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Geoscientific Model Development
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Supplement of

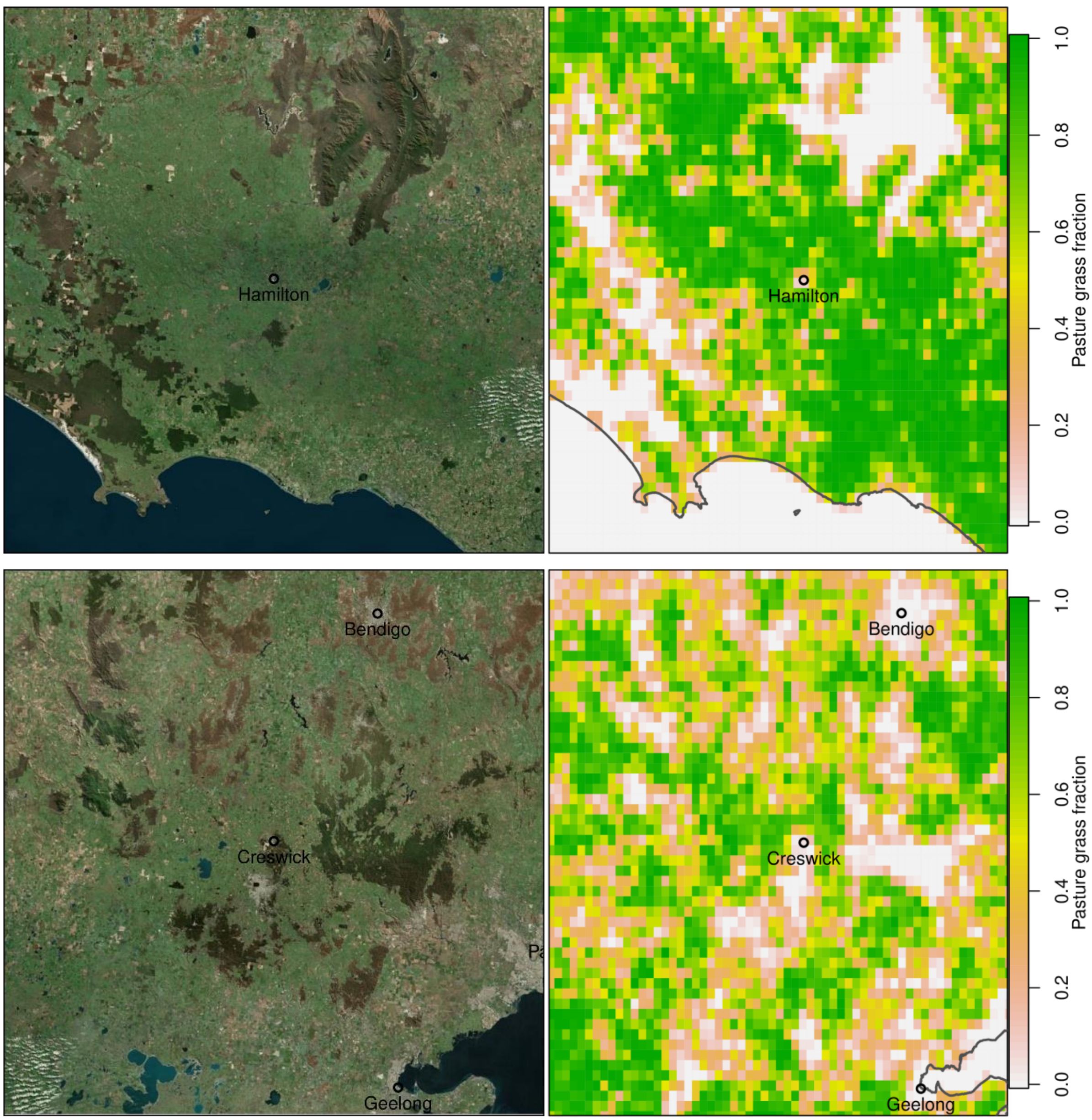
Development and evaluation of pollen source methodologies for the Victorian Grass Pollen Emissions Module VGPEM1.0

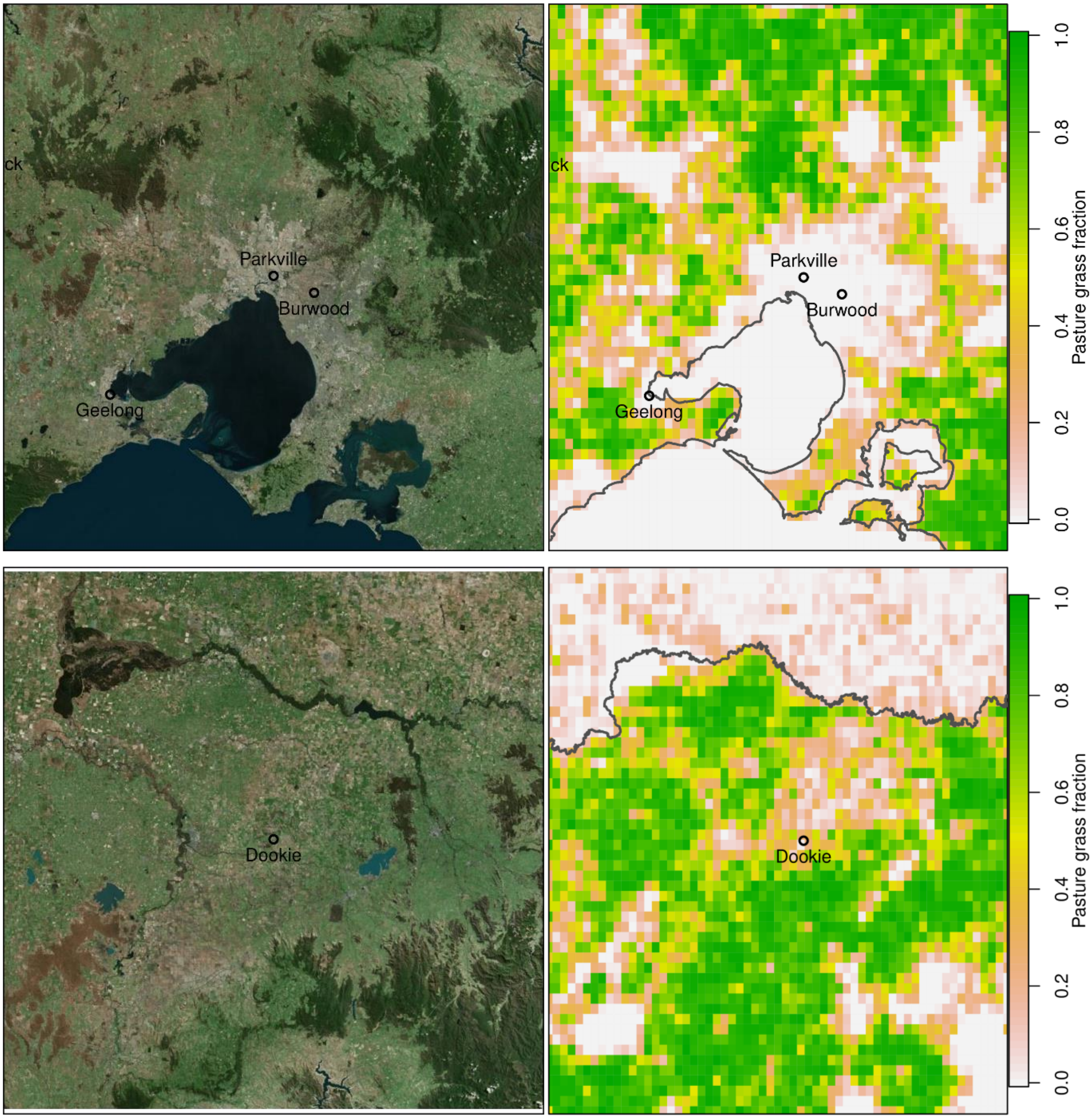
Kathryn M. Emmerson et al.

