Are we breaking the EMEP model?
Unexpected results from local land use changes

Janice Scheffler, Alice Fitch, Danial Owen,
Massimo Vieno, Eiko Nemitz, Laurence Jones

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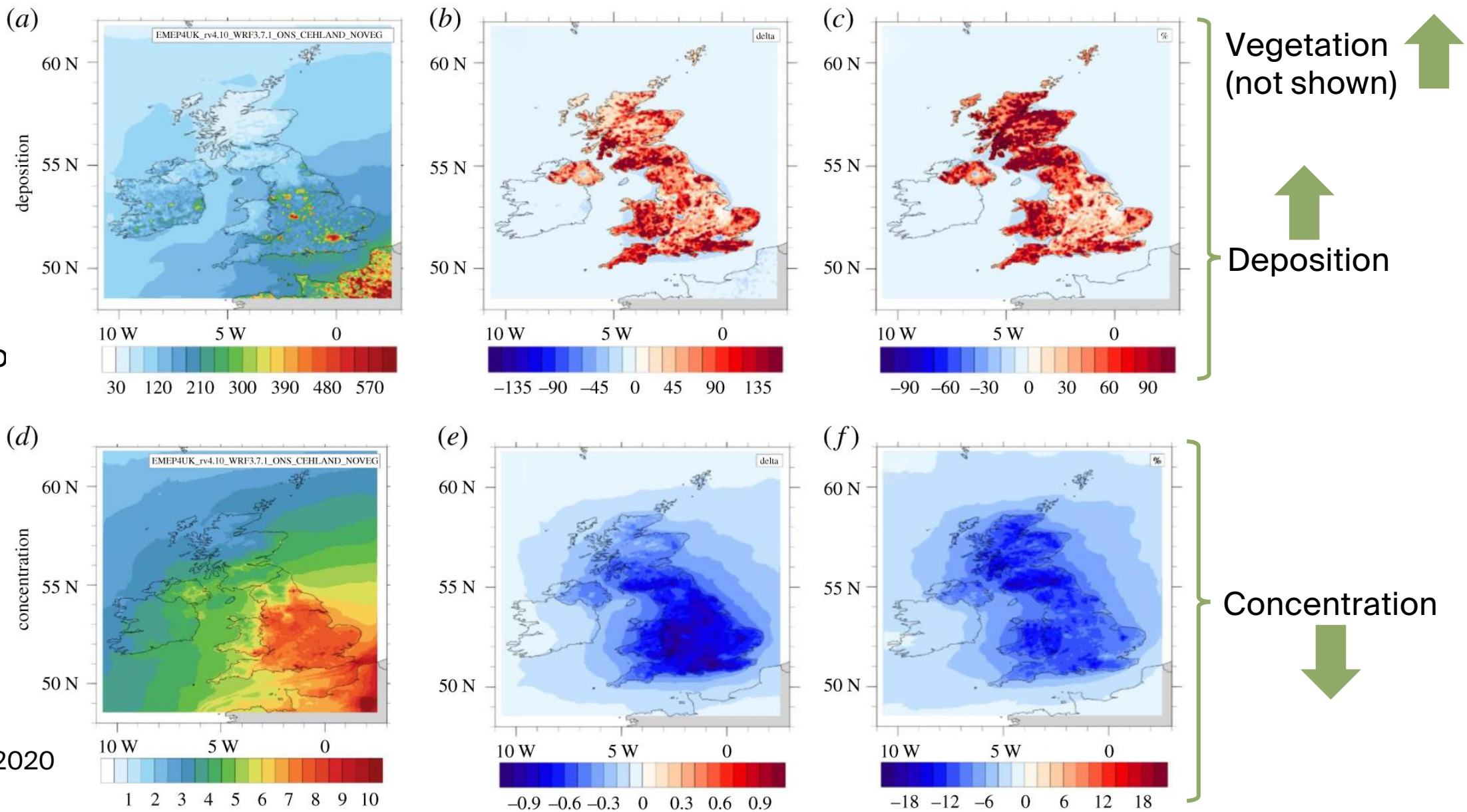
27th EMEP TFMM meeting

UKCEH Our planet. Decoded.

