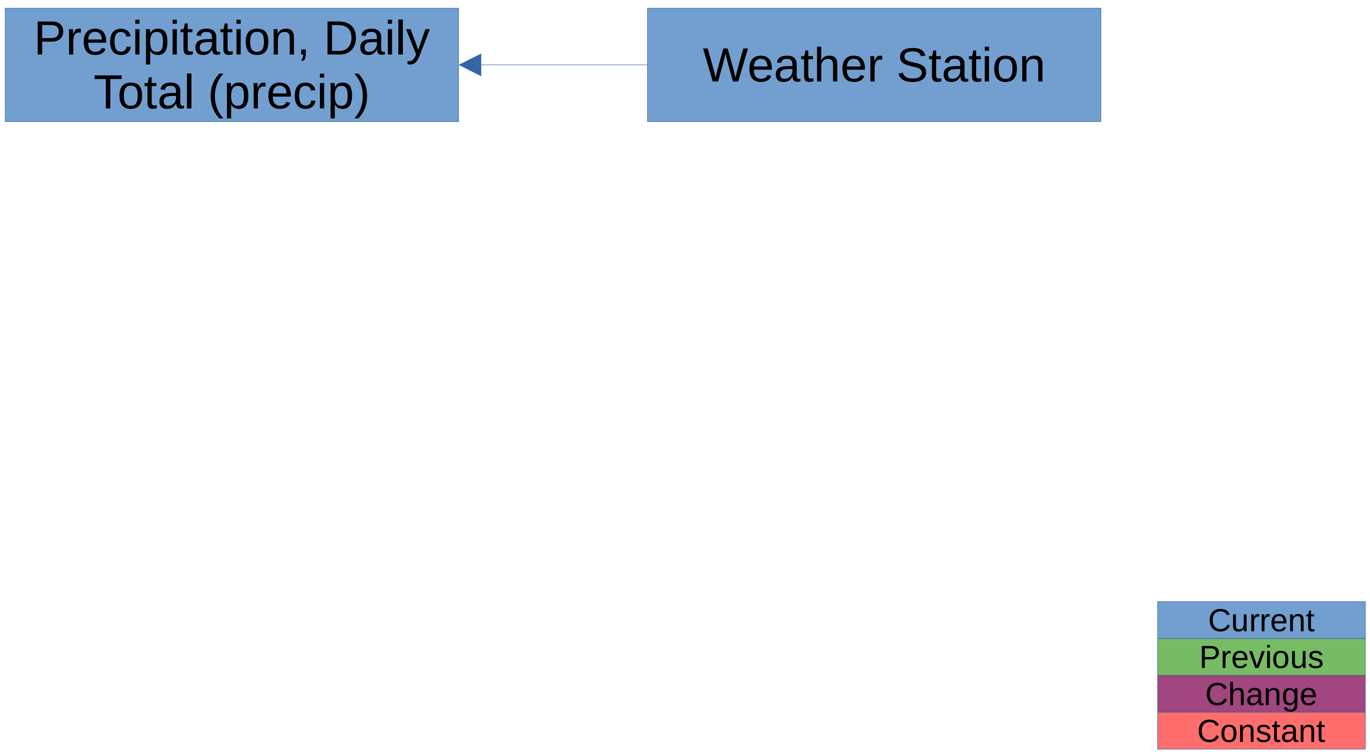

$$hhum = max\left(hum_t, for\ t \in \mathrm{Daily\_obs}\right)$$

# Humidity, Daily Minimum (lhum) [%]

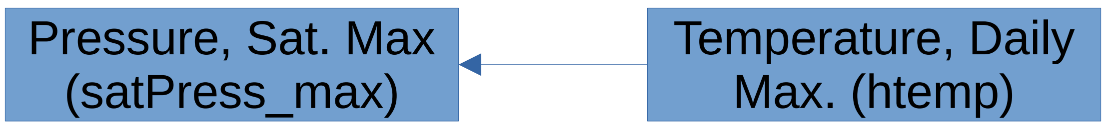



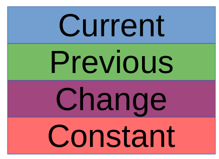

$$lhum = min\left(hum_t\,, for\ t \in \mathrm{Daily\_obs}\right)$$

## Precipitation, Daily Total (precip) [mm]



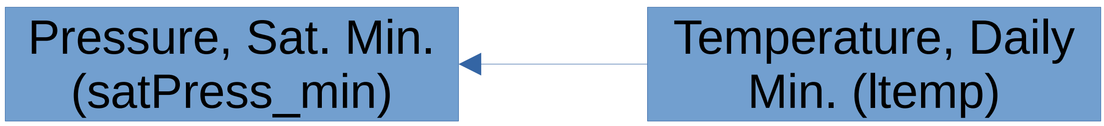
# Pressure, Saturation, Daily Maximum (satPress_max)

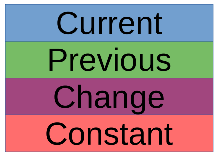



$$\text{satPress\_max} = 0.6108 \times \exp\left(\frac{17.27 \times htemp}{htemp + 237.3}\right)$$

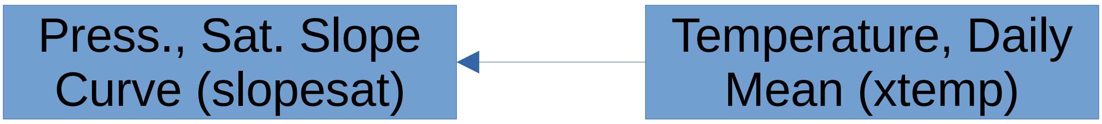
# Pressure, Saturation, Daily Minimum (satPress_min)

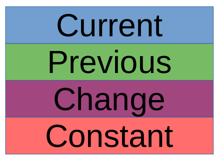



$$\text{satPress\_min} = 0.6108 \times \exp\left(\frac{17.27 \times ltemp}{ltemp + 237.3}\right)$$

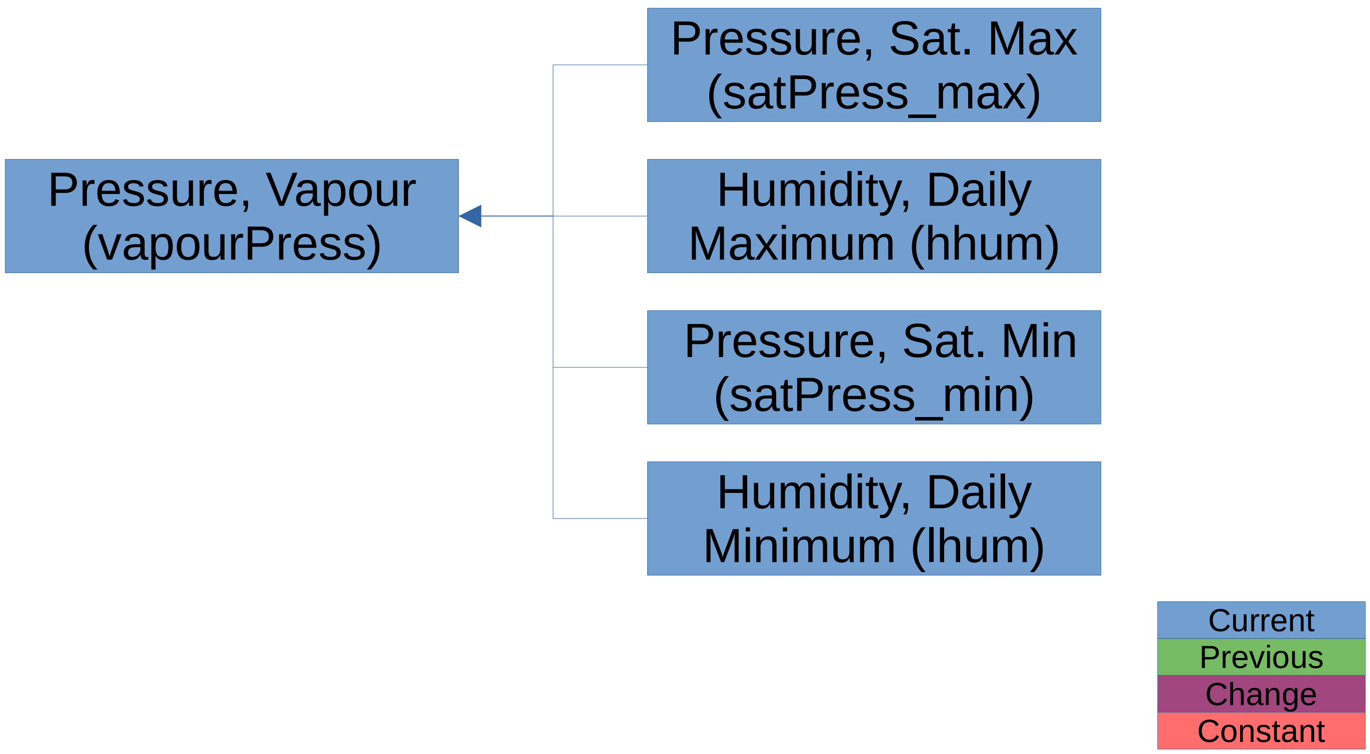
# Pressure, Saturation, Slope of Curve (slopesat)



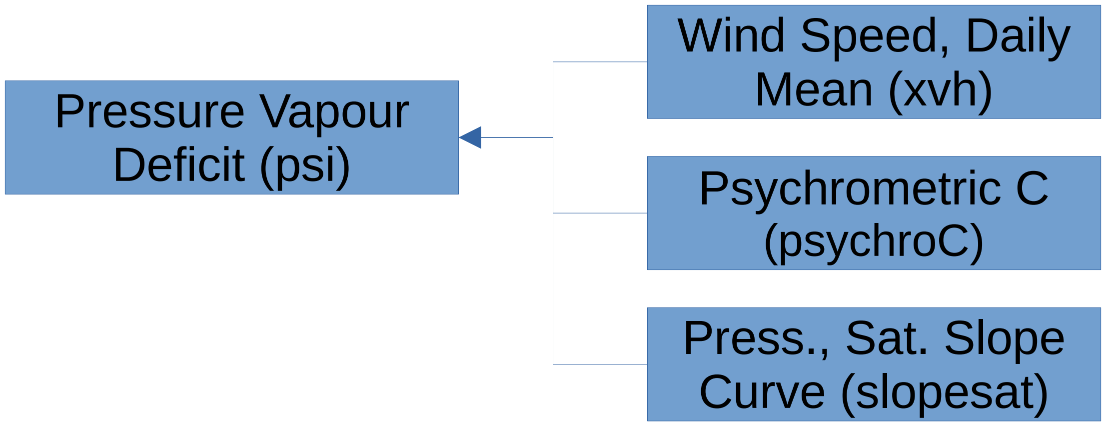

$$slopesat = \frac{4098 \times 0.6108 \times \exp\left(17.27 \times xtemp \div \left(xtemp + 237.3\right)\right)}{\left(xtemp + 237.3\right)^2}$$

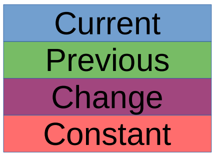
# Pressure, Vapour, Daily Mean (vapourPress)




$$vapourPress = \left( \frac{\mathrm{satPress\_max} \times hhum}{100} + \frac{\mathrm{satPress\_min} \times lhum}{100} \right) \div 2$$

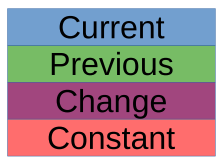
# Pressure, Vapour, Deficit (psi)



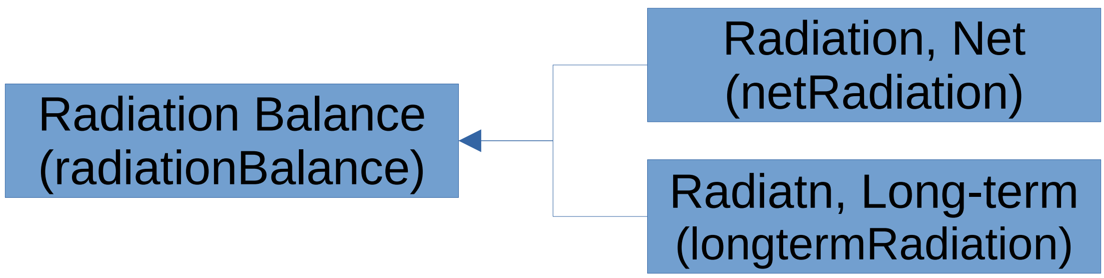

$$psi = \frac{psychroC}{slopesat + psychroC \times (1 + 0.34 \times xvh)}$$

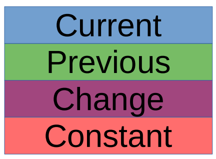
# Psychrometric C (pyschroC)