Correspondence to: Kathryn M. Emmerson (kathryn.emmerson@csiro.au)

1. Larger-scale satellite maps and pasture grass maps

We include larger-scale maps of each pollen count site (Figure S 1), showing the surrounding land use and the spatial variability and fraction of pasture grass. Sites are arranged west to east as described in Table 1 in the main paper.





ck
Parkville
Burwood
Geelong
Dookie
Pasture grass fraction
0.0
0.2
0.4
0.6
0.8
1.0

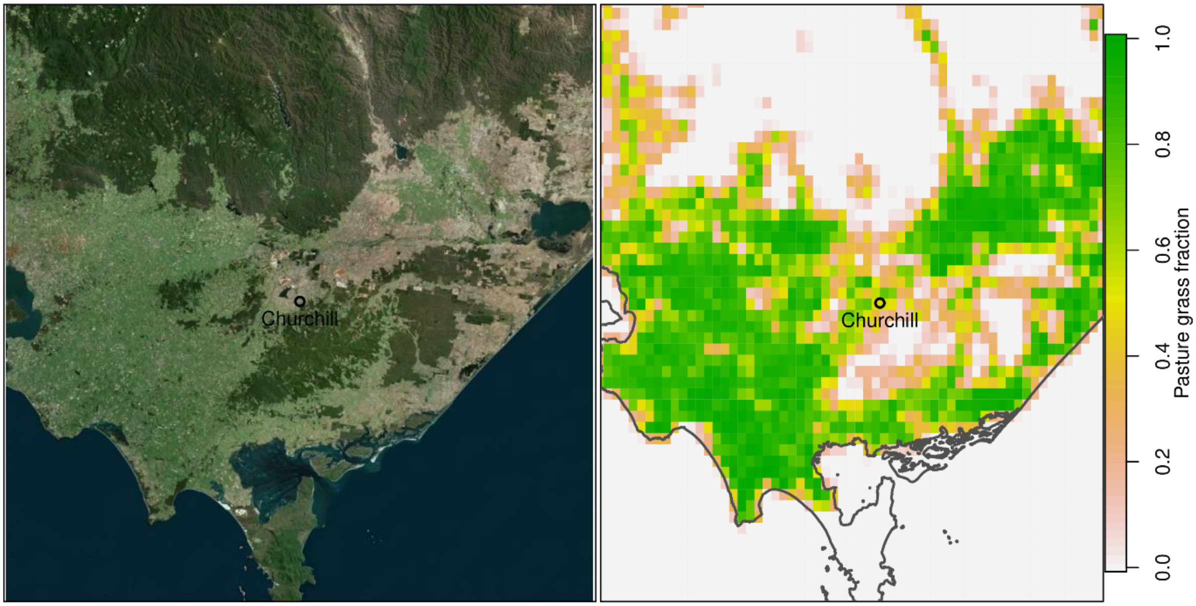


Figure S 1: larger-scale maps of land use surrounding each pollen count site.

2. Shifted Gaussian distributions based on observed patterns

Figure S 2 shows the observed pollen time series over the 2017 season at each of the count sites. We have fitted a normal distribution to these data, minimising the root mean squared error between the fit and the observations. The mean (mu), standard distribution (sd) and fitting parameter (SF) of each individual fit are given in the top left of each panel.

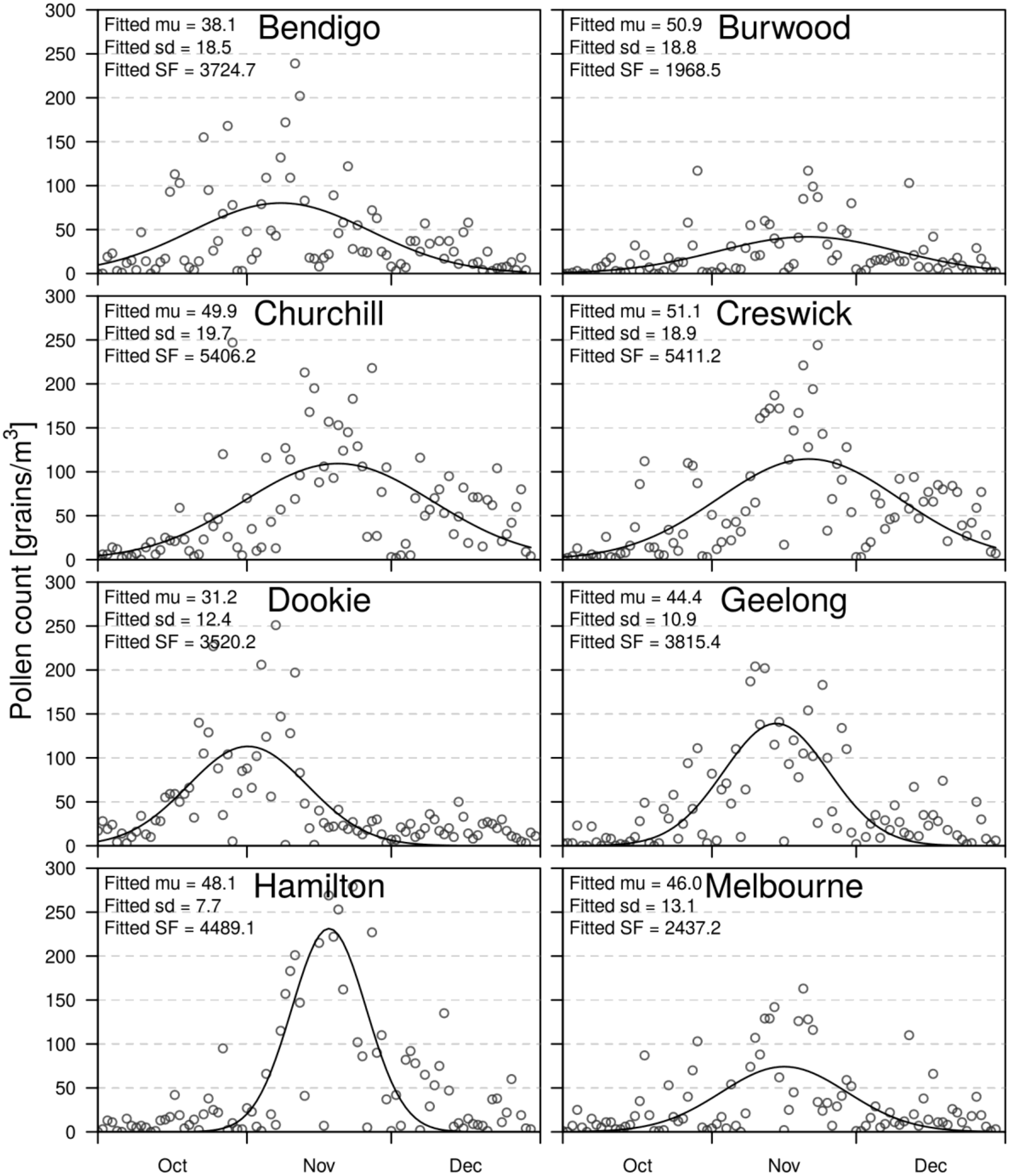


Figure S 2 Time series of observed pollen at each site, which has had a normal distribution fitted to these data.

3. Index of Agreement

The index of agreement (IOA) (Willmott et al. 2012) has been calculated using the ModStats package within Openair (Carslaw and Ropkins, 2012). The description of IOA has been taken from the Openair manual (Carslaw, 2015).