EMEPrv4.10
5 × 6 km²

For 2015

NoVEG:
all UK vegetation land cover converted to desert

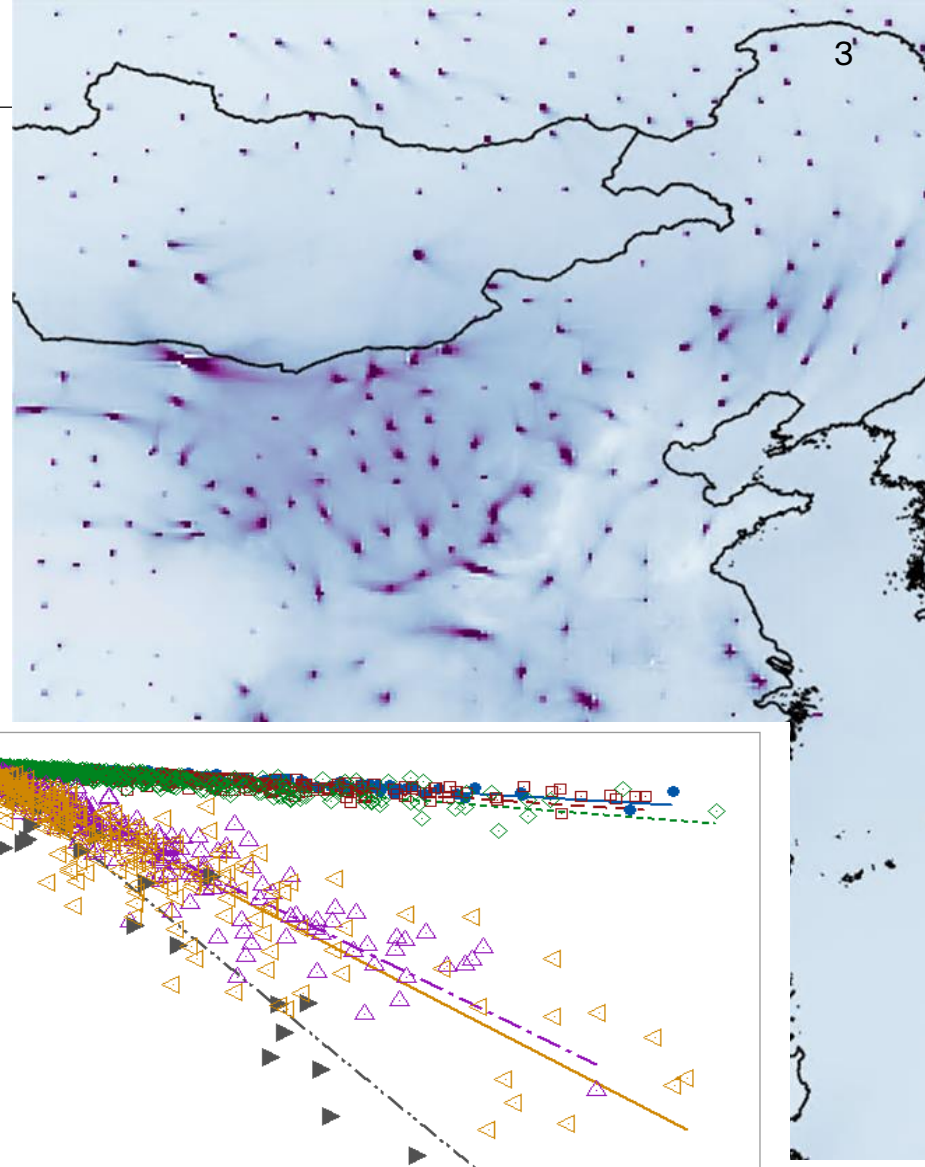


Nemitz et al., 2020

Scenario design to create bespoke meta-models

Selectively manipulate land cover in central cells to:

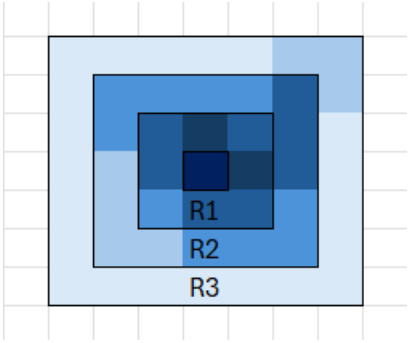
1. Extract role of e.g. tree cover, grassland on $PM_{2.5}$ concentrations
2. Separately calculate distance of 'transferred benefit'



Effect of scenario comparison over East Asia …

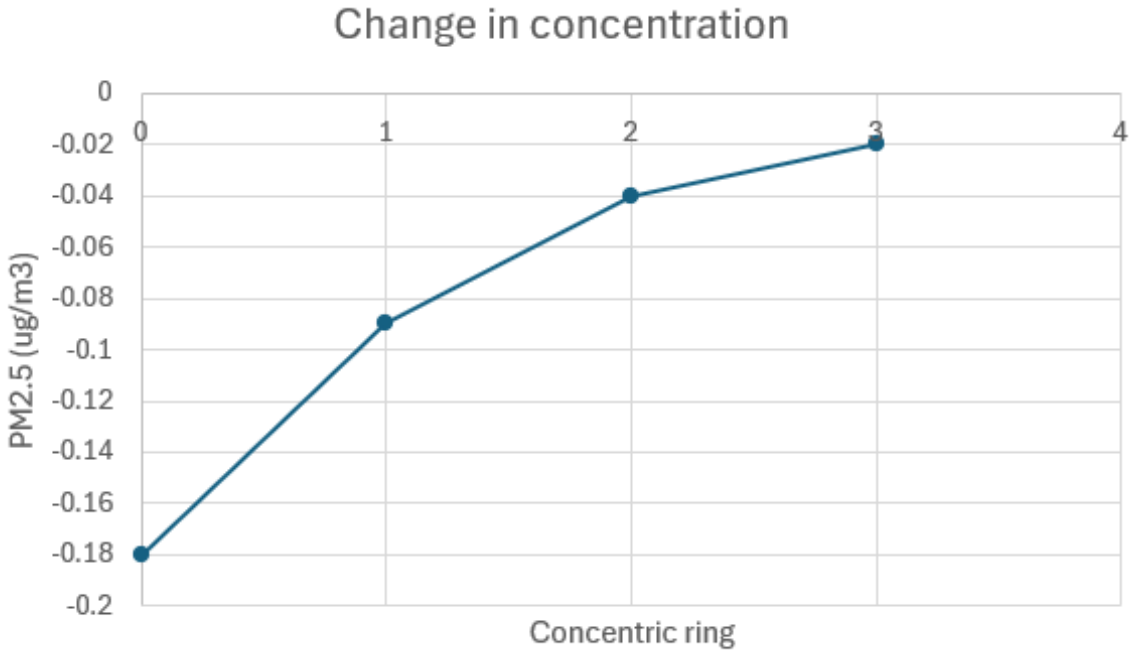
& resulting equations, using central cell results, for role of land cover in reducing $PM_{2.5}$

Calculating distance of 'transported benefits', i.e. how much does an intervention benefit neighbouring areas?



Expected effect (illustrated using dummy data):

1. Reduction of $PM_{2.5}$ due to e.g. trees is greatest in central cell
2. Some reduction of $PM_{2.5}$ in neighbouring cells, reducing with distance
3. (Likely to see directional effects from dominant pollution direction)