$$psychroC = 0.000665 \times press$$

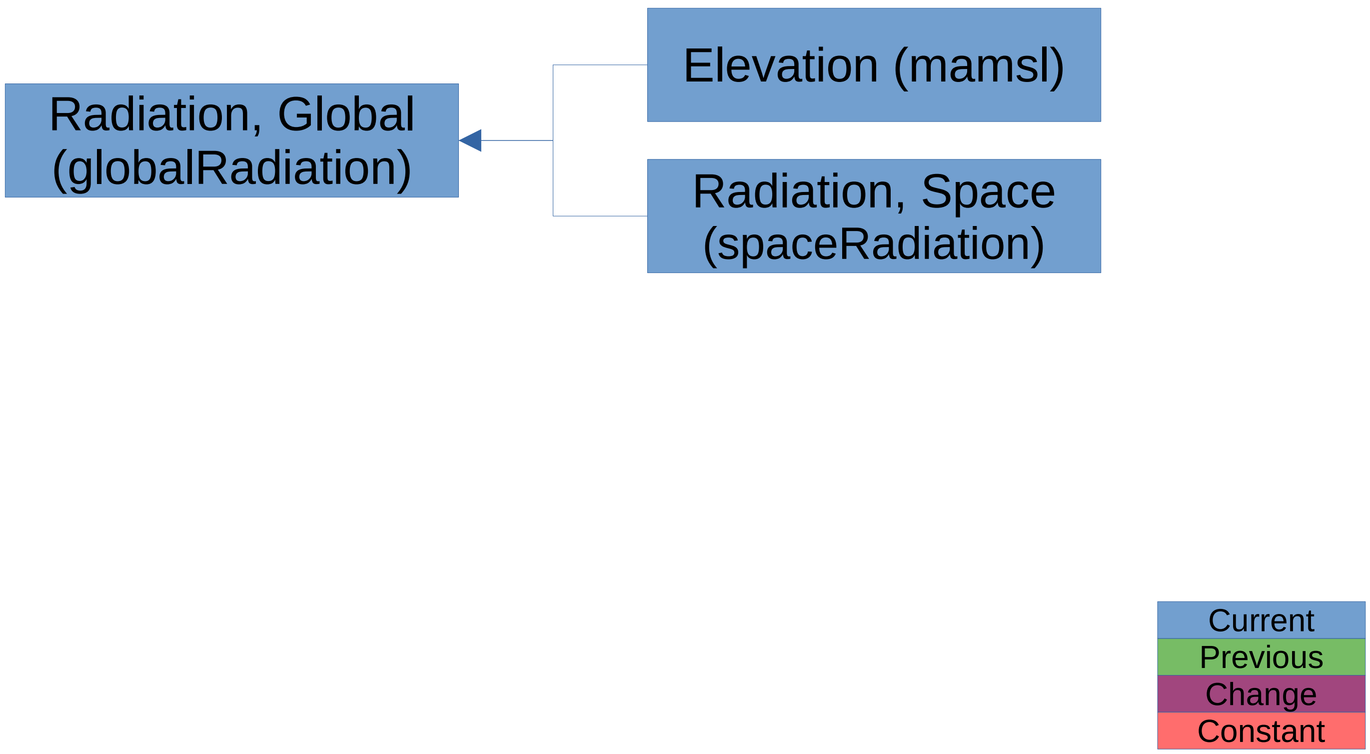
# Radiation, Balance (radiationBalance)



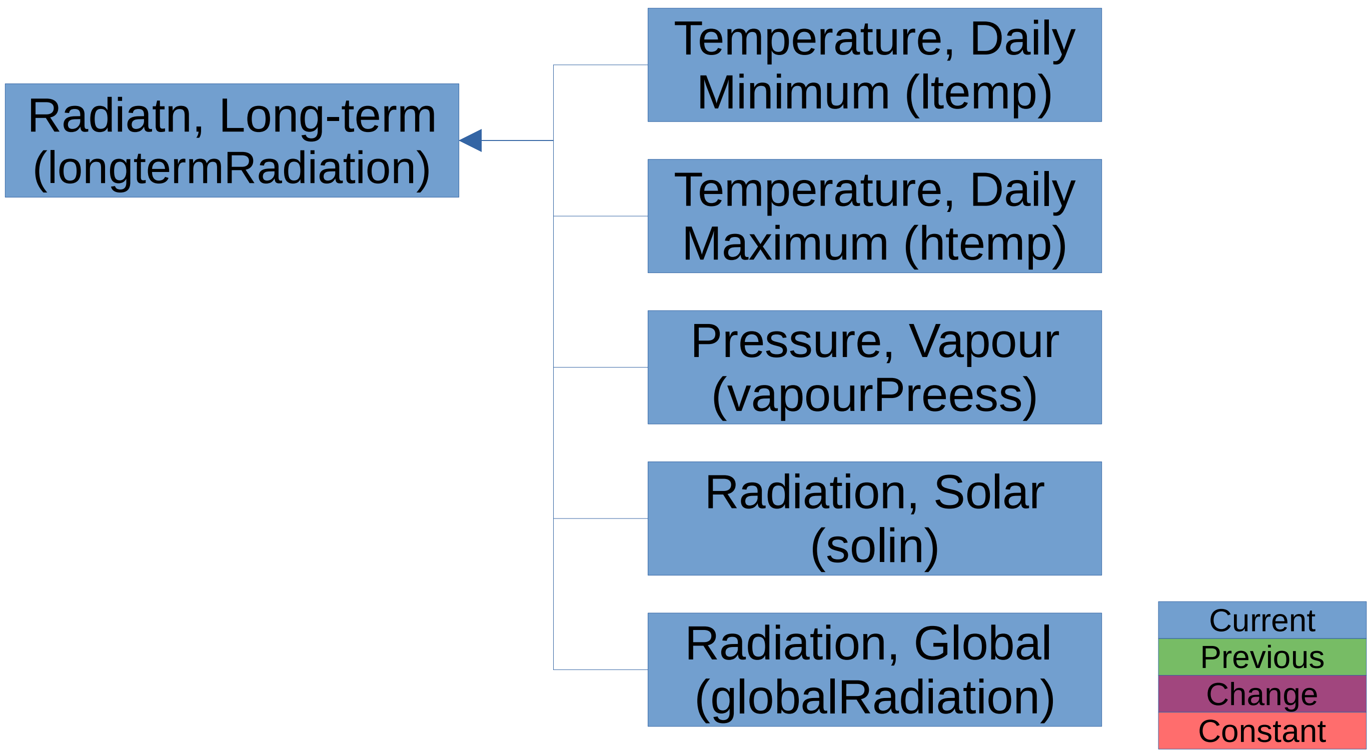

$$radiationBalance = 0.408 \times (netRadiation - longtermRadiation)$$

## Radiation, Global (globalRadiation)




$$globalRadiation = (0.75 + 2 \times 10^{-5}\, mamsl) \times spaceRadiation$$

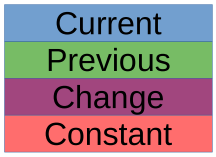
# Radiation, Long-term (longtermRadiation)




$$longtermRadiation = 4.903 \times 10^{-9} \times \left( \frac{(ltemp + 273.16)^4 + (htemp + 273.16)^4}{2} \right)$$

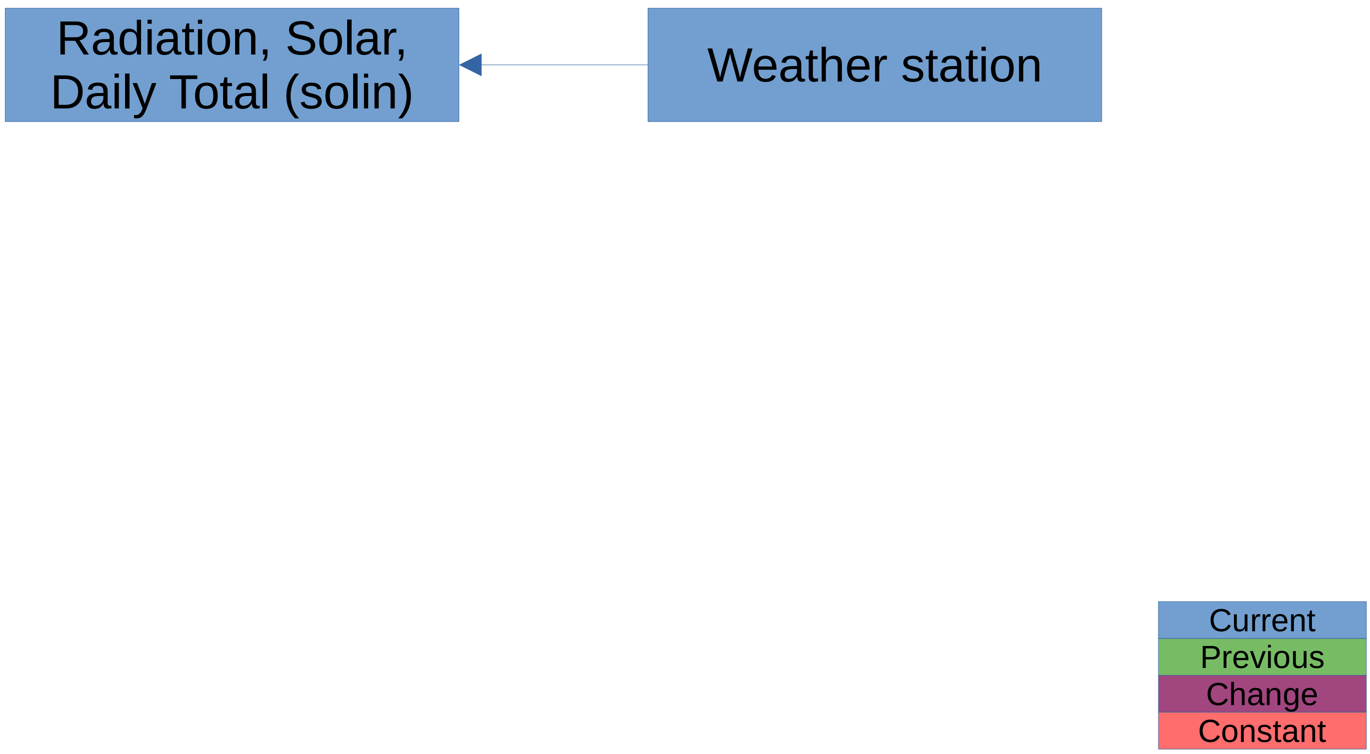
$$\text{x} \left(0.34 - 0.14 \times vapourPress^{0.5}\right) \times \left( \frac{1.35 \times solin}{globalRadiation} - 0.35 \right)$$

# Radiation, Daily Net (netRadiation) [MJ/m2/day]

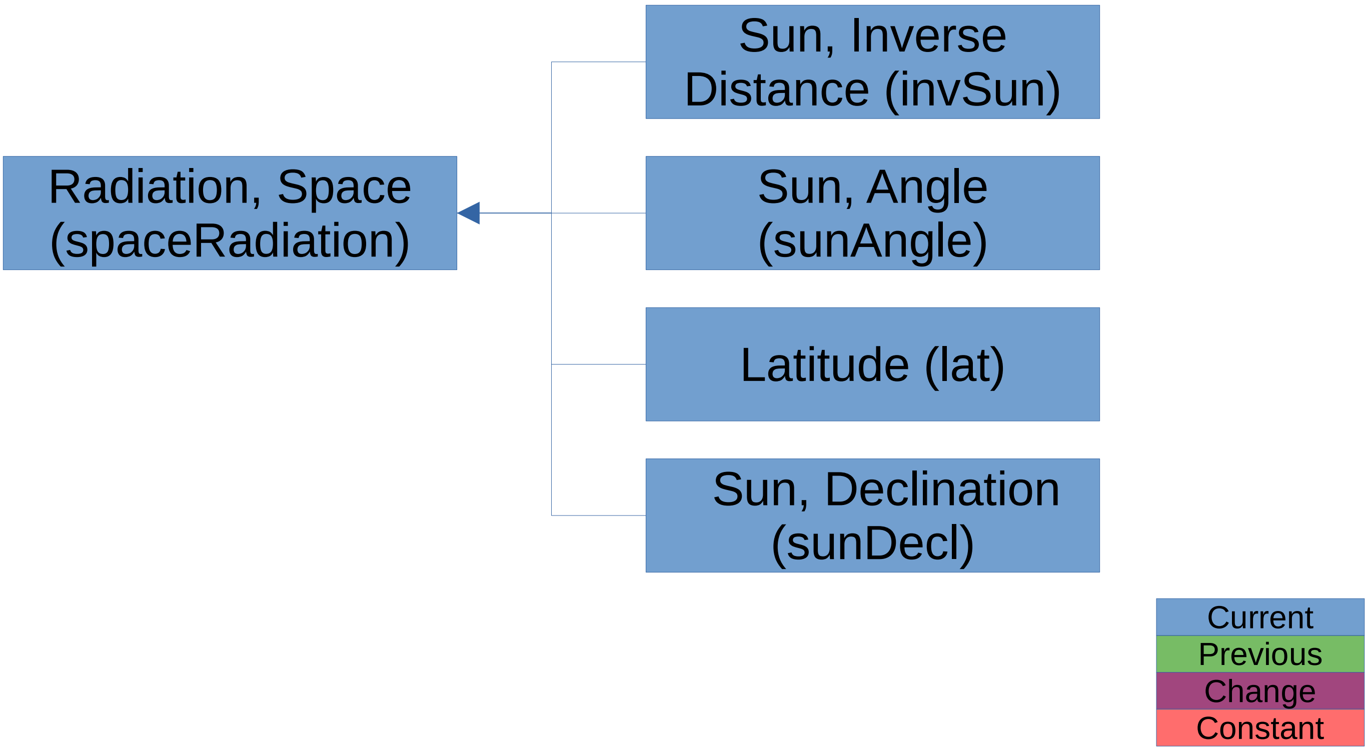




$$netRadiation = (1 - 0.23) \times solin$$

Radiation, Solar, Daily Total (solin) [MJ/m2/day]

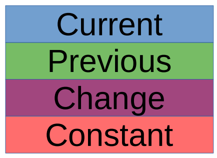


# Radiation, Space (spaceRadiation) []




$$spaceRadiation = \frac{24 \times 60 \times invSun}{\pi} \times \left( sunAngle \times \sin\left(\frac{lat \times \pi}{180}\right) \times \sin(sunDecl) + \cos\left(\frac{lat \times \pi}{180}\right) \times \cos(sunDecl) \times \sin(sunAngle) \right)$$