IOA spans between −1 and +1 with values approaching +1 representing better model performance. An IOA of 0.5, for example, indicates that the sum of the error magnitudes is one half of the sum of the observed-deviation magnitudes. When IOA = 0.0, it signifies that the sum of the magnitudes of the errors and the sum of the observed-deviation magnitudes are equivalent. When IOA = −0.5, it indicates that the sum of the error magnitudes is twice the sum of the perfect model-deviation and observed-deviation magnitudes. Values of IOA near −1.0 can mean that the model estimated deviations about O are poor estimates of the observed deviations; however, they also can mean that there is simply little observed variability — therefore, some caution is needed when the IOA approaches −1. It is defined as (with c = 2)

$$IOA = \begin{cases} 1.0 - \dfrac{\sum_{i=1}^{n} |M_i - O_i|}{c \sum_{i=1}^{n} |O_i - \overline{O}|}, when \\ \sum_{i=1}^{n} |M_i - O_i| \leq c \sum_{i=1}^{n} |O_i - \overline{O}| \\ \dfrac{c \sum_{i=1}^{n} |O_i - \overline{O}|}{\sum_{i=1}^{n} |M_i - O_i|} - 1.0, when \\ \sum_{i=1}^{n} |M_i - O_i| > c \sum_{i=1}^{n} |O_i - \overline{O}| \end{cases}$$

4. Gerrity score

For a multi-category forecast we may wish to reward correct forecasts of rare events more than correct forecasts of common events, and penalise forecasts that are very wrong more than forecasts that are only a slightly wrong. A class of scores called "Gerrity scores" (GS) do just this by multiplying the contingency table by a scoring matrix (which is really a set of weights) and summing to get a score. That is,

	Observed		
	L	M	H+
L	n_{11}	n_{12}	n_{13}

Scoring matrix

s_{11}	s_{12}	s_{13}

						X			
Forecast	M	n_{21}	n_{22}	n_{23}		X	s_{21}	s_{22}	s_{23}
	H+	n_{31}	n_{32}	n_{33}			s_{31}	s_{32}	s_{33}
	total	n_1	n_2	n_3					

$$GS = \frac{1}{N}\sum_{i=1}^{3}\sum_{j=1}^{3} n_{ij} s_{ij}$$

GS scores measure the skill, relative to random chance, of predicting the correct category and ranges from -1 to 1 (perfect). It can be used with multi-category forecasts of any dimension, but is probably most often applied to 3-category forecasts. The scoring matrix is computed from the climatology (base rate) of the observations, i.e. how often each category occurs, and has nothing to do with the forecasts. One can either use the long-term climatology or the sample climatology. The long-term climatology is better if it is available, but it is often the case that it must be estimated from the sample.

The following are the steps for computing the elements of the scoring matrix:

1. If using the sample climatology, compute the observed relative probability of each category i=1, 2, 3 as $p_i = n_i / N$ where n_i is the total number observed in each category and N is the total number of samples.

2. Compute intermediate variables a_i from the relative probabilities,

$$a_1 = (1 - p_1)/p_1 \qquad a_2 = (1 - p_1 - p_2)/(p_1 + p_2) \qquad a_3 = (1 - p_1 - p_2 - p_3)/(p_1 + p_2 + p_3)\,.$$

3. Compute diagonal elements of the scoring matrix as

$$s_{11} = 0.5 * (a_1 + a_2)$$
$$s_{22} = 0.5 * \left(\frac{1}{a_1} + a_2\right)$$
$$s_{33} = 0.5 * \left(\frac{1}{a_1} + \frac{1}{a_2}\right)$$

4. Compute off-diagonal elements of the scoring matrix as

$$s_{12} = s_{21} = 0.5 * (a_2 - 1)$$
$$s_{13} = s_{31} = -1$$
$$s_{23} = s_{32} = 0.5 * \left(\frac{1}{a_1} - 1\right)$$

For the Melbourne pollen forecasts, the scoring matrix is S =

0.24	- 0.45	- 1.00
- 0.45	1.38	0.83
- 1.00	0.83	6.00

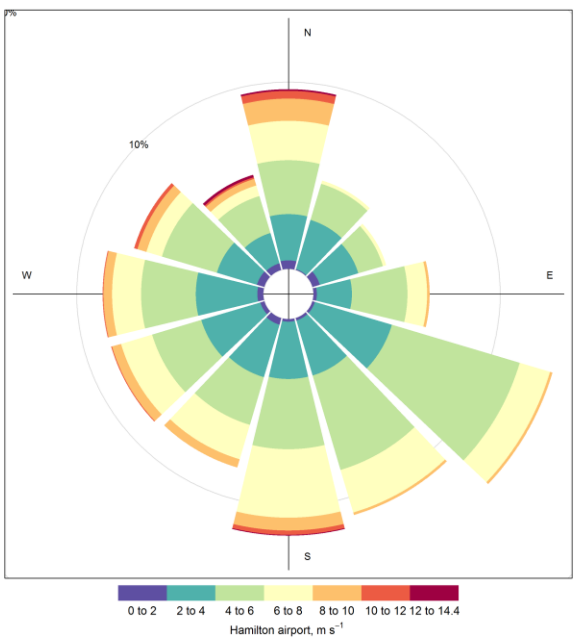
When multiplied by the three-category contingency table on the first page we get a Gerrity score for the 1-day forecasts of GS=0.468. It is greater than zero and therefore is a skilful value.

More information about verification scores is available online at www.cawcr.gov.au/projects/verification.

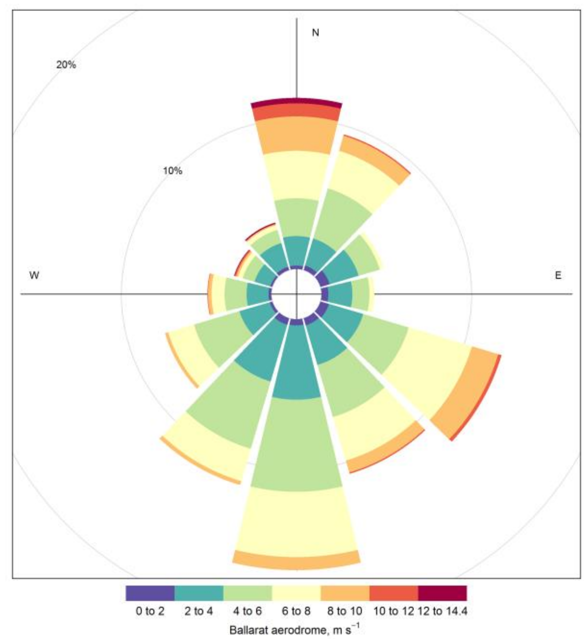
5. Wind roses

We plot wind roses (Figure S 3) for each of the AWS sites listed in Table 1 of the main paper during the period from 1 October 2017 to 31 December 2017.