Our Setup: Meteorology

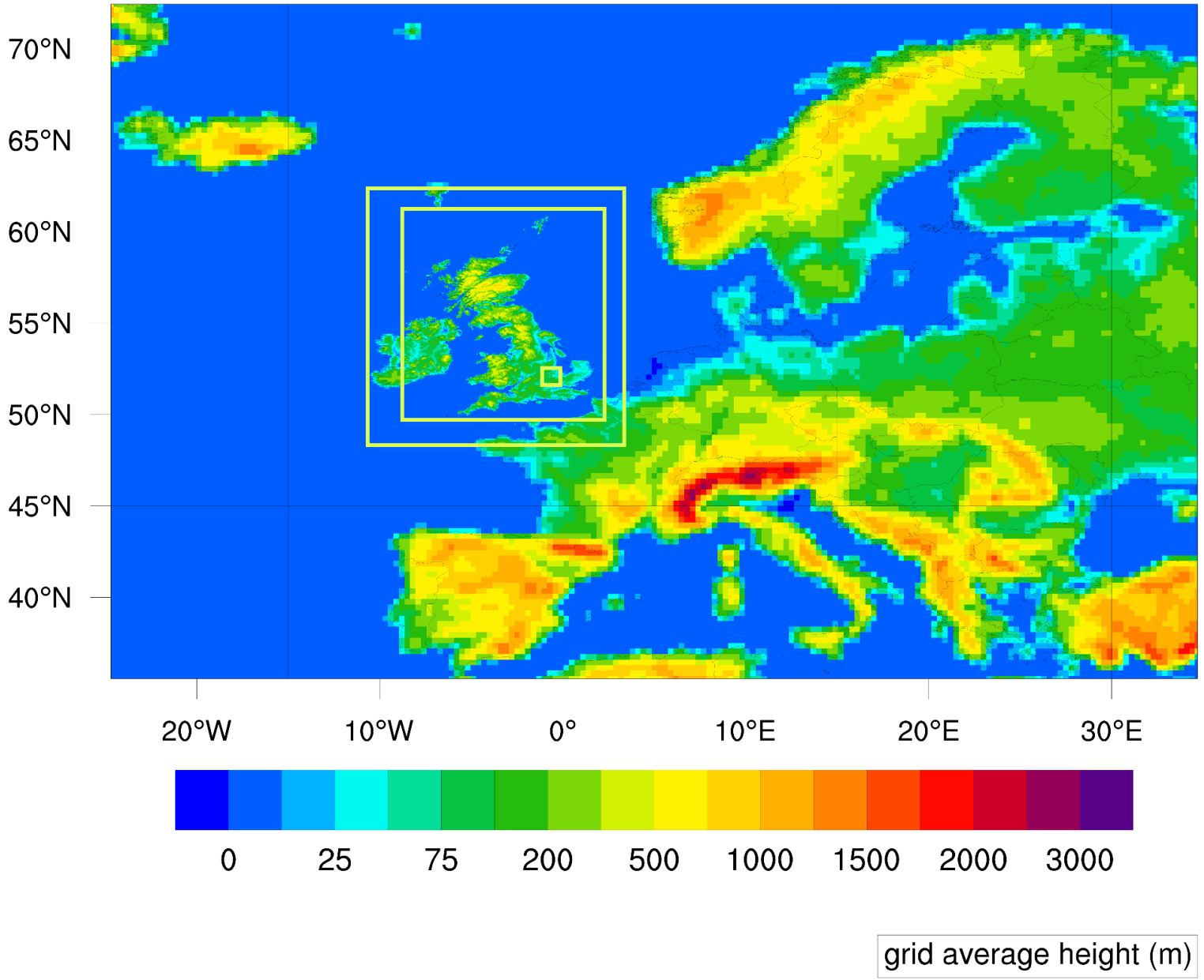
WRF4.4.2 (Skamarock et al., 2019) for 2021 nudged to ERA5

Projection: lat lon

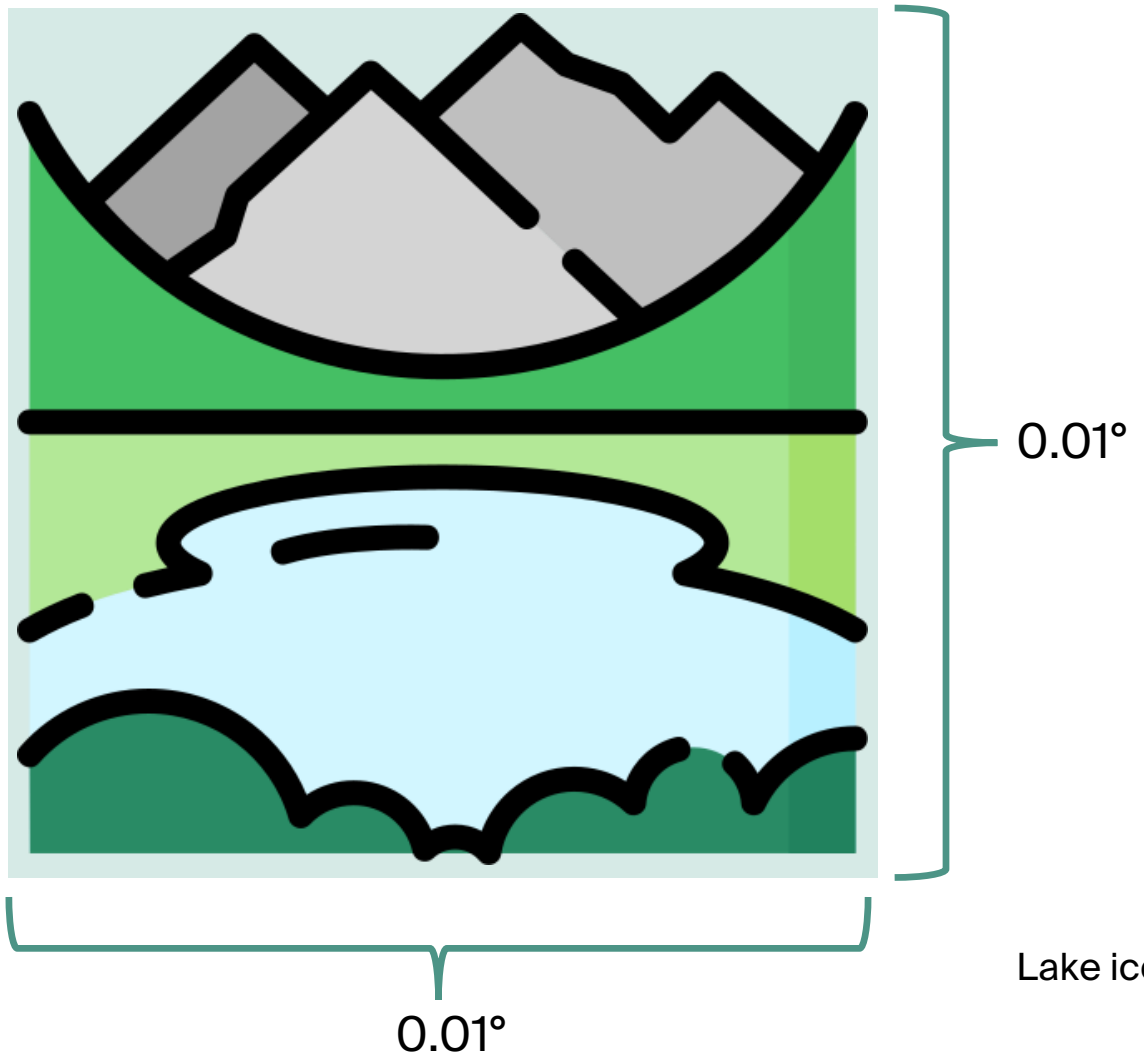
Using WRF for dynamic downscaling of meteorology