# Sun, Angle Relative to Equator (Declination) (sunDecl) [degrees]

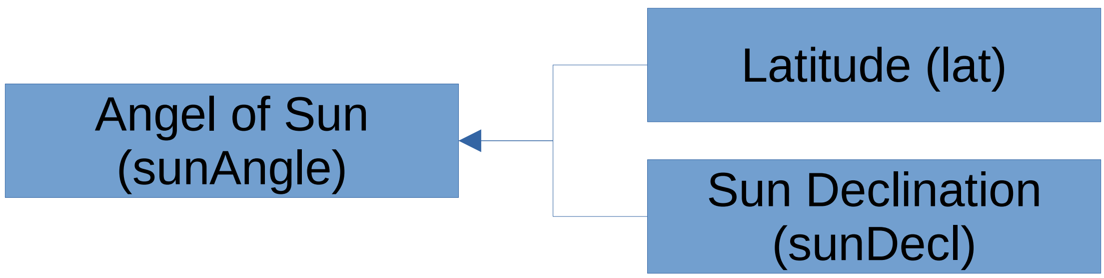



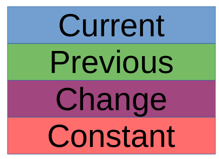

$$[\text{column wise, initial}]$$

$$sunDecl = 0.409 \times \sin\left(\frac{2 \times \pi \times doy}{365} - 1.39\right)$$

## Sun, Angle Relative to Orbital Plane (sunAngle) [degrees]

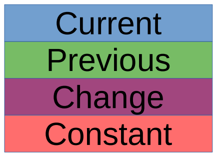
The angle of the sun relative to the equator is the declination (sunDecl)



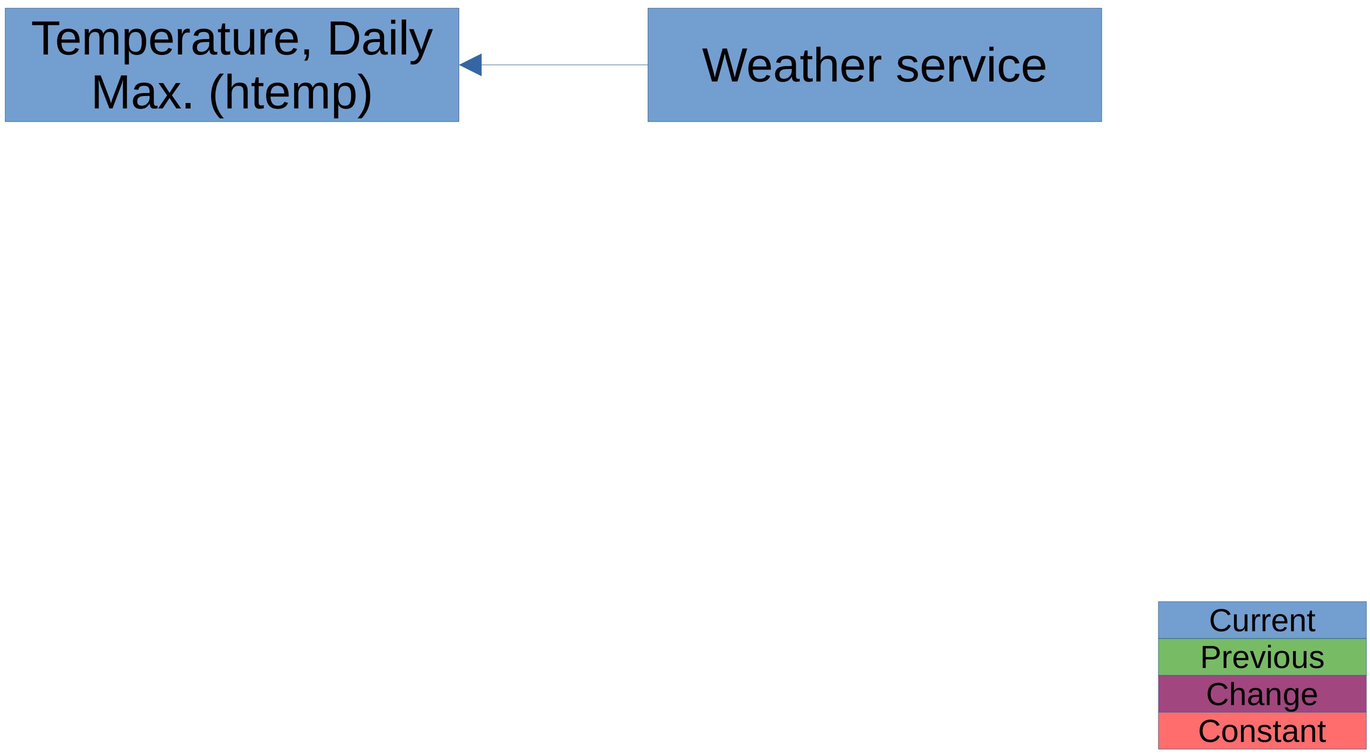

$$sunAngle = acos\left(-\tan\left(\frac{lat \times \pi}{180}\right) \times \tan(sunDecl)\right)$$

# Sun, Inverse Distance (invSun) []

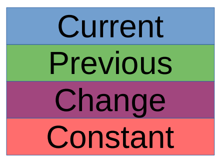

$$invSun = 1 + 0.033 \times \cos\left(\frac{2 \times \pi \times doy}{365}\right)$$

# Temperature, Daily Maximum (htemp)



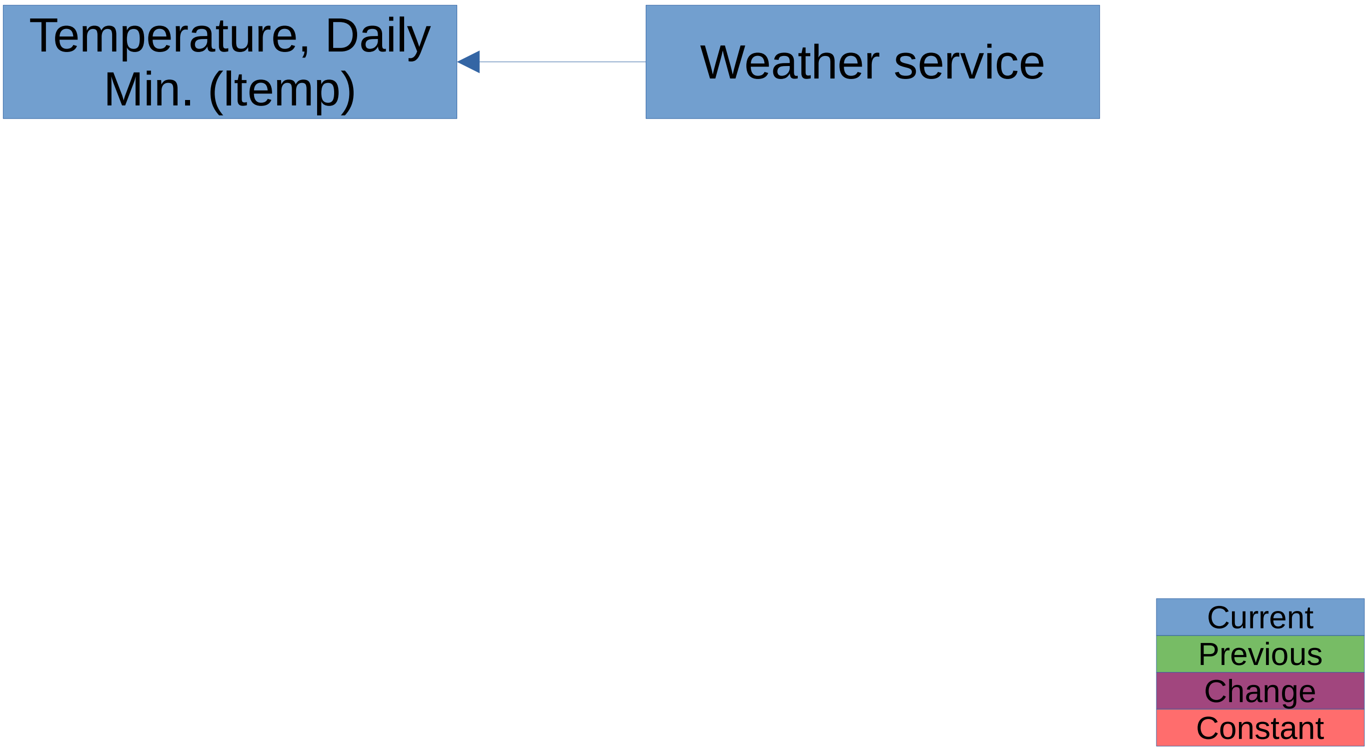

$$htemp = max\left(temp_t, for\ t \in \text{Daily\_obs}\right)$$

# Temperature, Daily Mean (xtemp)

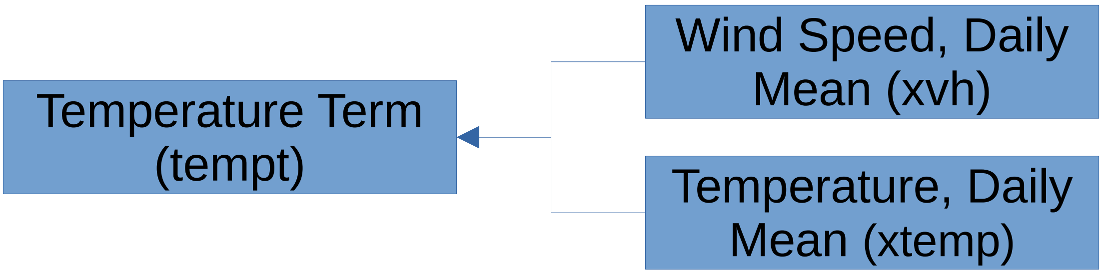

$$xtemp = \frac{1}{n}\left(\sum_{i=1}^{n} temp_i\right)$$

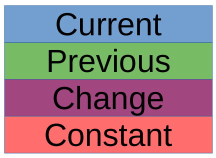
# Temperature, Daily Minimum (ltemp)




$$ltemp = min\left(temp_t, for\ t \in \mathrm{Daily\_obs}\right)$$

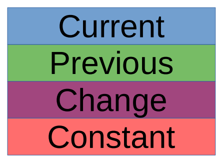
# Temperature Term (tempt)



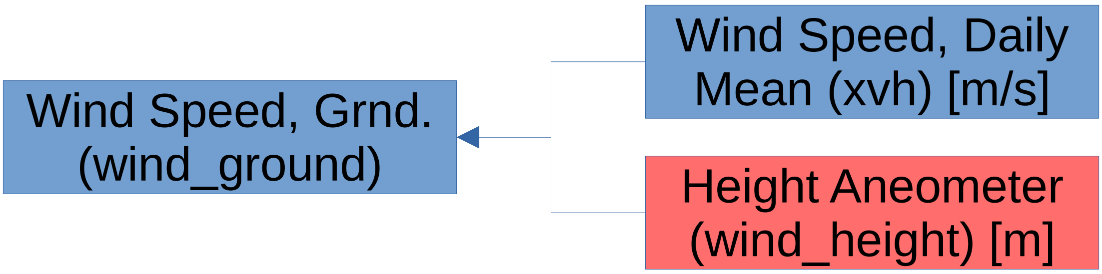

$$tempt = \frac{900 \times xvh}{xtemp + 273.15}$$

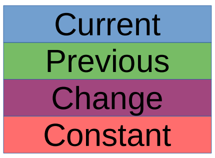
# Wind, Speed, Daily Mean (vxh)


$$xvh = \frac{1}{n}\left(\sum_{i=1}^{n} vh_i\right)$$

# Wind, Speed, At Ground Level (wind_ground) [m/s]



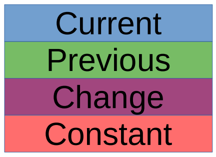




$$\text{wind\_ground} = \frac{xvh \times 4.87}{\log\left(67.8 \times \text{wind\_height} - 5.42\right)}$$

# MAIN CALCULATIONS
(ROW-WISE)

Canopy Cover (f).