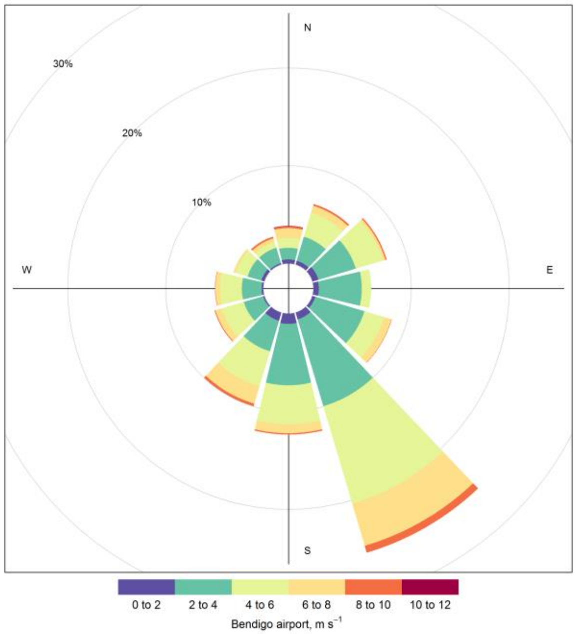
Hamilton Airport



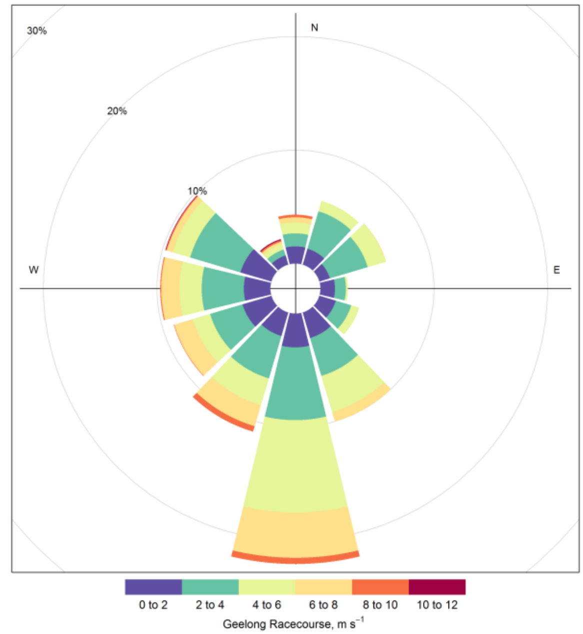
Ballarat aerodrome (Creswick)



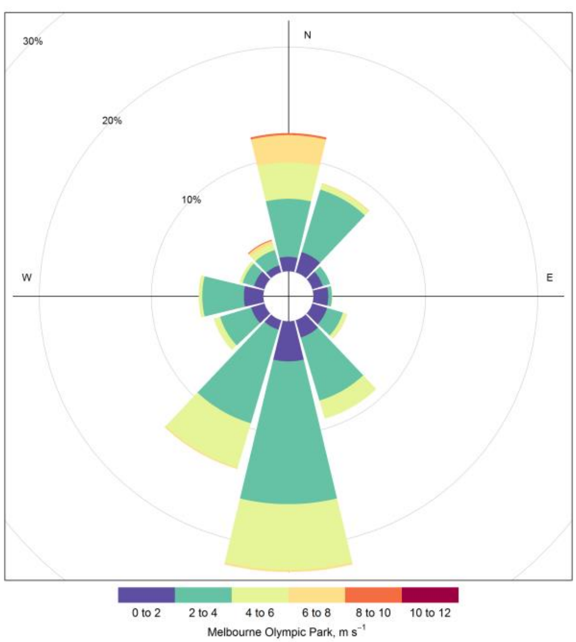
Bendigo Airport



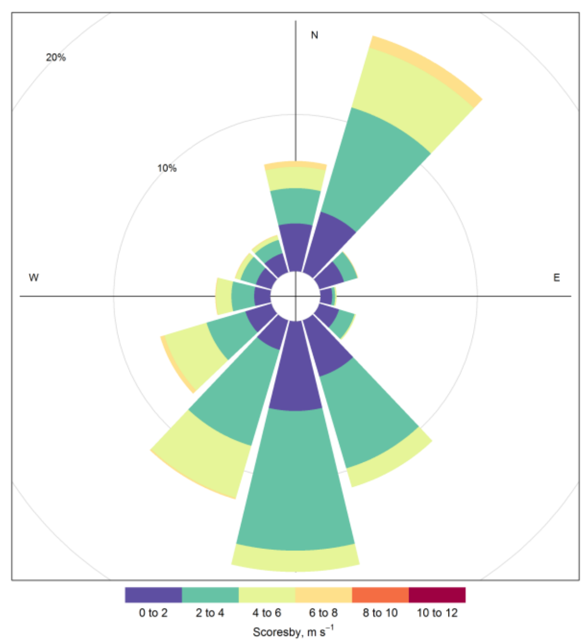
Geelong Racecourse



Melbourne Olympic Park



Scoresby (Burwood)



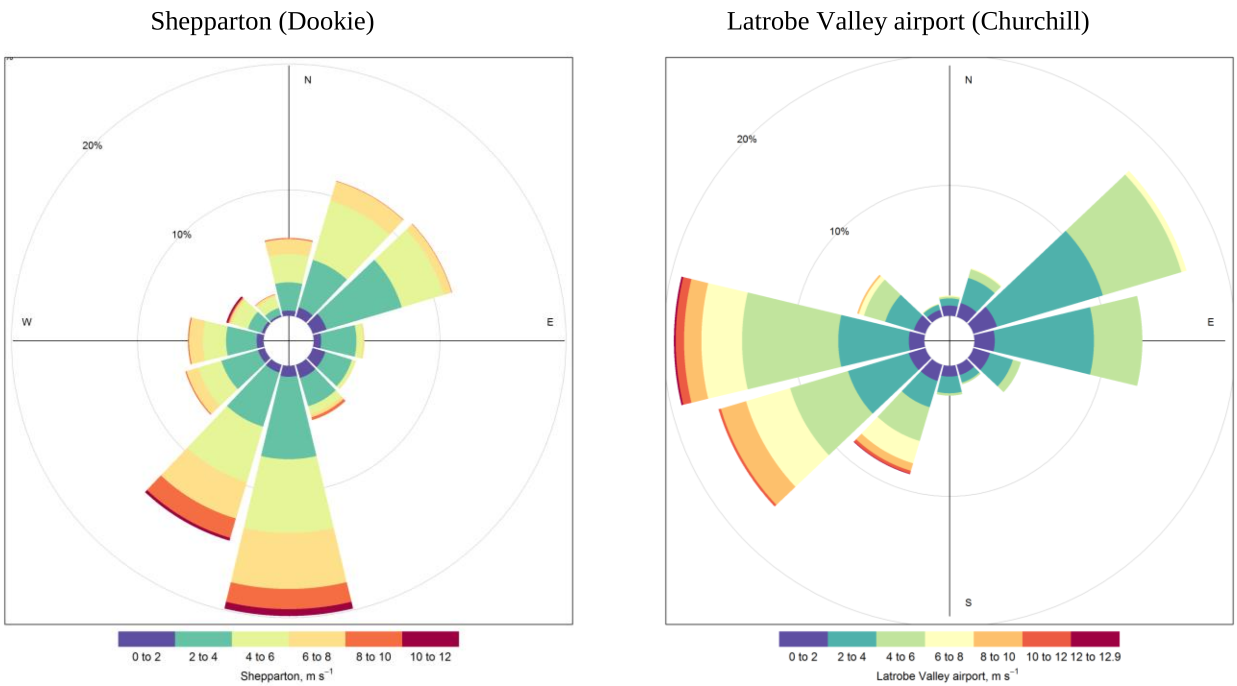


Figure S 3 Wind roses for each Automatic Weather Station closest to the pollen counting sites

6. References

Carslaw, D.C. and K. Ropkins, (2012). openair — an R package for air quality data analysis. Environmental Modelling & Software. Volume 27-28, pp. 52–61.

Carslaw, D.C. (2015). The openair manual — open-source tools for analysing air pollution data. Manual for version 1.1-4, King's College London.

Willmott, C. J., Robeson, S. M. and Matsuura, K. (2012), A refined index of model performance. Int. J. Climatol., 32: 2088-2094. doi:10.1002/joc.2419.