EU ~ 0.3° x 0.3°
BI ~ 0.1° x 0.1°
UK ~ 0.03° x 0.03°
BD ~ 0.01° x 0.01°
~ 1.1 km x 0.8 km

WRF output used to drive EMEP rv5.0 (Simpson et al., 2012; Vieno et al., 2016)



Mosaic approach for sub-grid variability

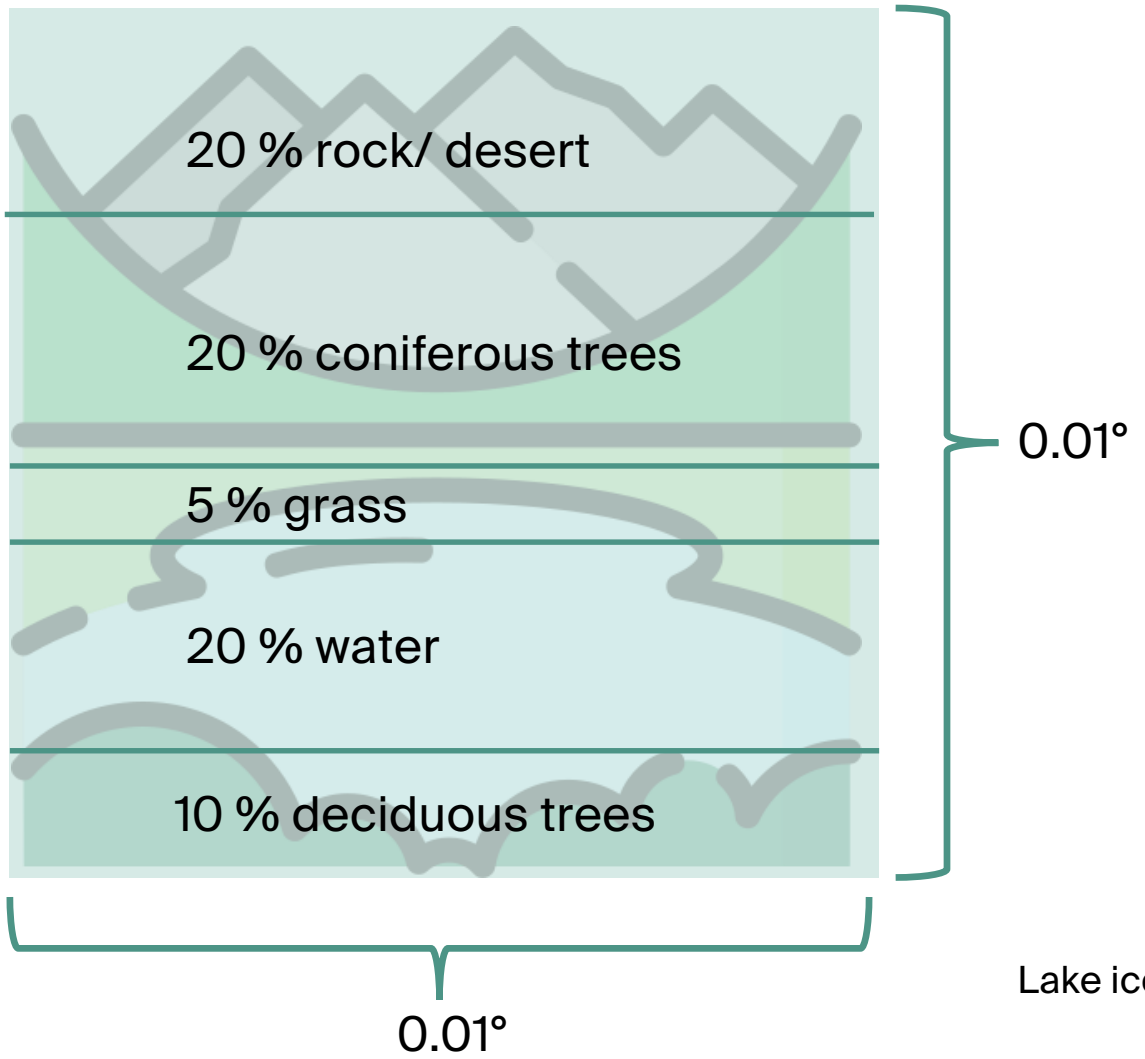


Model calculates grid average values valid for the horizontal grid

Mosaic approach can be used to represent variability within the grid cell

Lake icons created by Freepik - Flaticon

Mosaic approach for sub-grid variability



Model calculates grid average values valid for the horizontal grid

Mosaic approach can be used to represent variability within the grid cell

Deposition velocity V_g calculated per land cover k, then summed up per grid using land cover fraction f_k for compound *i*