A base level plus a sigmoidal growth fraction, dependent on the Stress Adjusted Cumulative Temperature (fTemp)

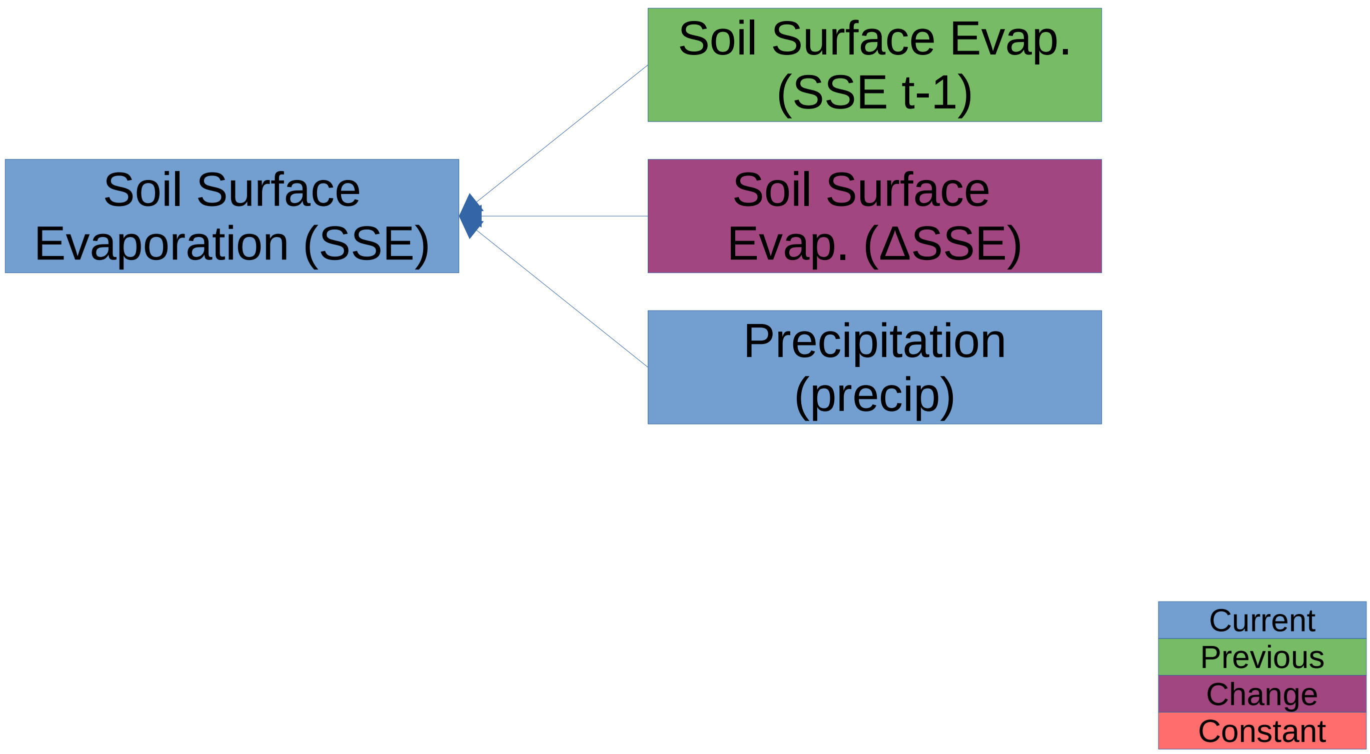




$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$f = 0.0015 + \frac{0.99 - 0.0015}{1 + \exp\left(-4 \times \log\left(\frac{fTemp}{1 - fTemp}\right)\right)}$$

$$if\left(doy < \mathrm{sow\_doy}\right) f = fZero$$

# Evaporation, Soil Surface (SSE)

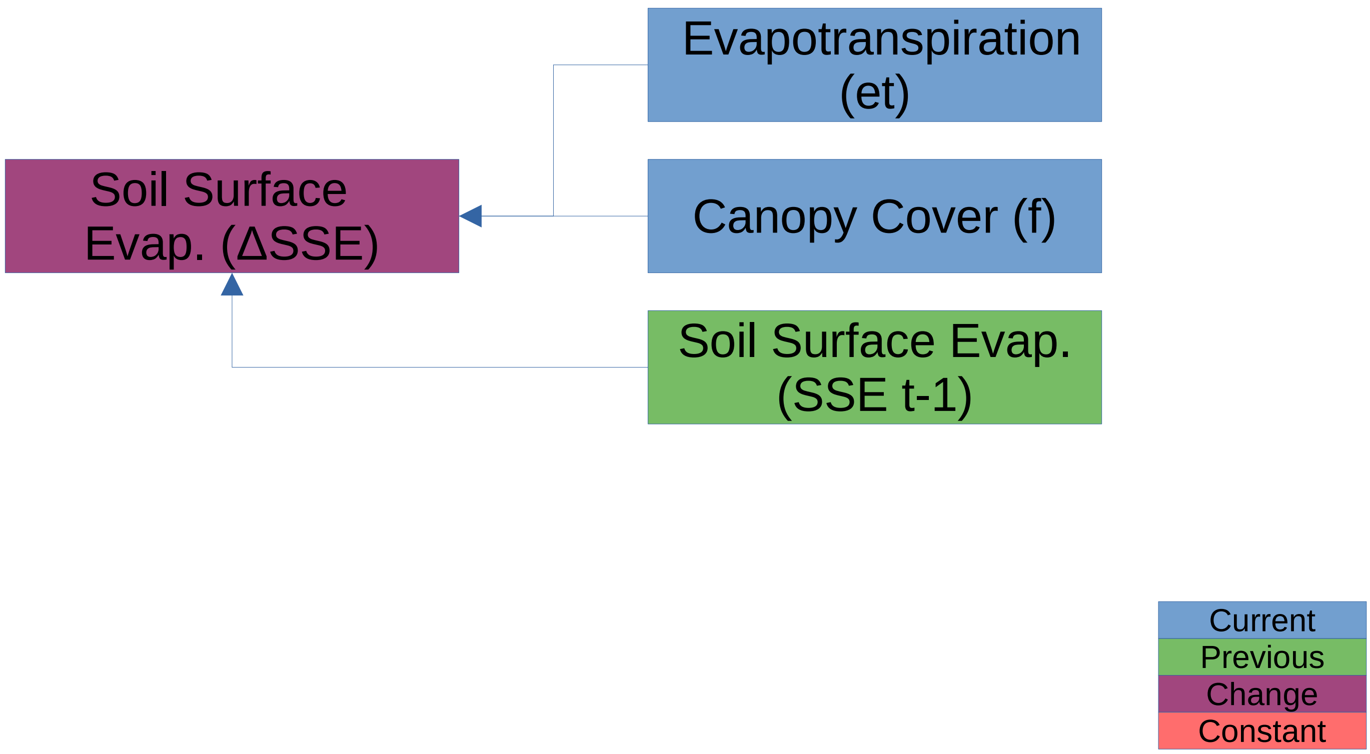



$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$SSE_t = SSE_{\mathrm{t\text{-}1}} + \Delta\, SSE - precip$$

$$if\left(doy < \mathrm{sow\_doy}\right) SSE_t = 0$$

# Evaporation, Soil Surface, Change in (ΔSSE)

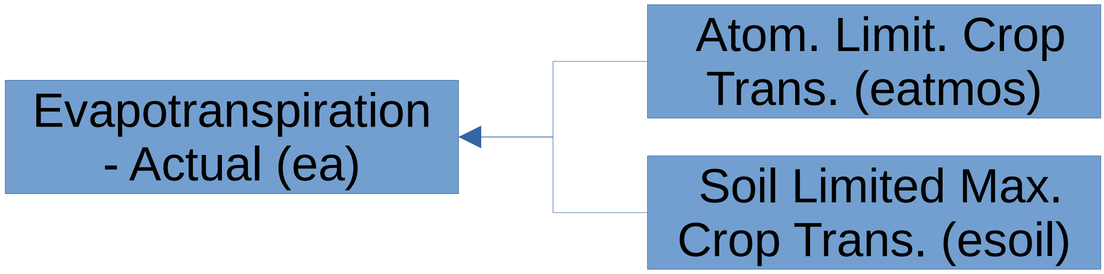


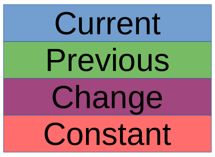

$$if\,(doy \geq \mathrm{sow\_doy}):$$

$$\Delta SSE = \begin{cases} if\,(f < 1, min(1.5, et) \times (1 - f)) \\ if\,(f = 1, 0) \end{cases}$$

$$if\,(SSE_{t\text{-}1} > 20)\,\Delta SSE = 0$$

# Evapotranspriation, Crop, Actual (ea)

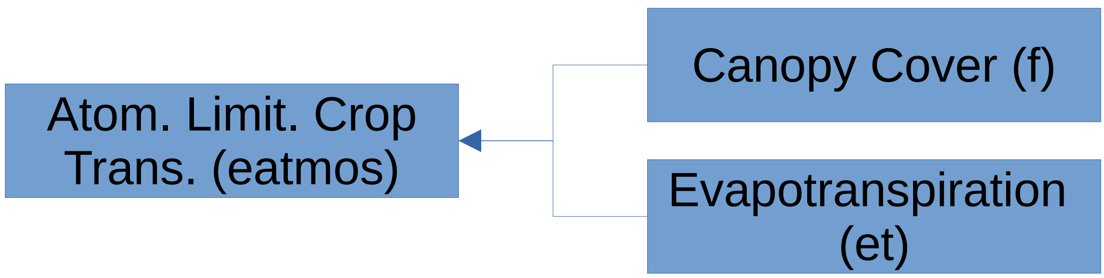


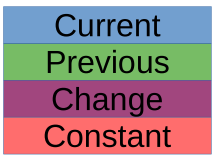




$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$ea = min\left(eatmos, esoil\right)$$

# Evapotranspiration, Crop, Atmosphere Limited (eatmos).



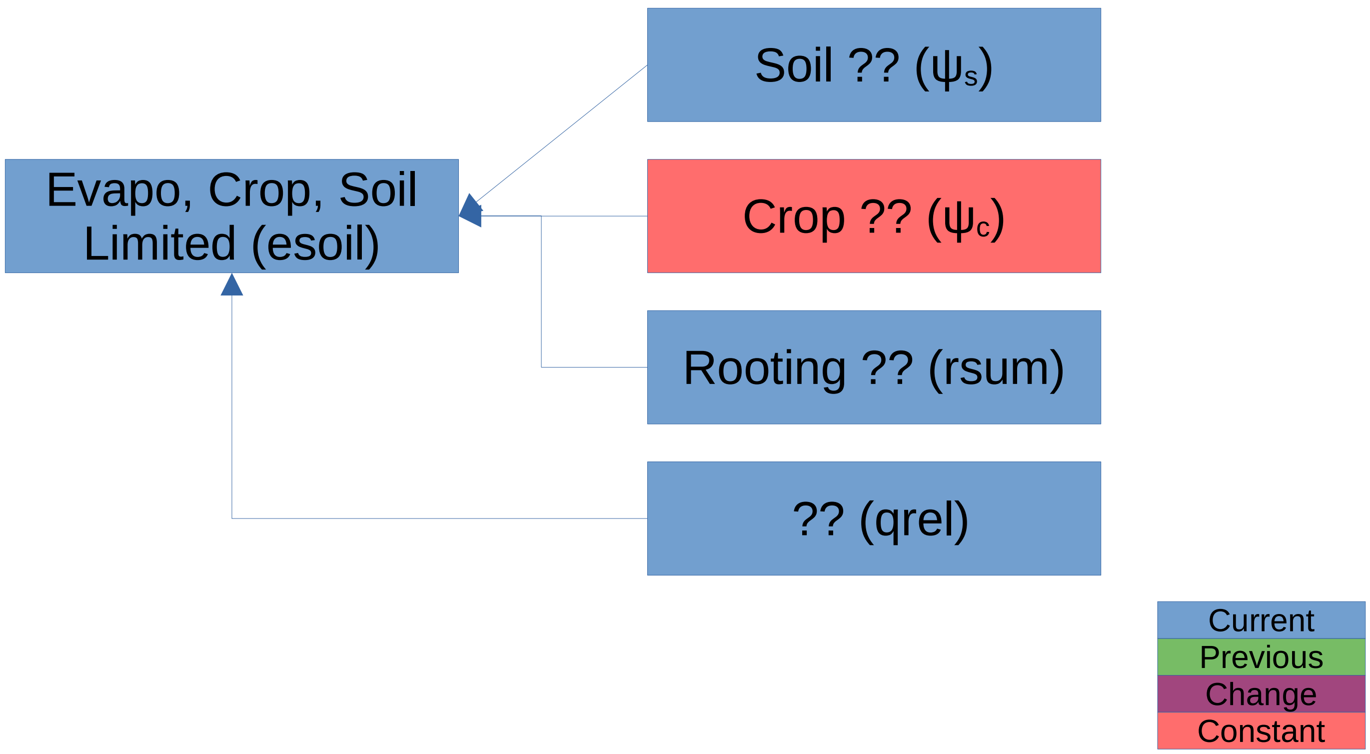




$$if\,(doy \geq \mathrm{sow\_doy}):$$

$$eatmos = 1.2 \times f \times et$$

$$if\,(eatmos \leq 0)\; eatmos = 0.001$$

# Evapotranspiration, Crop, Soil Limited (esoil)



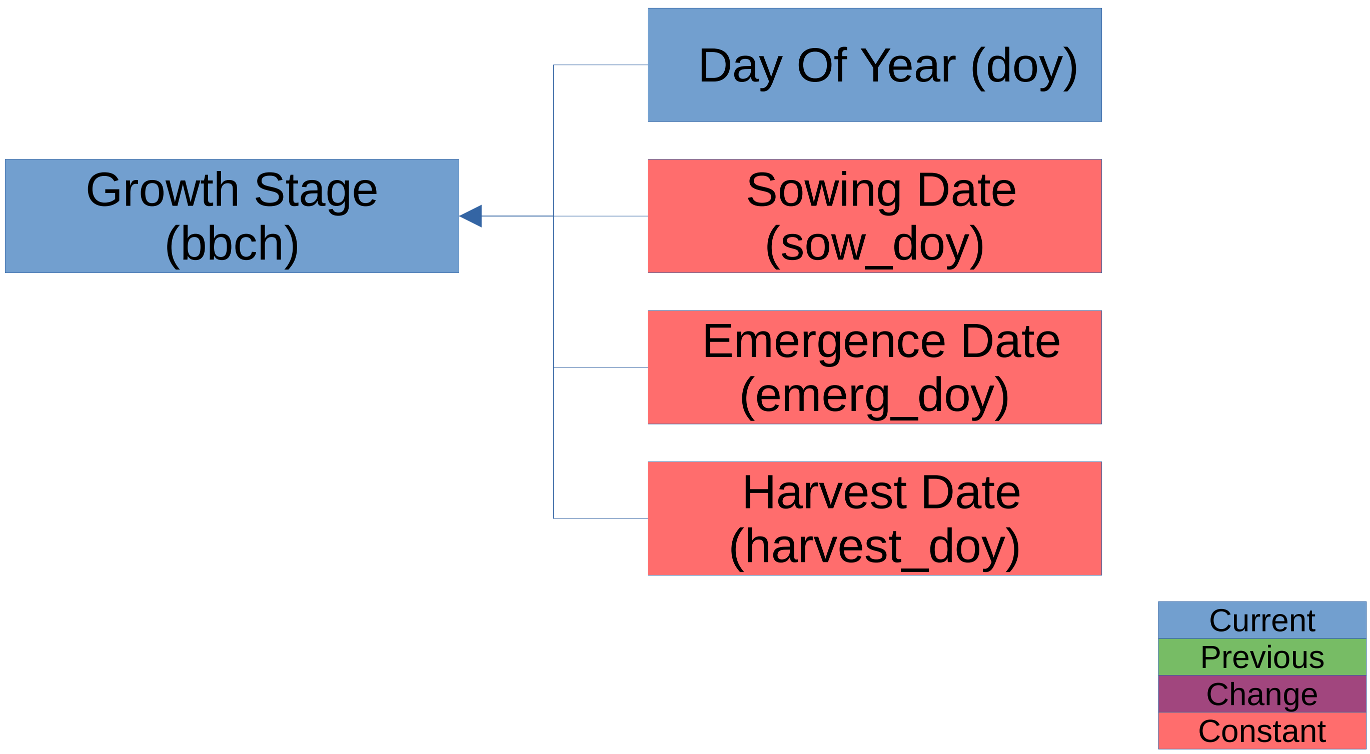

$$if\left(doy \geq \text{sow\_doy}\right):$$

$$esoil = \frac{\psi_s - \psi_c}{rsum}$$

$$if\left(qrel == 0\right) esoil = 0$$

Growth Stage (bbch)