7. Pollen emissions code VGPEM1.0

```
SUBROUTINE CTM_pollen_emissions (nx, ny, nz, zfull, dxy, wspd, U10m, V10m, sfctemp, sfcpres, mix_ratio, prcpR,
prcpU, tscr_24h,SH_24h,  CTM_clock_current_LST, geoGrid, zenith, pollen_veg, evi_gradient, last_available,
EVIfallDaySmoothed, EVIwinterMaxSmoothed, Srate, PollenFluxes)

IMPLICIT NONE

  INTEGER, INTENT(IN) :: nx  !east/west points
```

```
INTEGER, INTENT(IN) :: ny  !north/south points
INTEGER, INTENT(IN) :: nz  !vertical points
REAL, INTENT(IN), DIMENSION(nx,ny,nz) :: zfull  !unscaled cell heights (m)
REAL, INTENT(IN), DIMENSION(nx,ny) :: dxy        !cell areas (m2) - unscaled
REAL, INTENT(IN), DIMENSION(nx,ny) :: wspd      !wind speed (m/s)
REAL, INTENT(IN), DIMENSION(nx,ny) :: U10m      !U wind speed (m/s)
REAL, INTENT(IN), DIMENSION(nx,ny) :: V10m      !V wind speed (m/s)
REAL, INTENT(IN), DIMENSION(nx,ny) :: sfctemp   !surface temp (K)
REAL, INTENT(IN), DIMENSION(nx,ny) :: sfcpres      !surface pres (Pa)
REAL, INTENT(IN), DIMENSION(nx,ny,nz) :: mix_ratio   !mixing ratio (g/g)
REAL, INTENT(IN), DIMENSION(nx,ny)    :: prcpR  !resolved precipitation (m/s)
REAL, INTENT(IN), DIMENSION(nx,ny)    :: prcpU  !convective precipitation (m/s)

TYPE(clock_variable) :: CTM_clock_current_LST   !CTM current time in local solar time
TYPE(geo), INTENT(IN), DIMENSION(nx,ny) :: geoGrid !lat/long of all grid points
REAL, INTENT(IN), DIMENSION(nx,ny) :: zenith    !zenith angle by grid point
REAL, INTENT(IN), DIMENSION(nx,ny) :: pollen_veg   !veg for pollen
REAL, INTENT(IN), DIMENSION(nx,ny) :: evi_gradient   ! Gradient of the EVI
REAL, INTENT(INOUT), DIMENSION(nx,ny) :: last_available ! last available pollen on plants
REAL, INTENT(IN), DIMENSION(nx,ny,1) :: EVIfallDaySmoothed
REAL, INTENT(IN), DIMENSION(nx,ny,1) :: EVIwinterMaxSmoothed

 REAL, INTENT(INOUT) :: Srate(nx*ny,number_species) !Emsn rate array!cumulative emission rates (g/m3/s)
TYPE(PollenFlux), INTENT(INOUT),DIMENSION(nx*ny,number_pollen_sizes) :: PollenFluxes   !pollen flux in g/m3/s

! local definitions
INTEGER :: i,j,k,oneD,kday
REAL, DIMENSION(nx,ny) ::Pfx !holding area
REAL :: pollen_EF  ! emission factor for pollen based on jday
REAL :: relhum  ! relative humidity (0-1, just calculated again)
REAL :: relhum_24h  ! 24h relative humidity
real :: local_e
real :: local_solar_time ! the local solar time 0.0 to 23.99
real :: logit_y1 = 0.05, logit_y2 = 0.95 ! ordinates for the *_x1 and *_x2 values
```

```
real :: prc_x1, prc_x2   ! abcissae where logistic function reaches logit_y1, logit_y2 for precip
real :: prc_alpha, prc_c ! logistic function parameters for precip
real :: prc_logit0       ! ordinate of precip logistic function at prc=0
real :: rh_x1,  rh_x2   ! abcissae where logistic function reaches logit_y1, logit_y2 for rel hum
real :: rh_alpha,  rh_c ! logistic function parameters for rel hum
real :: loc_solar_mu    ! timing of the mean daily pollen release (in fractional hours)
real :: loc_solar_sigma1 ! standard deviation around the mean daily pollen release (in fractional hours)
real :: loc_solar_sigma2
real :: precip_sum_target ! rainfall amount [cm] required to achieve the maximum capacity in terms of pollen emissions
real :: doy_mu    ! mean day-of-year (in fractional days) of the pollen emissions peak
real :: doy_sigma ! standard deviation (in fractional days) around the emissions peak
real :: soy_mu    ! mean second-of-year (in seconds) of the pollen emissions peak
real :: soy_sigma ! standard deviation (in seconds) around the emissions peak
real :: immediate_timing  ! scaling factor for the immediate emissions (between 0 and 1). Essentially the fraction to release.
real :: gross_timing ! scaling factor for the emissions based on phenlology, this varies slowly with time. It take values between 0 and 1. Essentially the fraction to release.
real :: spatial ! the spatial scaling factor
real :: rh_factor
real :: prc_factor
real :: f_wind
real :: hour_factor1, hour_factor2
real :: t2_factor
real :: prc
real :: loss_factor        ! fraction of pollen available lost from plant to wet and dry deposition [0, 1]
real :: available          ! available pollen mass to release
real :: prod               ! amount of pollen produced per timestep
real :: loss               ! amount of pollen lost per timestep
real :: released           ! amount of pollen emitted per timestep
real :: rhour              ! the model time in UTC [fractional hour, i.e. 0 to 23.999]
real :: capacity_limit     ! maximum theoretical production [g/m2]
! parameters
real, parameter :: sqrt_two_pi = 2.506628274631 ! sqrt(2*pi)
real, parameter :: KtoC = 273.15     ! 0 degrees C in degrees Kelvin
real, parameter :: f_stagnant = 0.33 ! suppression factor in stagnant conditions
```

```
  real, parameter :: f_promote  = 0.67 ! promotion factor under windy conditions
  real, parameter :: usatur     = 5.0  ! saturation wind speed [m/s]
  real, parameter :: tsatur     = 15.0 ! saturation temperature
  real, parameter :: T_mid  = 15.0 ! midpoint of temperature factor [C]
  real, parameter :: T_rate = 0.33 ! rate of change in temperature factor at midpoint [1/C], before scaling factor is applied
! maximum theoretical production
  real :: max_capacity !  [g/m2]
  logical ::  first
  real, parameter :: dtstep = 3600.0 ! seconds since last function call (1 hour)

  real :: yday ! day of year
  real, DIMENSION(nx,ny) :: prcpThisDay, prcpPreviousDay ! current & previous days preciption in units of millimeters
  ! local variables
  real :: a0
  real :: b0
  real :: mu
  real :: ydayTest(3)
  integer :: iMinYdayTest
  real :: ydayToUse
  real, parameter :: sigma = 19.



! 1 kg / hectare = 1000 g / (10000 m^2) = 1 g / (10 m^2) = 0.1 g m^{-2}
! 464 kg/hectare = maximum theoretical pollen emission for perennial rye-grass (Smart, Tuddenham, Knox; 1979 ; Aust. J.
Bot. ; V27, pp. 333-342)
  max_capacity = 46.4 !  [g/m2]

  ! Need to convert LST hour into a local time (+10 for Victoria).
   time_zone=150./15.
    IF (CTM_clock_current_LST%hr .LE. (23.-time_zone)) THEN
     local_solar_time=CTM_clock_current_LST%hr + time_zone
    ELSE
     local_solar_time=CTM_clock_current_LST%hr - (time_zone + 1)
    END IF
```

```
  yday = real(CTM_clock_current_LST%jd)

!

!Initialise flux area
  PollenFluxes(:,:)%Poln_1=0.0
  Pfx(:,:)=0.0

! Apply normal distribution with integrated total = 464 kg/hectare as per Smart et al 1979
! depends on julian day, and season being oct 1st (jd 273, day 1) to dec 31st (day 92)