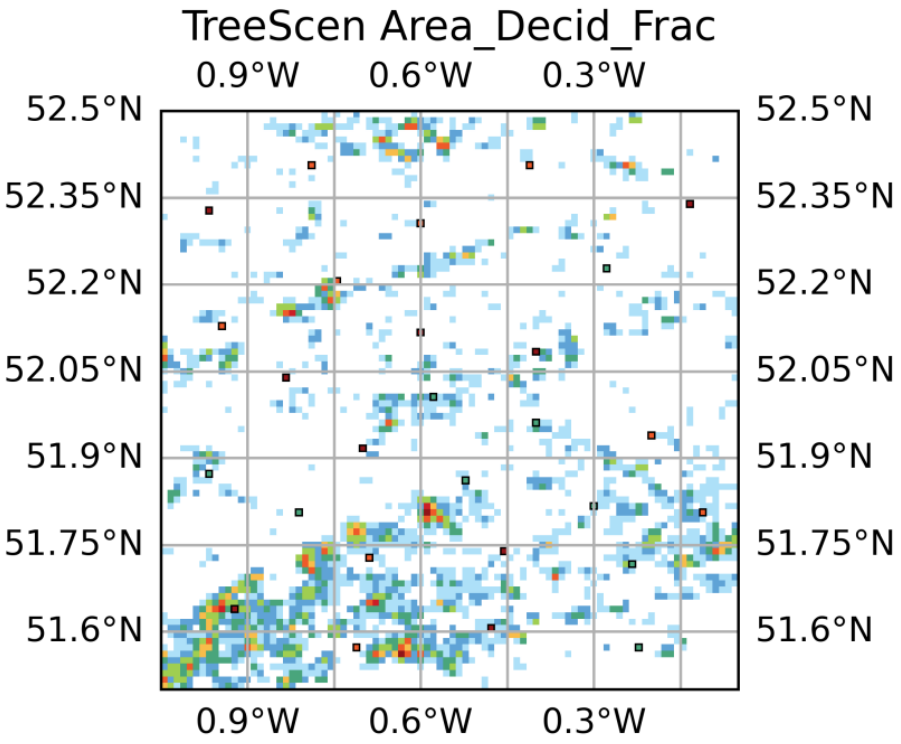
$$\widetilde{V}_{\mathrm{g}}^{i}(z) = \sum_{k=1}^{N} f_k \; V_{\mathrm{g},k}^{i}(z)$$

Lake icons created by Freepik - Flaticon

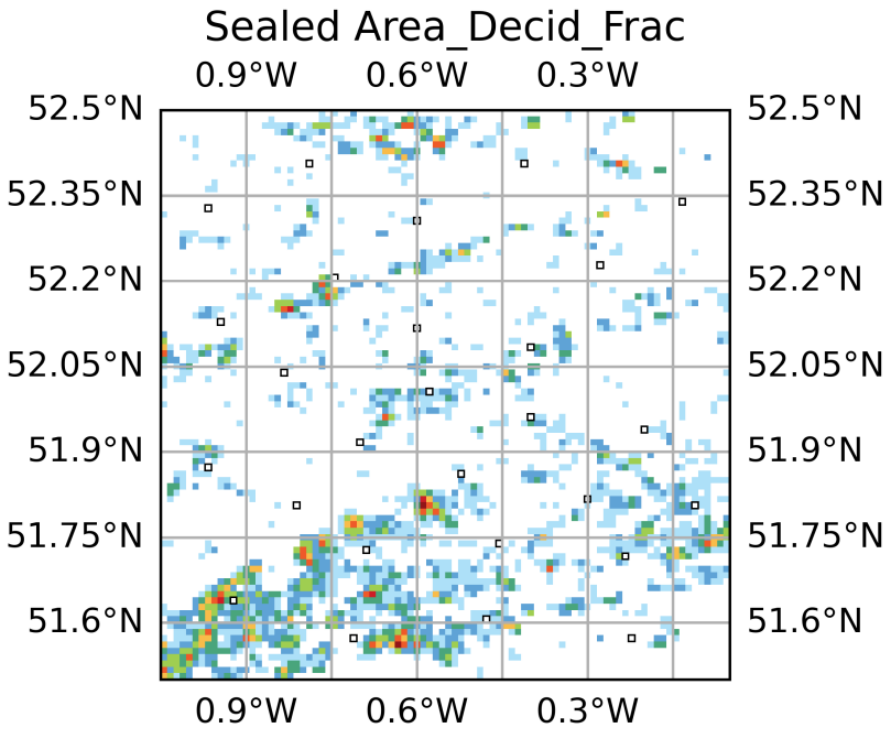
Land cover scenarios

Changing land cover (LC) in specific grid boxes
All sealed bare land (~ desert) ➔ … ➔ all deciduous trees