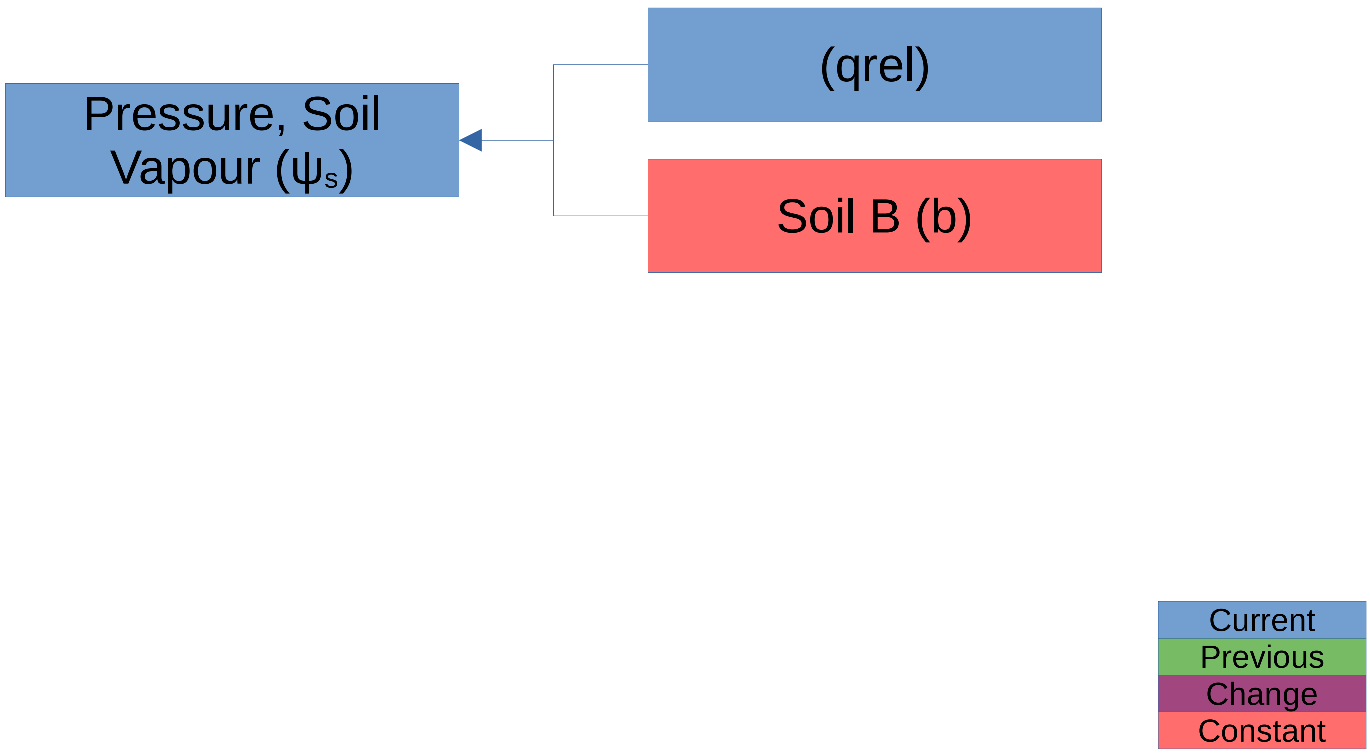
The last conditional equation looks like an insurance policy, but it seems a little off: shouldn’t it be if Cd_sow is less than Tzero (bbch = 01 means sown but not emerged).




$$bbch = \begin{Bmatrix} if\left(doy \geq \mathrm{sow\_doy}, 01\right) \\ if\left(doy \geq \mathrm{emerg\_doy}, 09\right) \\ if\left(doy \geq \mathrm{harvest\_doy}, 99\right) \\ else\left(0\right) \end{Bmatrix}$$

$$if\left(\mathrm{emerg\_doy} \leq \mathrm{sow\_doy} \wedge \mathrm{Cd\_sow} \geq Tzero\right) bbch = 01$$

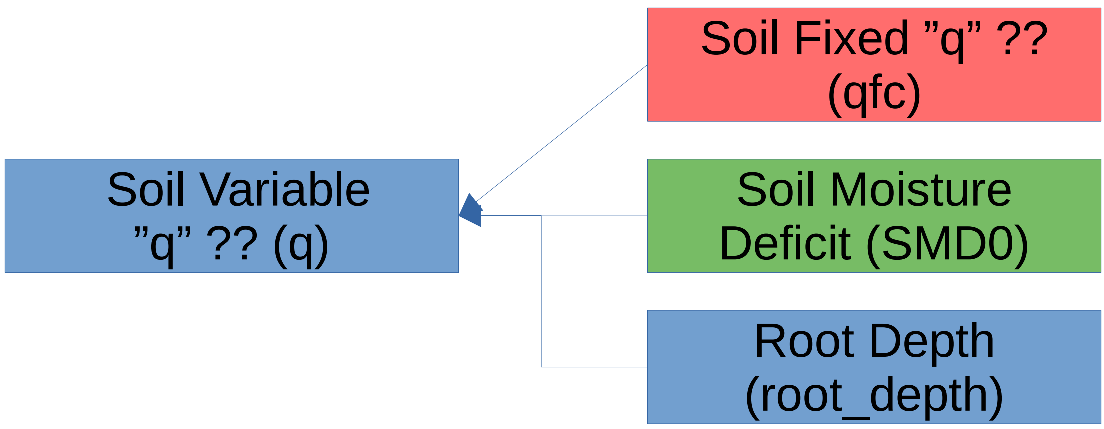
# Pressure, Soil Vapour ($\psi_s$) []

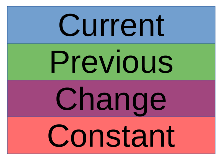



$$\psi_s = -5 \times qrel^{-b}$$

q, Soil Variable (q)

Soil Moisture Deficit (SMD0) is given as from the previous period as the majority of the time, this is what it will be (see SMD0).

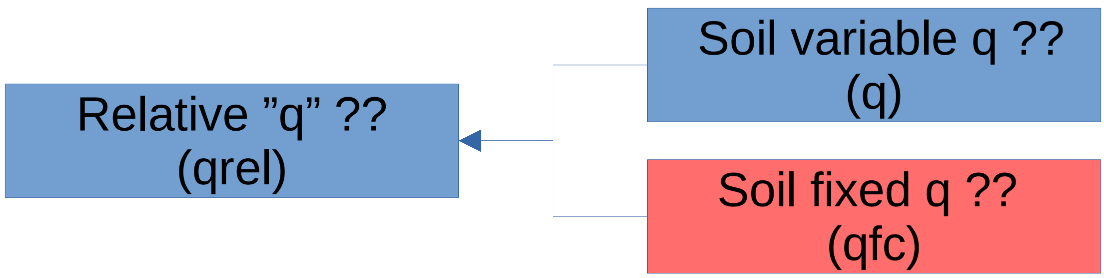


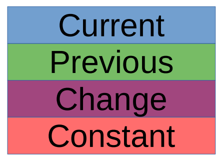




$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$q = max\left(qfc - \frac{SMD0}{\mathrm{root\_depth}}, 0.01\right)$$

# q, Relative (qrel)



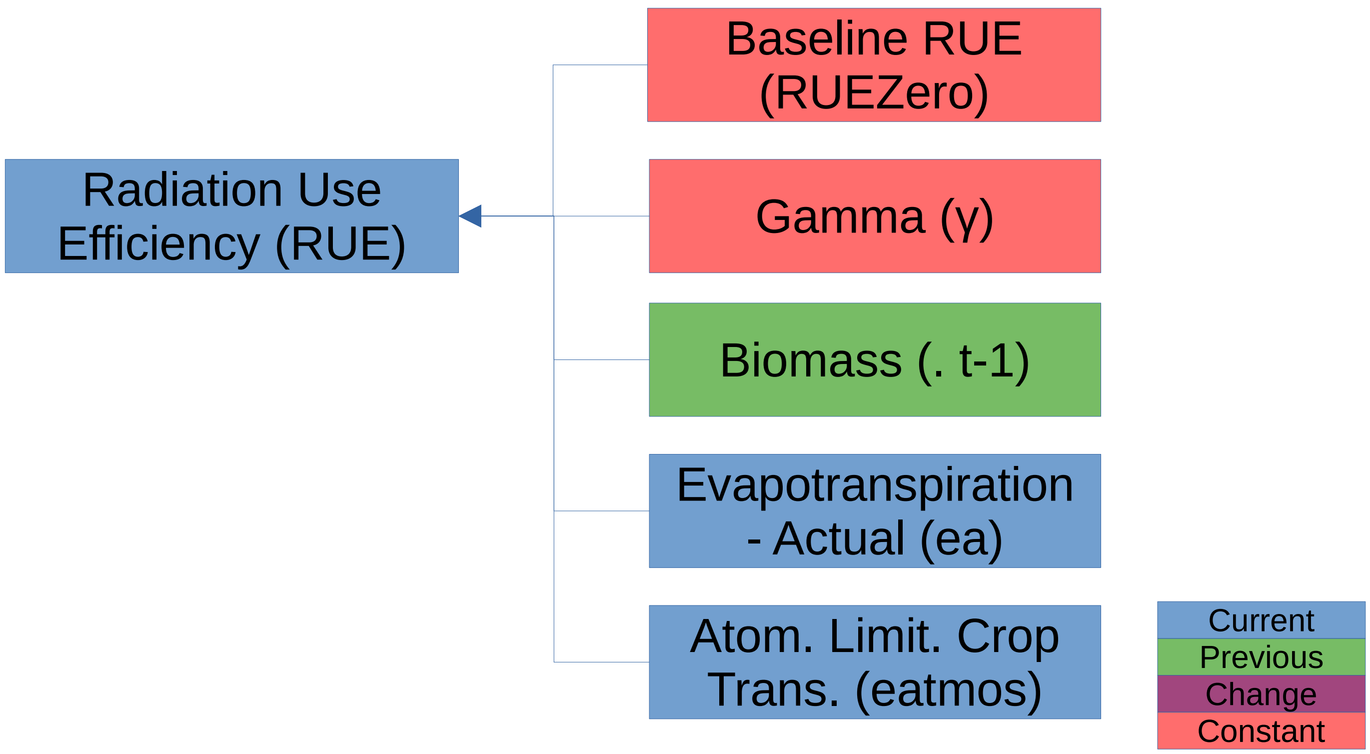

$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$qrel = \frac{q}{qfc}$$

$$if\left(doy < \mathrm{sow\_doy}\right) qrel = 1$$

Radiation Use Efficiency (RUE)

How much of the available solar energy can the plant use. Depends on amount biomass per hectare and the estimated rates of evapotranspiration.