! ignore leap year. From C:\Thunderstorm Asthma\Unit tracer results\equation of normal distribution

  kday=CTM_clock_current_LST%jd - 273  ! this becomes x
  pollen_EF=exp(-0.5*(((kday-46.5)/26.702)**2))*9.53E-8 ! adjusted for 464 kg hec-1

  ! define parameters for the pollen emissions functions (logistic representation)

  ! relative humidity
  rh_x1 = 0.5
  rh_x2 = 0.8
  rh_c = (rh_x1 + rh_x2)/2.0
  rh_alpha = 2 * log((1 - logit_y1)/logit_y1)/(rh_x2 - rh_x1)

  prc_x1 = 0.0
  ! precipitation -
  prc_x2 = 0.5 ! originally in units of cm
  prc_c = (prc_x1 + prc_x2)/2.0
  prc_alpha = 2 * log((1 - logit_y1)/logit_y1)/(prc_x2 - prc_x1)
  prc_logit0 = logistic(0.0, prc_c, -prc_alpha)
  precip_sum_target = 40.0 ! de Morton et al., Int J Biometeorol (2011) 55:613-622, fig 4

  loc_solar_mu = 12.0        ! Smart & Knox, Aust. J. Bot. 1979, 27, 317-331, figure 6 KME - bimodal?
  loc_solar_sigma1 = 2.0      ! Smart & Knox, Aust. J. Bot. 1979, 27, 317-331, figure 6
```

```
  loc_solar_sigma2 = 4.0
    ! this is normalised to take value 1.0 when loc_solar_time == loc_solar_mu
  hour_factor1 = gaussian_pdf(local_solar_time, loc_solar_mu, loc_solar_sigma1) * (loc_solar_sigma1 * sqrt_two_pi)
  hour_factor2 = gaussian_pdf(local_solar_time, loc_solar_mu, loc_solar_sigma2) * (loc_solar_sigma2 * sqrt_two_pi)


  doy_mu    = 319.0 ! de Morton et al., Int J Biometeorol (2011) 55:613-622, fig 1 - KME: SAYS NOV 30th = 334
  doy_sigma = 18.0 ! de Morton et al., Int J Biometeorol (2011) 55:613-622, fig 1
  soy_mu    = doy_mu   *24.0*60.0*60.0 ! convert from day-of-year to second-of-year
  soy_sigma = doy_sigma*24.0*60.0*60.0 ! convert from day-of-year to second-of-year



  first = .true.
  Pfx(i,j)=0.
! fill pointer area in Srate with PollenFlux
  DO k=1,number_pollen_sizes

! fill PollenFlux array
  DO j=1,ny
   DO i=1,nx

     oneD=i+(j-1)*nx  !nxny

       relhum = calc_rel_humid(sfctemp(i,j), sfcpres(i,j), mix_ratio(i,j,1) )
       relhum_24h = calc_rel_humid(tscr_24h(i,j), sfcpres(i,j), SH_24h(i,j) )

       prc = prcpR(i,j) + prcpU(i,j) * 3.6e6 !m/s ->mm/hr *1000*3600

       ! emissions decrease with relative humidity (hence negative rh_alpha)
       rh_factor  = f_stagnant + f_promote * logistic(relhum,  rh_c,  -rh_alpha) ! moderated
       ! rh_factor  = logistic(relhum,  rh_c,  -rh_alpha)

       ! emissions decrease with precipitation (hence negative prc_alpha), also normalise so that no penalty is applied for zero
rainfall
```

```
prc_factor = f_stagnant + f_promote * logistic(prc,prc_c, -prc_alpha)/prc_logit0 ! moderated
! prc_factor = logistic(prc, prc_c, -prc_alpha)/prc_logit0

! temperature factor (follows the wind speed factor)
t2_factor = f_stagnant + f_promote * logistic(sfctemp(i,j) - KtoC, T_mid, T_rate)

! following equation 11 in Sofiev, 2013
f_wind = f_stagnant + f_promote * (1 - exp(-(wspd(i,j))/usatur))

SELECT CASE (pollen_emissions_parameterisation)
 case (1)
   immediate_timing = wspd(i,j)
   gross_timing = pollen_EF
   spatial = pollen_veg(i,j)
   Pfx(i,j) = immediate_timing * gross_timing * spatial
  case (2)
   immediate_timing = wspd(i,j)
   gross_timing = evi_gradient(i,j)
   spatial = pollen_veg(i,j)
   Pfx(i,j) = immediate_timing * gross_timing * spatial
  case (3)
   immediate_timing = wspd(i,j)
   gross_timing = evi_gradient(i,j)
   spatial = 1.0 ! embodied in evi_gradient
   Pfx(i,j) = immediate_timing * gross_timing * spatial
  case (4)
   immediate_timing = hour_factor1 * rh_factor * prc_factor * f_wind * t2_factor
   gross_timing = evi_gradient(i,j)
   spatial = pollen_veg(i,j)
   Pfx(i,j) = immediate_timing * gross_timing * spatial
  case (5)
   immediate_timing = hour_factor1 * rh_factor * prc_factor * f_wind * t2_factor
   gross_timing = pollen_EF
   spatial = pollen_veg(i,j)
```

```
      Pfx(i,j) = immediate_timing * gross_timing * spatial
     case (6)
      immediate_timing = hour_factor2 * rh_factor * prc_factor * f_wind * t2_factor
      gross_timing = pollen_EF
      spatial = pollen_veg(i,j)
      Pfx(i,j) = immediate_timing * gross_timing * spatial

    case (7)
      ! Production-loss model.
      !
      ! emis = available * immediate_timing
      ! available = last_available + production - loss
      ! loss = L(last_available, rain, humidity)
      ! production = capacity * gross_timing
      ! capacity = f'(landuse, prec_sum)
      ! gross_timing = g(temp_sum, lat)
      ! immediate_timing = h(wind, humidity, time_of_day)
      !
      gross_timing = pollen_EF
      immediate_timing = hour_factor2 * rh_factor * prc_factor * f_wind * t2_factor
      ! prc has units mm/hr
      loss_factor = calculate_loss_factor(prc , dtstep)
      capacity_limit = max_capacity
      prod = capacity_limit * pollen_veg(i,j) * gross_timing * dtstep
      loss = last_available( i,j ) * loss_factor
      available = last_available( i,j ) + prod - loss
      released = available * immediate_timing
      Pfx( i,j ) = released
! Note: we don't subtract the loss term ...
      last_available(i,j) = available - released ! .. because it's equivalent to: last_available(i,j) = last_available(i,j) + prod - loss - released

   case (8)
     !shifted Gaussian shapes depending on lon,lat
```

```
immediate_timing = hour_factor2 * rh_factor * prc_factor * f_wind * t2_factor

IF (geoGrid(i,j)%lat .GT. -37.0) THEN
  pollen_EF = exp(-0.5*(((kday-34.65)/15.45)**2))*9.53E-8 ! Bendigo and Dookie

ELSEIF (geoGrid(i,j)%lat .LE. -37.0 .AND. geoGrid(i,j)%lon .GT. 143.5) THEN
   pollen_EF = exp(-0.5*(((kday-50.5)/19.3)**2))*1.2E-7 ! Creswick and Churchill

ELSE
   pollen_EF = exp(-0.5*(((kday-48.1)/7.7)**2))*1.56E-7 ! Hamilton
ENDIF

gross_timing = pollen_EF
spatial = pollen_veg(i,j)
Pfx(i,j) = immediate_timing * gross_timing * spatial

case (9)
prcpThisDay(i,j) = prc *24. ! should be the past 24-hours rainfall [mm]
prcpPreviousDay(i,j) = prc *24. ! should be the previous 24 hours of rainfall [mm]

     Pfx( i,j ) = emitAlaStatisticalModel_v1(EVIfallDaySmoothed(i,j,1), EVIwinterMaxSmoothed(i,j,1),
prcpThisDay(i,j), prcpPreviousDay(i,j), sfctemp(i,j) - KtoC, relhum * 100., U10m(i,j), V10m(i,j),  yday)

case (10)
prcpThisDay(i,j) = prc*24. ! should be the past 24-hours rainfall [mm]
prcpPreviousDay(i,j) = prc*24. ! should be the previous 24 hours of rainfall [mm]

Pfx( i,j ) = emitAlaStatisticalModel_v2(EVIfallDaySmoothed(i,j,1), EVIwinterMaxSmoothed(i,j,1),