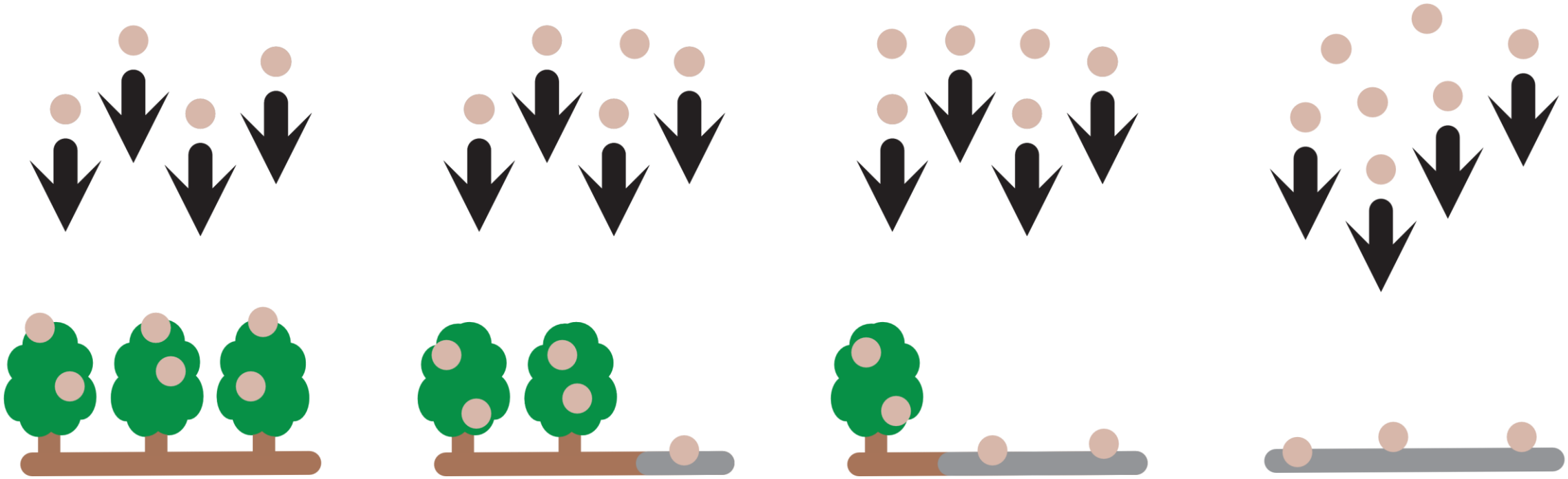
Tree Scenario



Sealed Scenario



Different grid boxes with different ratios of LC



All tree

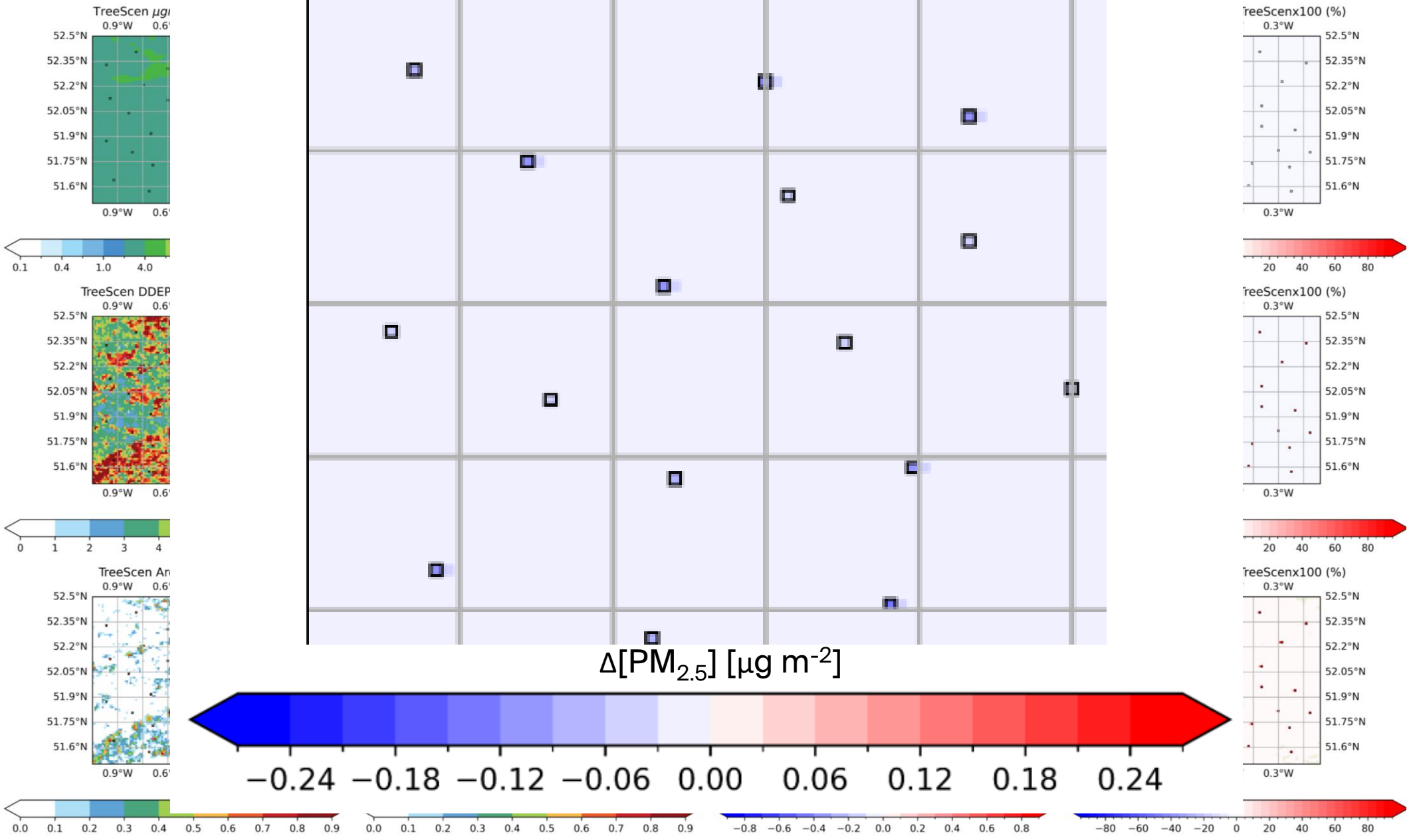
2/3 tree cover
1/3 sealed bare land

1/3 tree cover
2/3 sealed bare land

All sealed bare land
= desert but w/o
re-suspension

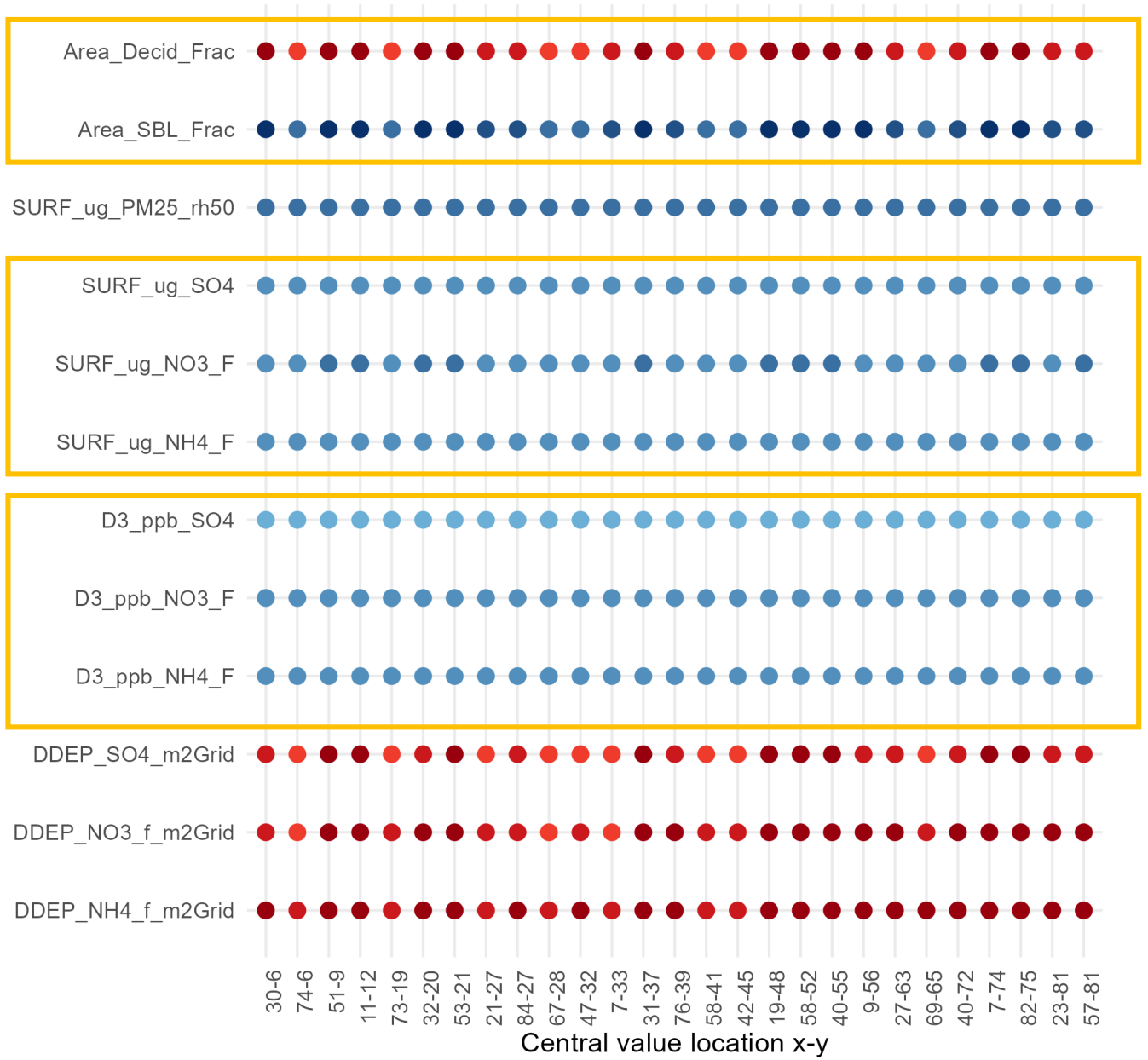
Tree Scenario: different grid boxes – different ratios