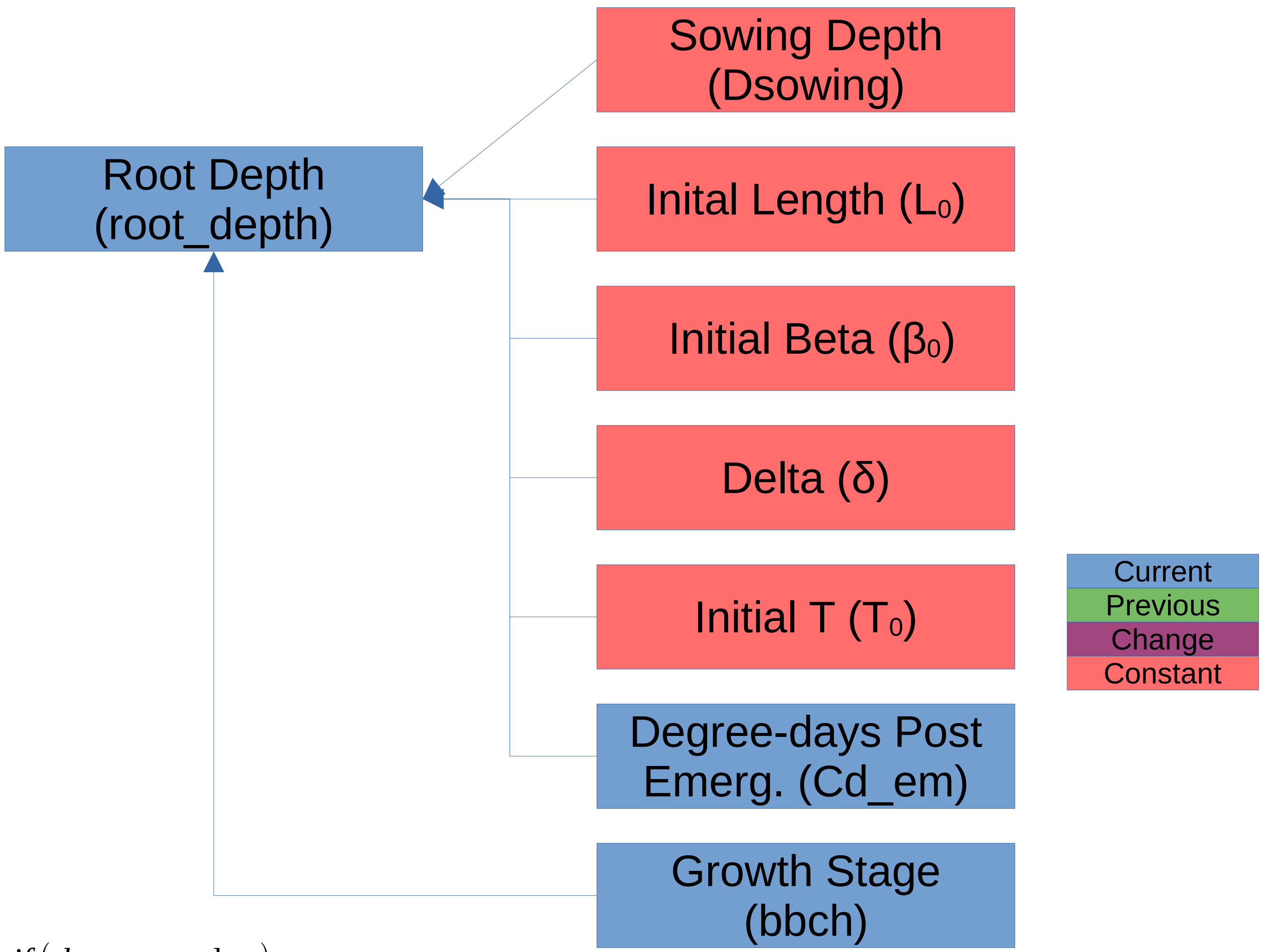

$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$RUE = 0.6 \times RUEZero \times \exp\left(-\gamma \times biomass_{\text{t-1}}\right) + \frac{0.4 \times RUEZero \times ea}{eatmos} \times \exp\left(-\gamma \times biomass_{\text{t-1}}\right)$$

$$RUE = \left(RUEZero \times \exp\left(-\gamma \times biomass_{\text{t-1}}\right)\right)\left(0.6 + \frac{0.4 \times ea}{eatmos}\right)$$

Root depth (root_depth)

Basically a function of sowing depth and cumulative temperature post-emergence.



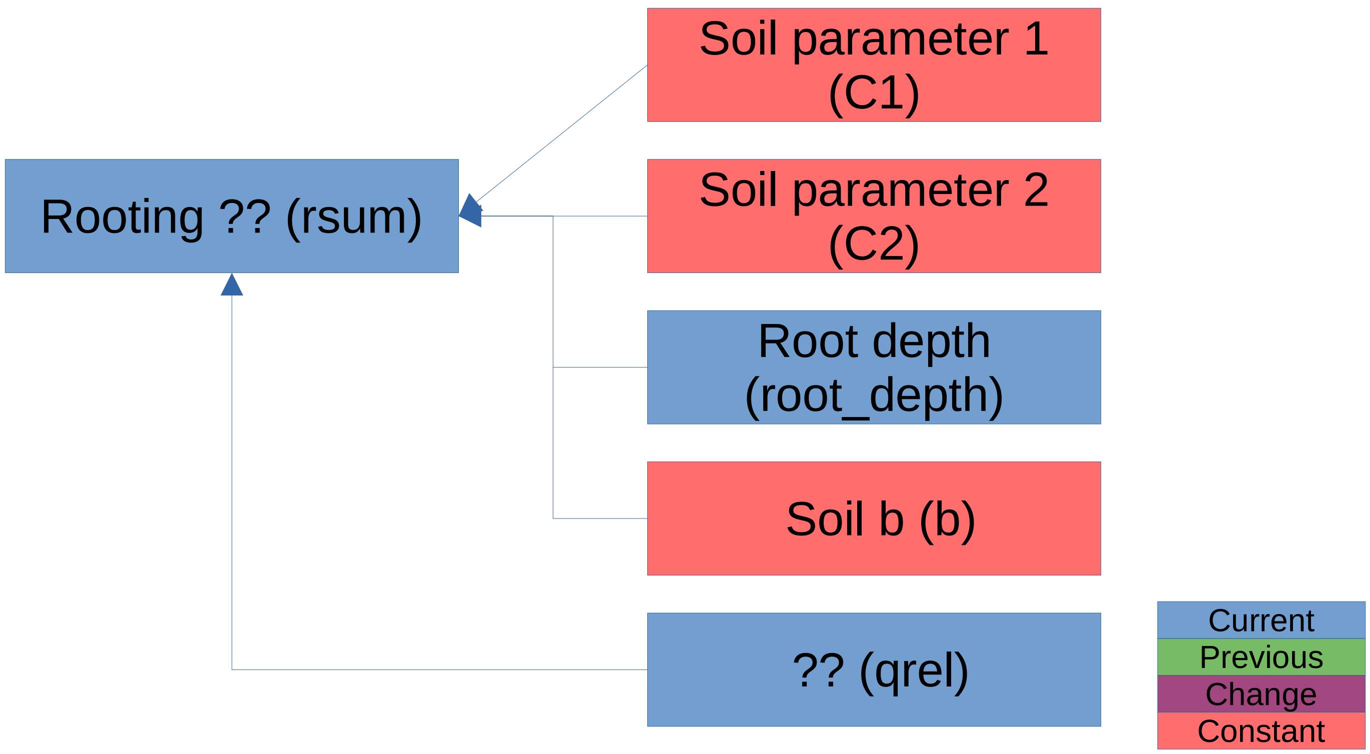

$$if\,(doy \geq \text{sow\_doy}):$$

$$\text{root\_depth} = Dsowing + L_0 * \exp\left(\frac{\beta \times (1 - \exp(-\delta \times (Cd_{em} - T_0)))}{\delta}\right)$$

$$if\,(bbch < 09)\ \text{root\_depth} = Dsowing$$

Rooting (rsum)

Qrel^(-2xb+3) is also given as hc_soil, EXCEPT the negative in front of the 2?!?!



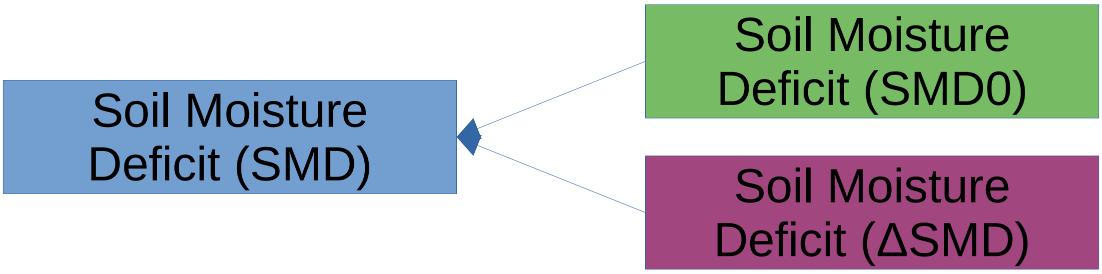

$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

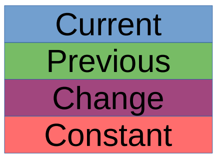
$$rsum = C1 + \frac{C2 \times \left(qrel^{-2 \times b + 3} - 1\right)}{\mathrm{root\_depth}}$$

$$if\left(qrel == 0\right) rsum = C1$$

Soil Moisture Deficit (SMD)

Estimate of how much more water the soil could hold.
Increases with ΔSMD > 0.



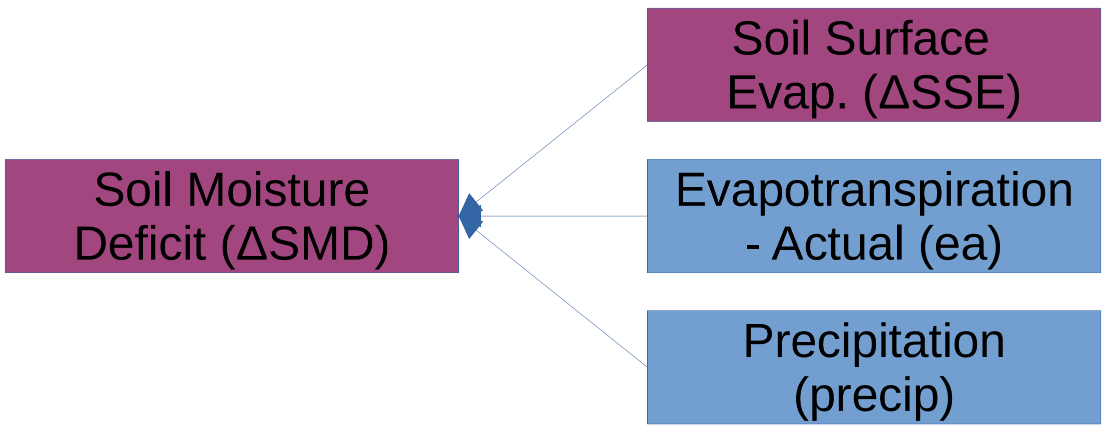

$$if\,(doy \geq \mathrm{sow\_doy}):$$

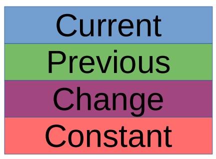
$$SMD_t = SMD0 + \Delta SMD$$

$$if\,(doy < \mathrm{sow\_doy})\; SMD = 0$$

Soil Moisture Deficit, Change in (ΔSMD)

The change in the amount of water in the soil. Positive if there is evaporation or transpiration, negative if there is rain. Taken as 0 if ΔSMD < 0 and SMD = 0 (IS IT????).



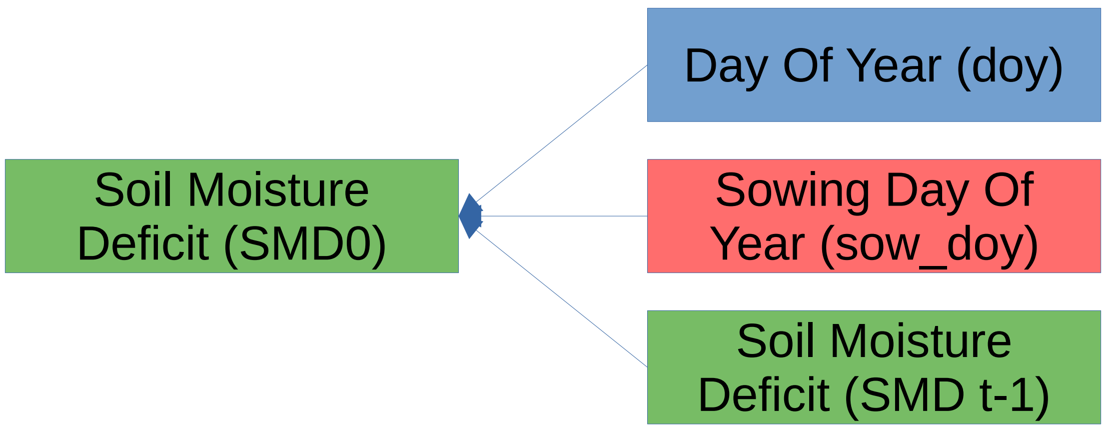



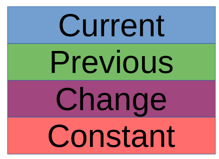

$$if\ (doy \geq \mathrm{sow\_doy}):$$

$$\Delta SMD = \Delta SSE + ea - precip$$

# Soil Moisture Deficit, Initial (SMD0)

Soil Moisture Deficit (SMD0) is given as from the previous period as the majority of the time, this is what it will be (see SMD0).