prcpThisDay(i,j), prcpPreviousDay(i,j), sfctemp(i,j) - KtoC, relhum * 100., U10m(i,j), V10m(i,j), yday,)

case default
  Pfx( i,j ) = 0.0
end SELECT
```

```
     Srate(oneD,pPN(k))=Srate(oneD,pPN(k))+Pfx(i,j)

!This allows more than one size fraction within poln_1.
! also change the units here from g/m3/s to g/cell area/s while in nxny loop
     PollenFluxes(oneD,k)%poln_1 = Pfx(i,j)/zfull(i,j,1)*dxy(i,j)

   END DO !ny
  END DO !nx

   END DO !pollen size pointer

END SUBROUTINE CTM_pollen_emissions

MODULE CTM_pollen_auxiliary_routines

contains
  !--------------------------------------------------------------------
  !  calculate relative humdity based on water vapour mixing ratio, temperature & pressure
  !--------------------------------------------------------------------
  real function calc_rel_humid(ta, prs, qv)
    implicit none
    ! real :: calc_rel_humid  ! relative humidity, OUTPUT, units = fraction (0-1)
    real, intent(in) :: ta  ! air temperature,    INPUT, units = K
    real, intent(in) :: prs ! pressure,           INPUT, units = PA
    real, intent(in) :: qv  ! water vapor mixing ratio, INPUT, units = kg/kg
    ! constants
    real, parameter  :: vp0   = 611.29 ! vapor press of water at 0 C [ Pa ]
    real, parameter  :: svpt0 = 273.15 ! constant for saturation vapor pressure [K]
    real, parameter  :: mvoma = 0.622  ! ratio of mol. weight of water vapor to mol weight of air [dimensionless]
    ! local variables
    real             :: e_sat ! sat vap pres (Pa) as fn of T (deg K)
    real             :: tempc ! air temperature, units = C
    real             :: qsat  ! sat water vapor mixing ratio, units = kg/kg
    real             :: h2ovp ! ambient water vapor pressure [ Pa ]
```

```
  tempc = ta-svpt0
  e_sat = vp0 * exp( 17.625 * tempc / ( 243.04 + tempc ) )
  !       qsat = e_sat * mvoma / ( prs - e_sat )
  !       rh = qv / qsat
  h2ovp = prs * qv / ( mvoma  + qv )
  calc_rel_humid = MAX( 0.005, MIN( 0.99, h2ovp / e_sat ) )

  return
end function calc_rel_humid

!--------------------------------------------------------------------
!       Logistic function (a smooth approximation to a piecewise-linear ramp between 0 and 1)
!--------------------------------------------------------------------
function logistic(x, c, alpha) result(y)
  implicit none
  real, intent(in) :: x       ! abcissa of the logistic function
  real, intent(in) :: c       ! midpoint (abcissa when ordinate = 0.5)
  real, intent(in) :: alpha   ! rate of increase (dydx(x=c) = 0.25 alpha)
  real             :: y       ! ordinate

  y = 1.0/(1.0 + exp(-alpha*(x-c)))

  return
end function logistic

!--------------------------------------------------------------------
!       A smooth function that approximates y = min(x,1.0)
!--------------------------------------------------------------------
function smooth_ramp(x) result(y)
  implicit none
  ! arguments
  real, intent(in) :: x
  real             :: y
```

```
  ! local parameters
  real, parameter  :: alpha = 10.0     ! smoothness parameter. Increasing alpha means a sharper transition from y=x to y=1.0
  real, parameter  :: c     = 0.999995459903963 ! intercept, c = log(exp(alpha) - 1)/alpha, so that smooth_ramp(0.0) = 0.0

  y = 1 - (1/alpha)*log(1 + exp(alpha*(c - x)))

  ! relationship between alpha and c
  !       0 = 1 - (1/alpha)*log(1 + exp(alpha*c))
  !       1 = (1/alpha)*log(1 + exp(alpha*(c))
  !       alpha = log(1 + exp(alpha*c))
  !       exp(alpha) = 1 + exp(alpha*c)
  !       exp(alpha*c) = exp(alpha) - 1
  !       alpha*c = log(exp(alpha) - 1)
  !       c = log(exp(alpha) - 1)/alpha
  return
end function smooth_ramp

!-------------------------------------------------------------------
!       The Gaussian probability density function
!-------------------------------------------------------------------
function gaussian_pdf(x, mu, sigma) result(fx)
  implicit none
  real, intent(in) :: x      ! the abcissa of the Gaussian distribution PDF
  real, intent(in) :: mu     ! the mean of the Gaussian distribution
  real, intent(in) :: sigma  ! the standard deviation of the Gaussian distribution
  real             :: fx     ! the ordinate of the Gaussian distribution PDF

  ! parameters
  real, parameter  :: sqrt_two_pi = 2.506628274631

  fx = exp( -0.5 * (((x-mu)/sigma)**2)) / (sigma * sqrt_two_pi)

  return
end function gaussian_pdf
```

```
!----------------------------------------------------------------------
! Calculate the loss rate based on exponential decay, accelerated by rainfall
!----------------------------------------------------------------------
function calculate_loss_factor(rain, tstep) result(loss_factor)
  implicit none
  real             :: loss_factor ! output: fraction of pollen available lost from plant to wet and dry deposition [0, 1]
  real,   intent(in) :: rain       ! rain per hour [cm]
  real,   intent(in) :: tstep      ! length of timestep [s]

  real, parameter :: half_life_dry = 2.0 ! pollen assumed to have a half-life of 2 days on the plant in dry conditions
  real, parameter :: half_life_rain = 0.5 ! pollen assumed to have a half-life of 0.5 days on the plant in rainy conditions
  real, parameter :: rain_thresh = 0.2 ! threshold rain rate per hour above which the pollen half-life is set to half_life_rain [cm]
  real, parameter :: ln2 = 0.693147180559945

  real :: half_life
  real :: rain_factor
  real :: lambda ! decay rate
  real :: dt
  real, parameter :: seconds_per_day = 86400.0

  rain_factor = min(rain/rain_thresh,1.0)
  half_life = rain_factor*half_life_rain + (1.0-rain_factor)*half_life_dry
  lambda = ln2/half_life
  dt = tstep/seconds_per_day
  loss_factor = dt*lambda
  ! rain = 0.0            => rain_factor = 0.0 => half_life = half_life_dry
  ! rain = rain_thresh    => rain_factor = 1.0 => half_life = half_life_rain
  ! rain = 0.5*rain_thresh => rain_factor = 0.5 => half_life = 0.5*(half_life_rain + half_life_dry)

  return
end function calculate_loss_factor
```

```
!----------------------------------------------------------------------
! Estimate the seasonal pollen capacity based on the rainfall
!----------------------------------------------------------------------
function capacity_factor(precip_sum, max_capacity, precip_sum_target) result(capacity)
  implicit none
  real, intent(in) :: precip_sum
  real, intent(in) :: max_capacity
  real, intent(in) :: precip_sum_target
  real             :: capacity

  capacity = max_capacity * smooth_ramp(precip_sum/precip_sum_target)