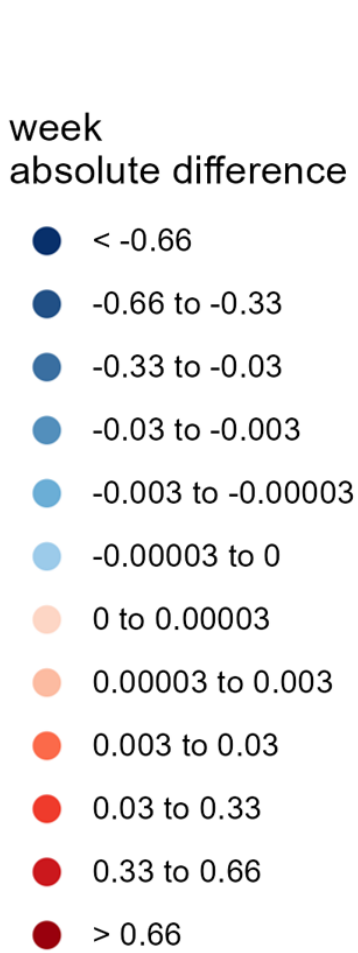
Sealed Scenario

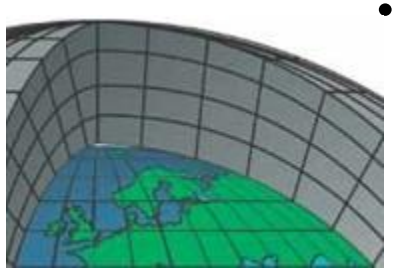

TreeScen μg
TreeScen DDEP
TreeScen Ar
TreeScenx100 (%)
TreeScenx100 (%)
TreeScenx100 (%)
0.9°W
0.3°W
52.5°N
52.35°N
52.2°N
52.05°N
51.9°N
51.75°N
51.6°N
0.1 0.4 1.0 4.0
0 1 2 3 4
20 40 60 80
Δ[PM2.5] [μg m-2]
−0.24 −0.18 −0.12 −0.06 0.00 0.06 0.12 0.18 0.24
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
−0.8 −0.6 −0.4 −0.2 0.0 0.2 0.4 0.6 0.8
−80 −60 −40 −20 0 20 40 60 80

May

$PM_{2.5}$ = SO_4 + $NO_{3,f}$ + $NH_{4,f}$ + ...