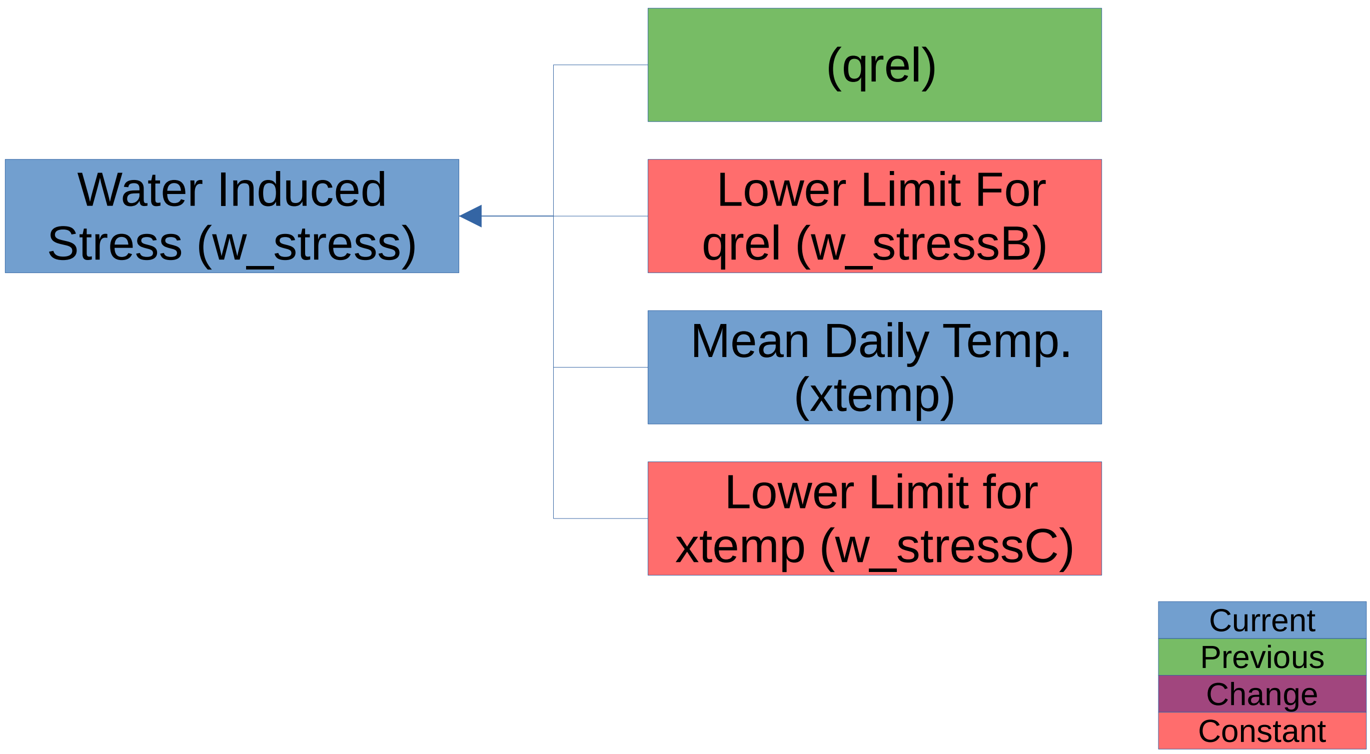

$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$SMD0 = \begin{Bmatrix} if\left(doy == \mathrm{sow\_doy}, 0\right) \\ if\left(SMD_{t-1} < 0, 0\right) \\ else\left(SMD_{t-1}\right) \end{Bmatrix}$$

$$if\left(doy < \mathrm{sow\_doy}\right) SMD0 = 20$$

Stress, Water Deficit Induced (w_stress)

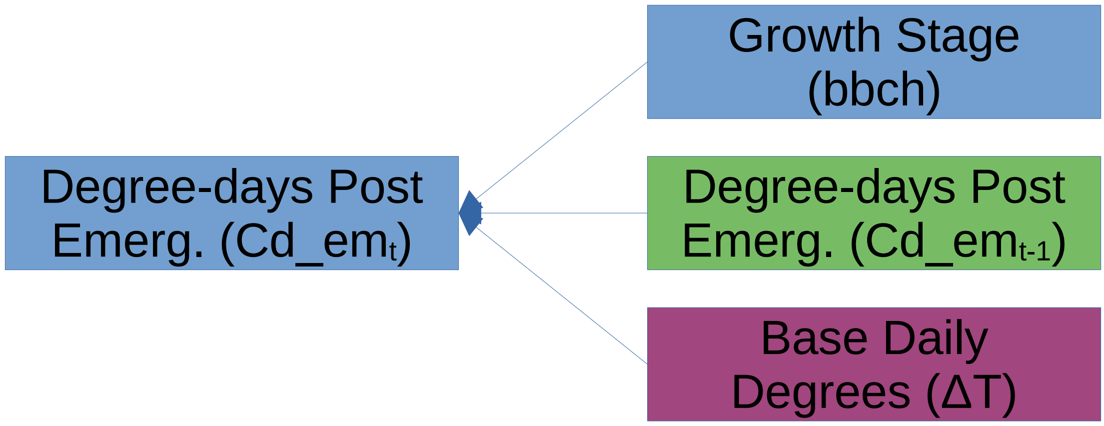
NB: In my R code, I had w_stressC written as Wstresc at one point (last instance in calc of w_stress). Is this an error by me or an issue in the OpenModel version?

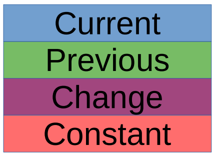



$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$\mathrm{w\_stress} = \begin{cases} if\left(qrel < \mathrm{w\_stressB} \wedge xtemp > \mathrm{w\_stressC}, \dfrac{qrel \times \mathrm{w\_stressC}}{\mathrm{w\_stressB}}\right) \\ else\left(1\right) \end{cases}$$

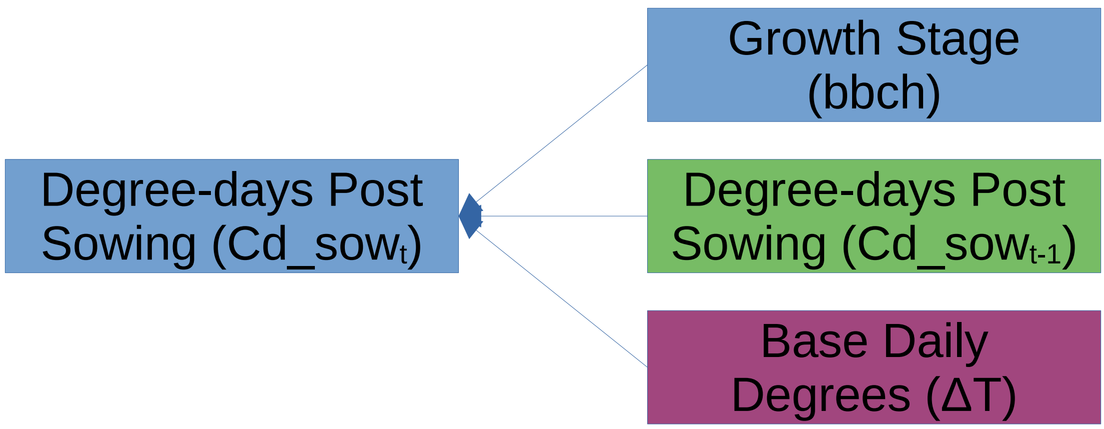
Temperature, Post Emergence, Cumulative (Cd_em)

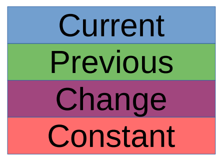



$$\mathrm{Cd\_em}_t = \begin{cases} if\left(bbch \geq 09, 90 + \mathrm{Cd\_em}_{t\text{-}1} + \Delta T\right) \\ else\left(0\right) \end{cases}$$

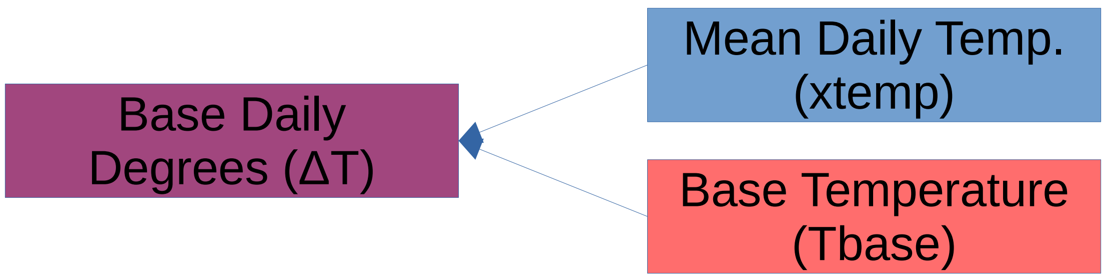
# Temperature, Post Sowing, Cumulative (Cd_sow)

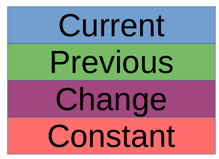



$$\mathrm{Cd\_sow}_t = \begin{Bmatrix} if\left(bbch \geq 01, \mathrm{Cd\_sow}_{t-1} + \Delta T\right) \\ else\left(0\right) \end{Bmatrix}$$

# Temperature, Re-Based, Daily (ΔT)

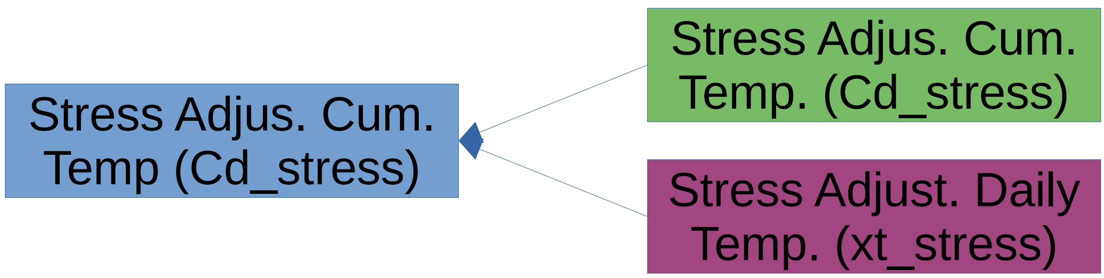


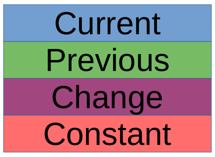




$$\Delta T = xtemp - Tbase$$

$$if\,(\Delta T < 0)\,\Delta T = 0$$

# Temperature, Stress Adjusted, Cumulative (Cd_stress)




$$if\left(doy \geq \text{sow\_doy}\right):$$

$$\text{Cd\_stress}_t = \text{Cd\_stress}_{\text{t-1}} + \text{xt\_stress}, \textit{where } \text{xt\_stress} \equiv \Delta\, \text{Cd\_stress}$$

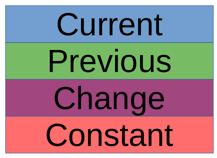
$$if\left(\text{Cd\_stress} > 950\right) \text{Cd\_stress} = 950$$

$$if\left(doy < \text{sow\_doy}\right) \text{Cd\_stress} = 0$$

Temperature, Stress Adjusted, Cumulative (fTemp)

A fraction of Stress Adjusted Cumulative Temperature (Cd_stress). This seems unnecessary, except for...

Note that Cd_stress is readjusted after it is used to calculated fTemp, so fTemp can be above 0.950, but only by the amount of the current day’s Stress Adjusted Temperature.

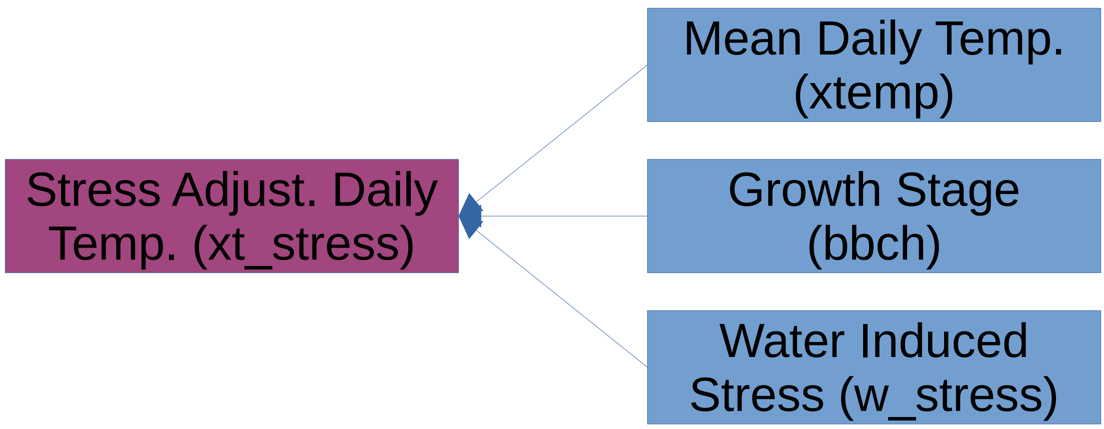



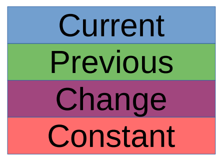

$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$fTemp = \mathrm{Cd\_stress} \times 0.0001$$

$$if\left(fTemp \leq 0.00001\right) fTemp = 0.00001$$

# Temperature, Stress Adjusted, Daily (xt_stress)



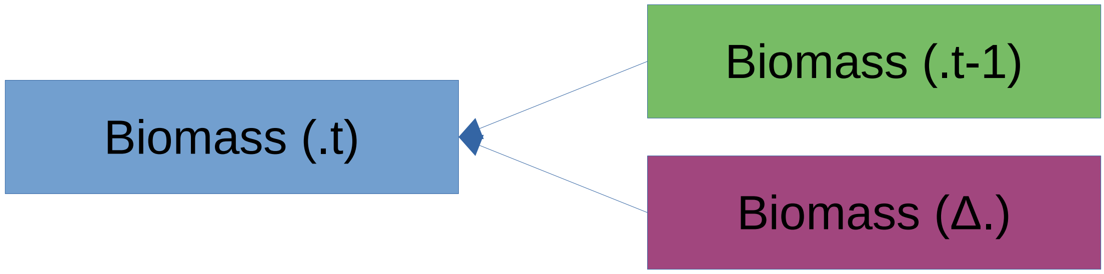



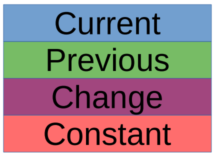

$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$\mathrm{xt\_stress} = \begin{Bmatrix} if\left(xtemp > 3 \wedge xtemp < 25 \wedge bbch \geq 09, \left(xtemp - 3\right) \times \mathrm{w\_stress}\right) \\ else\left(0\right) \end{Bmatrix}$$

Yield, Biomass (biomass)

Potential biomass = root plus top.