  return
end function capacity_factor

 ! probability density function of the Cauchy distribution
  function dcauchy(x, x0, gamma) result (y)
    implicit none
    ! arguments
    real, intent(in) :: x ! x-value at which to calculate the
    real, intent(in) :: x0 ! location parameter for the distribution
    real, intent(in) :: gamma ! spread parameter for the distribution
    real :: y ! the resulting PDF value
    ! local variables
    real, parameter :: pi = 3.14159265358979

    y =  ( 1.0 / (pi * gamma)) * (gamma**2 / ( (x - x0)**2 + gamma**2 ) )

    return
  end function dcauchy

  ! copied from numerical recipes in F77 (SUBROUTINE LOCATE)
  subroutine find_interval(n,xvals,xtest,idx)
    implicit none
```

```
    ! arguments
    integer, intent(in) :: n
    real, intent(in) :: xvals(n), xtest
    integer, intent(out) :: idx
    ! local variables
    integer :: ilow, imid, iup

    ilow = 0
    iup = n+1
10  if(iup-ilow .gt. 1)then ! If we are not yet done,
      imid=(iup+ilow)/2 ! compute a midpoint,
      if((xvals(n) .ge. xvals(1)) .eqv. (xtest .ge. xvals(imid))) then
        ilow = imid !  and replace either the lower limit
      else
        iup = imid ! or the upper limit, as appropriate.
      endif
      goto 10 ! Repeat until
    endif ! test condition 10 is satisfied.

    if(xtest .eq. xvals(1)) then ! Then set the output
      idx = 1
    else if(xtest.eq.xvals(n))then
      idx = n-1
    else
      idx = ilow
    endif
    return
  end subroutine find_interval

  function emitAlaStatisticalModel_v1(EVIfallDaySmoothed, EVIwinterMaxSmoothed, &
        prcpThisDay, prcpPreviousDay, TM, RH, U10m, V10m, yday,) result(emis)
    implicit none
    ! arguments
    real, intent(in) :: EVIfallDaySmoothed
```

```
real, intent(in) :: EVIwinterMaxSmoothed
real, intent(in) :: prcpThisDay
real, intent(in) :: prcpPreviousDay
real, intent(in) :: TM
real, intent(in) :: RH
real, intent(in) :: U10m, V10m
real, intent(in) :: yday
real :: emis

! local variables
real :: a0
real :: b0
real :: mu

real :: a1
real :: b1
real :: sf

real :: lnsmooth
real :: l1pRN, l1pRNm1upwind

real :: WD, wd2
real :: f5x5, f6x6
integer :: idx
real :: lnFC
real :: TMtest, RHtest
real, parameter :: sigma = 19.
real :: ydayTest(3)
integer :: iMinYdayTest
real :: ydayToUse


! regression coefficients from the EVI fall day to pollen peak day
! MU = (a0 + b0 * EVIfallDaySmoothed(ix,iy)) %% 365
```

```
! ! based on unsmoothed data:
! a0 = 246.679166
! b0 = 0.251085
! ! based on smoothed data:
a0 = 0.0
b0 = 1.0
mu = mod(a0 + b0 * EVIfallDaySmoothed, 365.0)
! regression coefficients from the EVI winter max to the pollen season magnitude
! SF = pmax(a1 + b1 * EVIwinterMaxSmoothed(ix,iy),0)
! ! based on smoothed data:
a1 = -4355.913
b1 = 21490.343
sf = max(a1 + b1 * EVIwinterMaxSmoothed,0.0)

! The following chunk of code determines whether the centre of
! the phenology curve is closest to the day-of-year yday-365,
! yday or yday+365. The ydayToUse is then the value among
! yday-365, yday or yday+365 that is closest to day-of-year 'mu'
! (the centre of the distribution).
ydayTest = (/ abs(yday - 365 - mu), abs(yday - mu), abs(yday + 365 - mu) /)
iMinYdayTest = minloc(ydayTest,1)
ydayToUse = yday + 365.*real(iMinYdayTest - 2)

lnsmooth = log(dcauchy(ydayToUse,mu,sigma)*sf)

! prcpThisDay should be in units of mm
l1pRN = log(1.0+prcpThisDay)

! prcpPreviousDay should be in units of mm
l1pRNm1upwind = log(1.0+prcpPreviousDay)

TMtest = max(min(TM, TM_x(nTMpoints)), TM_x(1))
call find_interval(nTMpoints,TM_x,TMtest,idx)
f5x5 = TM_y(idx)
```

```
  RHtest = max(min(RH, RH_x(nRHpoints)), RH_x(1))
  call find_interval(nRHpoints,RH_x,RHtest,idx)
  f6x6 = RH_y(idx)

     lnFC = -0.290379277 + 0.970041571 * lnsmooth - 0.182604732 * l1pRNm1upwind + &
     & -0.117335246 * l1pRN + f5x5 + f6x6
  emis = exp(lnFC)-1.0

  return
end function emitAlaStatisticalModel_v1

function emitAlaStatisticalModel_v2(EVIfallDaySmoothed, EVIwinterMaxSmoothed, &
   prcpThisDay, prcpPreviousDay, TM, RH, U10m, V10m, yday) result(emis)
  implicit none
  ! arguments
  real, intent(in) :: EVIfallDaySmoothed
  real, intent(in) :: EVIwinterMaxSmoothed
  real, intent(in) :: prcpThisDay
  real, intent(in) :: prcpPreviousDay
  real, intent(in) :: TM
  real, intent(in) :: RH
  real, intent(in) :: U10m, V10m
  real, intent(in) :: yday
  real :: emis

  ! local variables
  real :: a0
  real :: b0
  real :: mu

  real :: a1
  real :: b1
  real :: sf
```

```
real :: lnsmooth
real :: l1pRN,

real :: WD, wd2
integer :: idx
real :: lnFC
real :: TMtest, RHtest
real, parameter :: sigma = 19.
real :: ydayTest(3)
integer :: iMinYdayTest
real :: ydayToUse

real :: RH2test, sRH2val
real :: TM4test, sTM4val
real :: RNtest, sRNval

real :: WS3


! regression coefficients from the EVI fall day to pollen peak day
! MU = (a0 + b0 * EVIfallDaySmoothed(ix,iy)) %% 365
! ! based on smoothed data:
a0 = 181. + 21.477641
b0 = 0.384697
mu = mod(a0 + b0 * EVIfallDaySmoothed, 365.0)
! regression coefficients from the EVI winter max to the pollen season magnitude
! SF = pmax(a1 + b1 * EVIwinterMaxSmoothed(ix,iy),0)
! ! based on smoothed data:
a1 = 267.6271
b1 = 8853.9903
sf = min(max(a1 + b1 * EVIwinterMaxSmoothed, 0.0), 1.5*6894.355)

! The following chunk of code determines whether the centre of
```

```
    ! the phenology curve is closest to the day-of-year yday-365,
    ! yday or yday+365. The ydayToUse is then the value among
    ! yday-365, yday or yday+365 that is closest to day-of-year 'mu'
    ! (the centre of the distribution).
    ydayTest = (/ abs(yday - 365 - mu), abs(yday - mu), abs(yday + 365 - mu) /)
    iMinYdayTest = minloc(ydayTest,1)
    ydayToUse = yday + 365.*real(iMinYdayTest - 2)

    lnsmooth = log(dcauchy(ydayToUse,mu,sigma)*sf)

    WS3 = sqrt(U10m**2 + V10m**2)

    RH2test = max(min(RH, RH2_x(nRH2points)), RH2_x(1))
    call find_interval(nRH2points,RH2_x,RH2test,idx)
    sRH2val = RH2_y(idx)

    TM4test = max(min(TM, TM4_x(nTM4points)), TM4_x(1))
    call find_interval(nTM4points,TM4_x,TM4test,idx)
    sTM4val = TM4_y(idx)

    RNtest = max(min(prcpThisDay, RN_x(nRNpoints)), RN_x(1))
    call find_interval(nRNpoints,RN_x,RNtest,idx)
    sRNval = RN_y(idx)

    lnFC = 1.225480027 + 0.769707046 * lnsmooth - 0.032793100 * WS3 + sRH2val + sTM4val + sRNval

    emis = exp(lnFC)-1.0

    return
  end function emitAlaStatisticalModel_v2

END MODULE CTM_pollen_auxiliary_routines
```