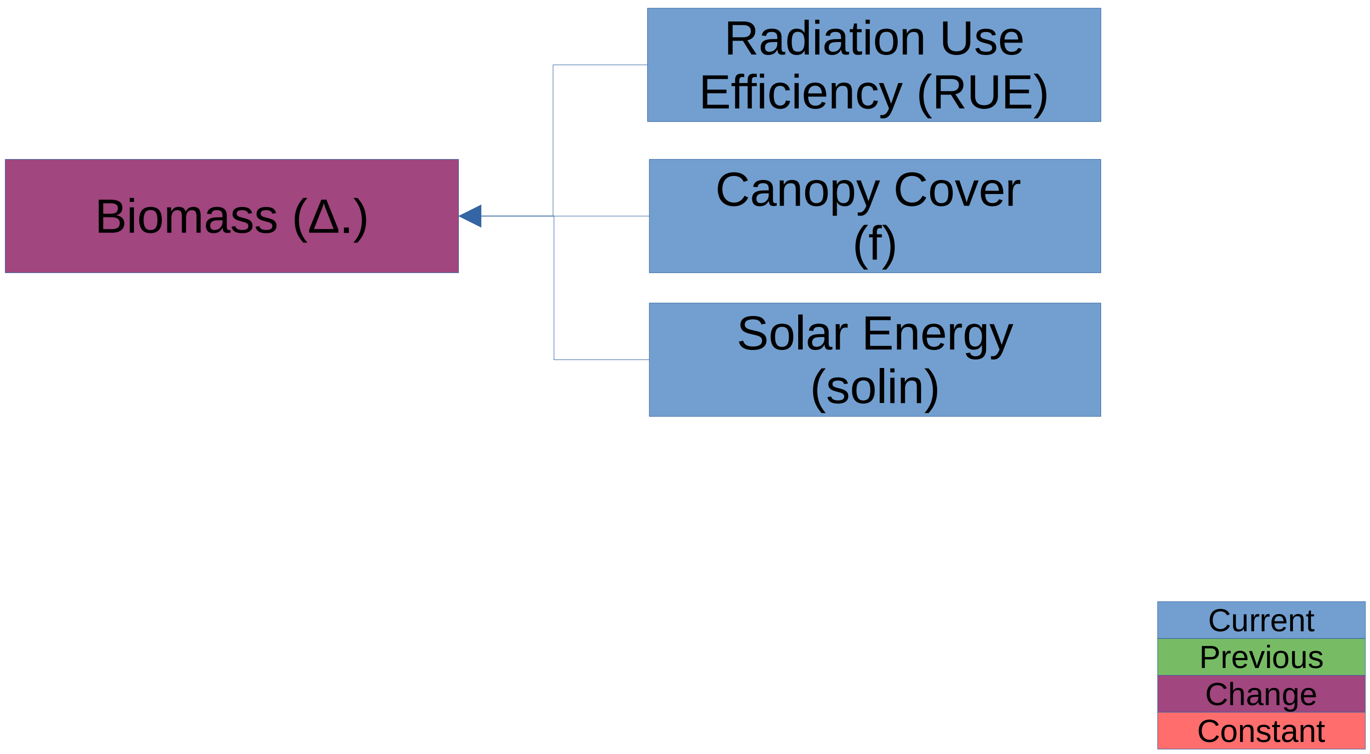

$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$biomass_t = biomass_{t-1} + \Delta\, biomass$$

$$if\left(doy < \mathrm{sow\_doy}\right) biomass_t = 0$$

Yield, Biomass, Change in (Δ biomass)

Increase in biomass (root plus top) in any given period.

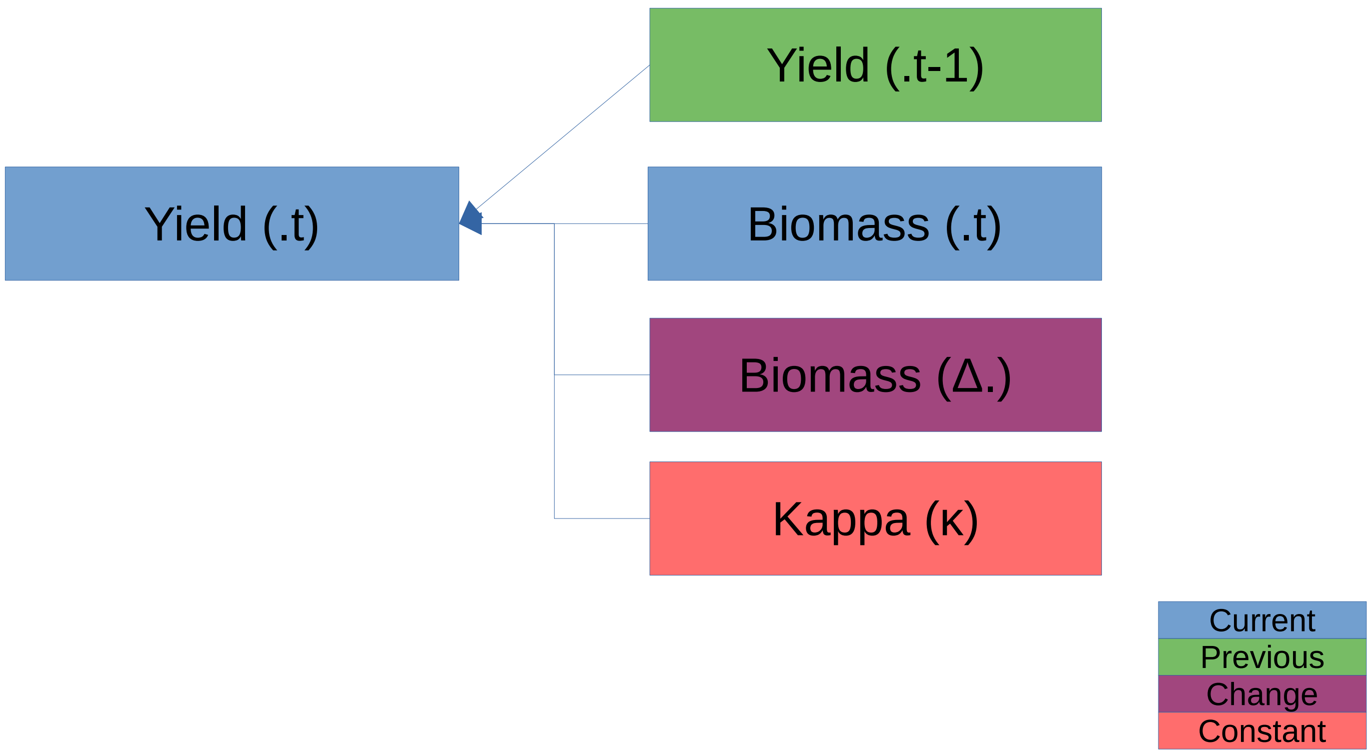



$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$\Delta\, biomass = RUE \times f \times solin$$

Yield, Root (yield)

Potential root yield



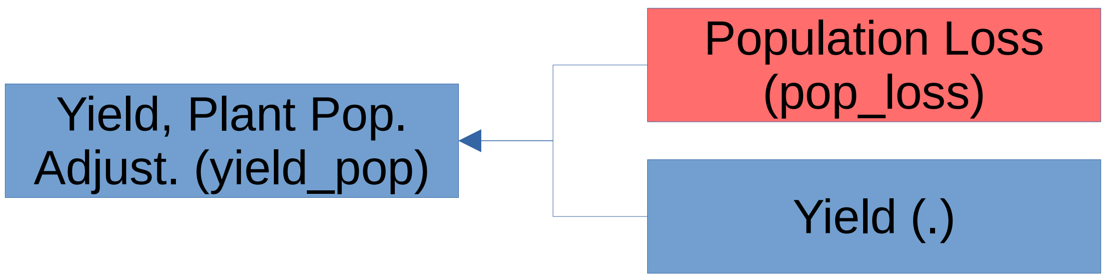

$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

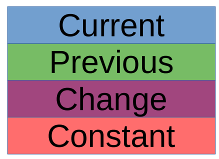
$$yield_t = yield_{t\text{-}1} + \frac{\Delta\, biomass \times \kappa \times biomass_t}{1 + \kappa \times biomass_t}$$

$$if\left(doy < \mathrm{sow\_doy}\right) yield_t = 0$$

## Yield, Root, Plant Population Adjusted (yield_pop)

Potential root yield adjusted for the observed plant population. Plant populations above 90 000 will result in no adjustment.



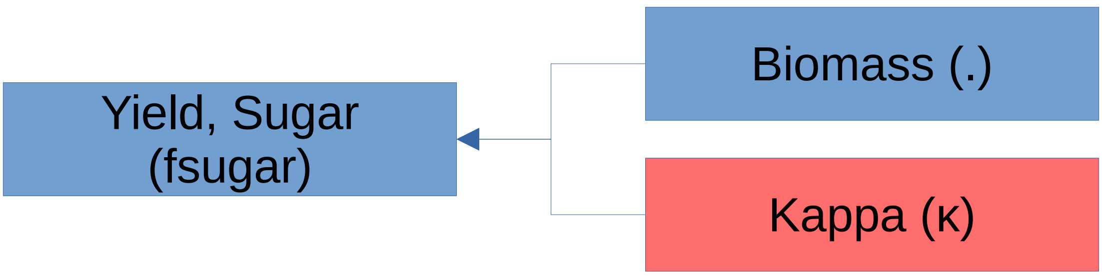

$$[\text{row-wise}, \mathit{main}]$$

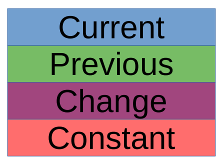
$$\mathit{if}\,(\mathit{doy} \geq \text{sow\_doy}):$$

$$\text{yield\_pop} = \text{pop\_loss} \times \mathit{yield}$$

Yield, Sugar (fsugar)

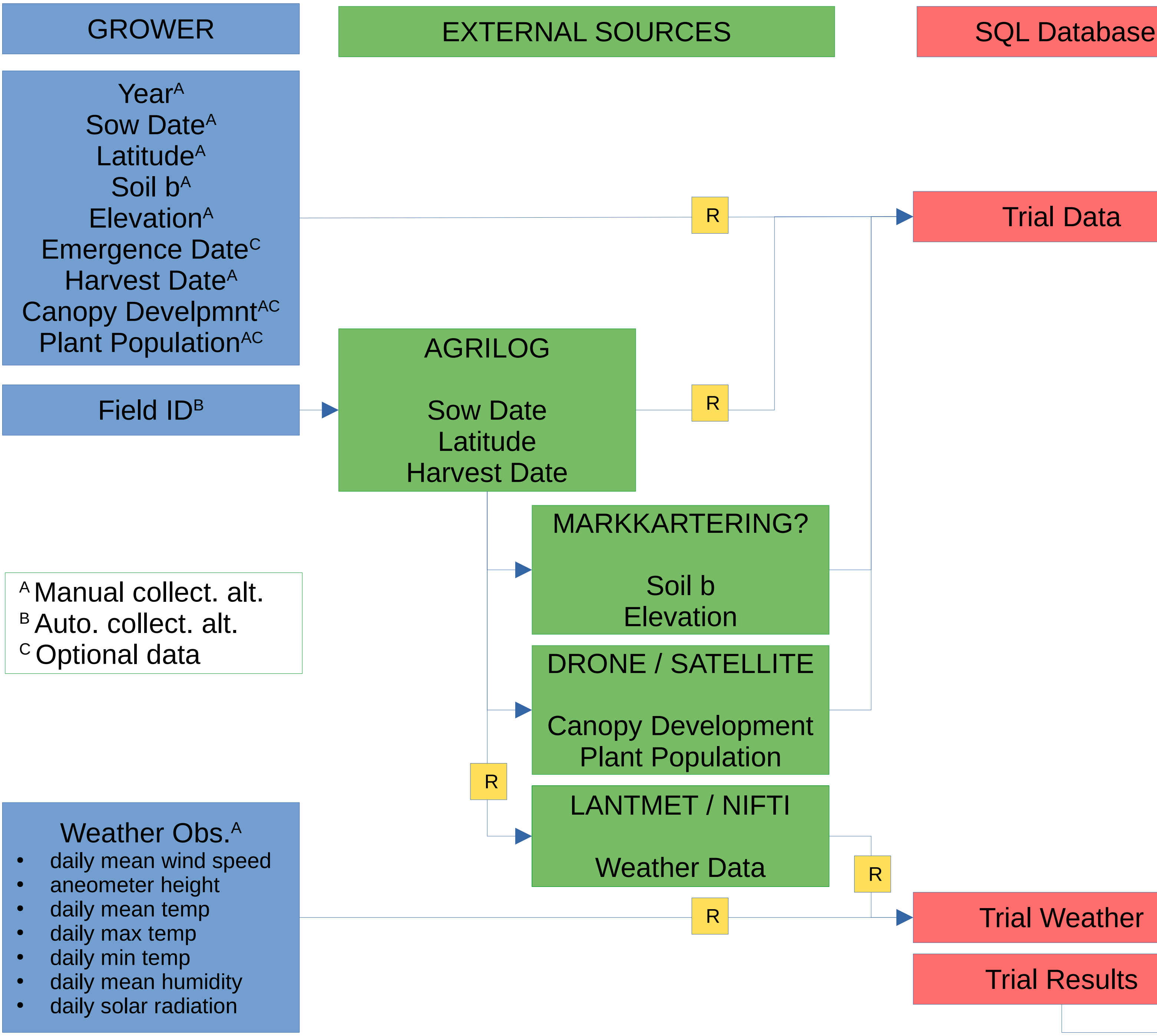
Potential sugar yield. Given Kappa is a constant, Sugar Yield is in direct relation to the Biomass estimate.




$$if\left(doy \geq \mathrm{sow\_doy}\right):$$

$$fsugar = \frac{\kappa \times biomass}{1 + \kappa \times biomass}$$


GROWER
EXTERNAL SOURCES
SQL Database
Year^A
Sow Date^A
Latitude^A
Soil b^A
Elevation^A
Emergence Date^C
Harvest Date^A
Canopy Develpmnt^AC
Plant Population^AC
R
Trial Data
AGRILOG
Sow Date
Latitude
Harvest Date
Field ID^B
R
MARKKARTERING?
Soil b
Elevation
^A Manual collect. alt.
^B Auto. collect. alt.
^C Optional data
DRONE / SATELLITE
Canopy Development
Plant Population
R
LANTMET / NIFTI
Weather Data
Weather Obs.^A
daily mean wind speed
aneometer height
daily mean temp
daily max temp
daily min temp
daily mean humidity
daily solar radiation
R
R
Trial Weather
Trial Results