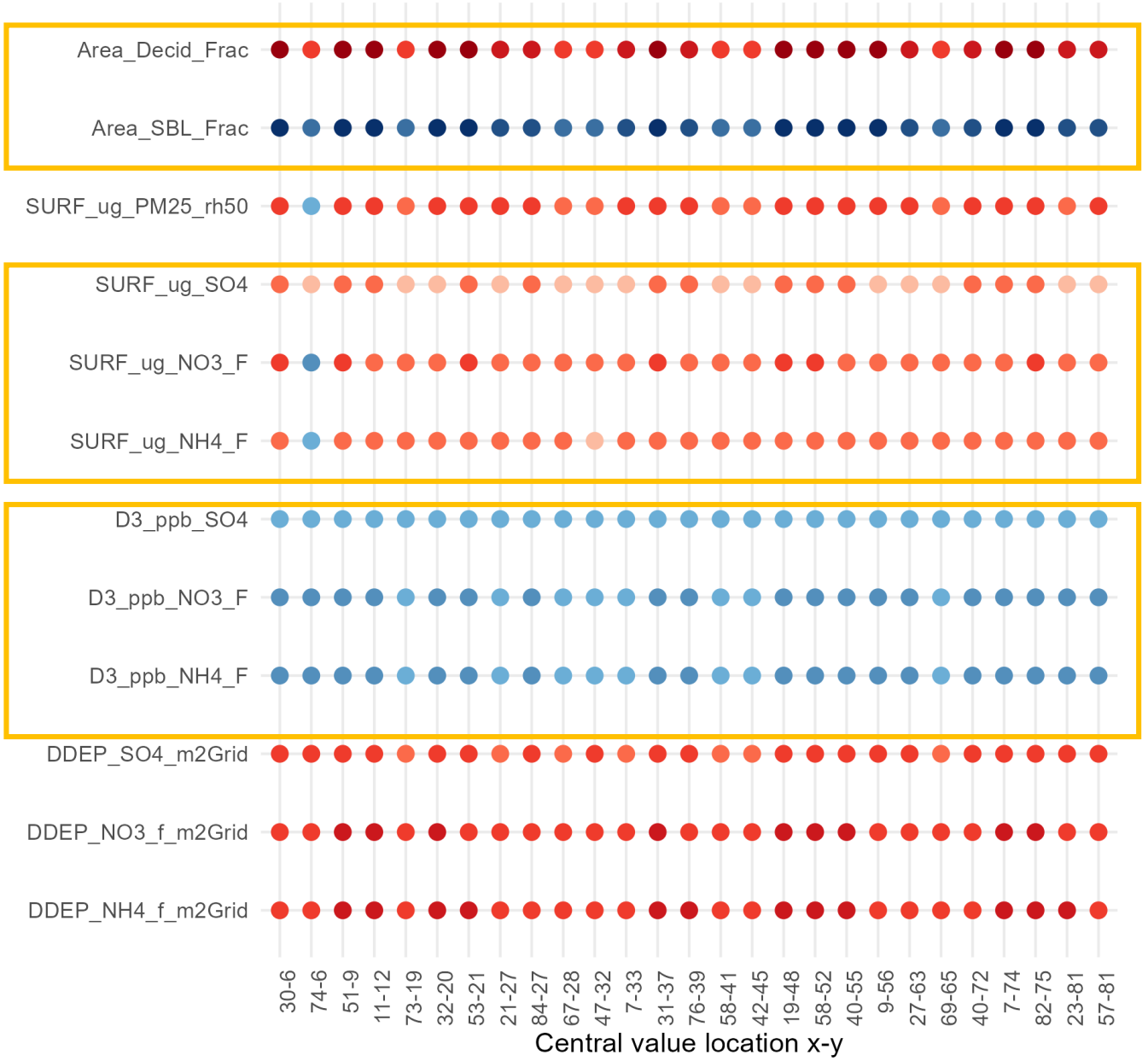


More trees

✓ Lower surface concentration

✓ Lower concentration in lowest level

Nov

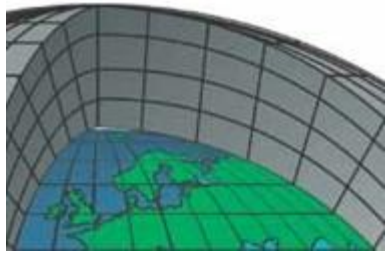


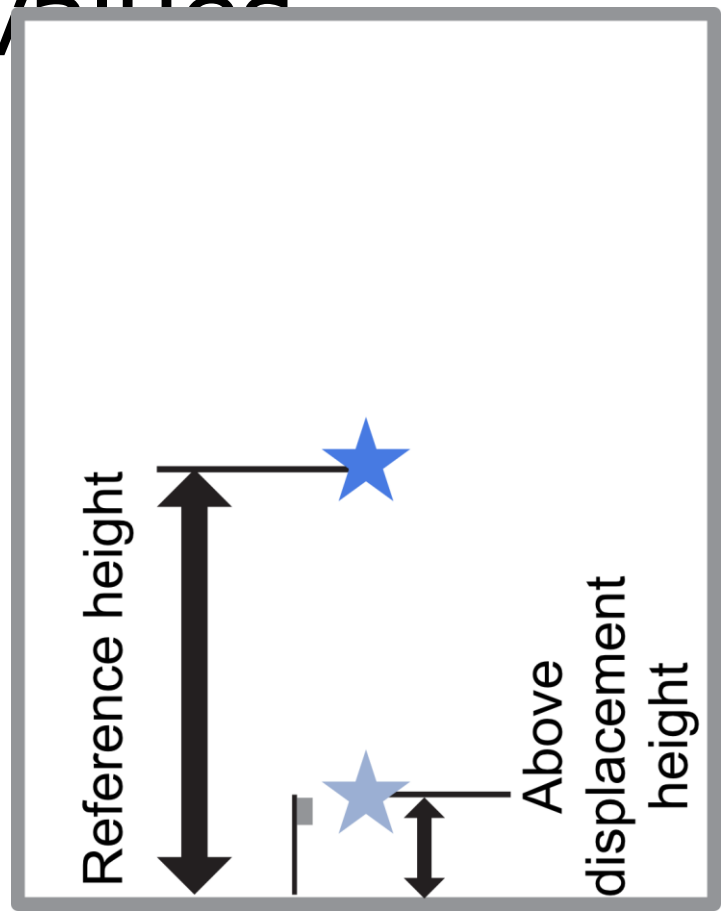
More trees

✗higher surface concentration???

✓Lower concentration in lowest level

From 3D values to surface values

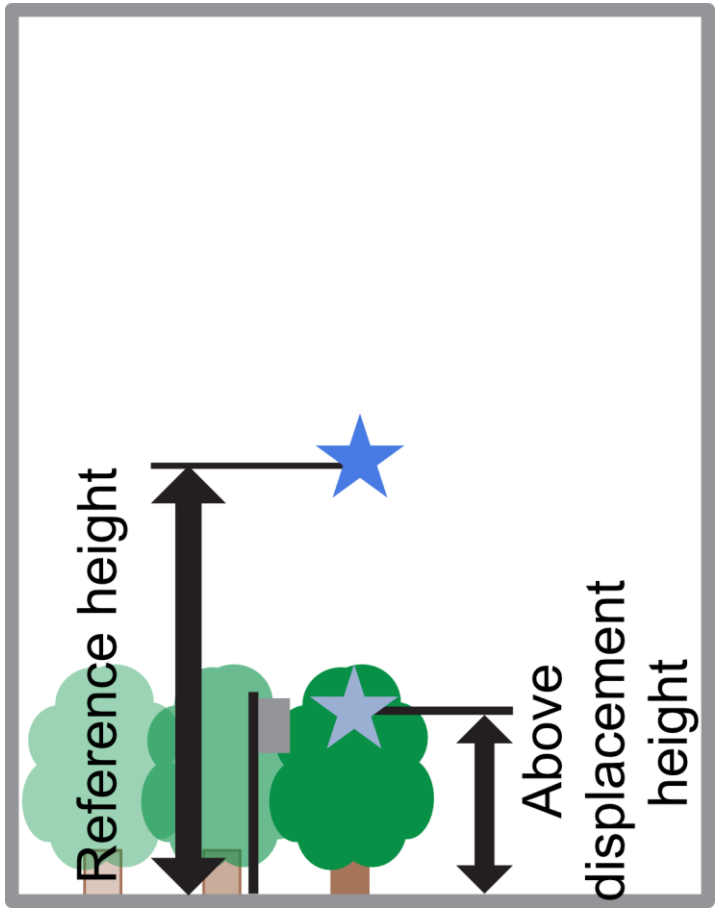




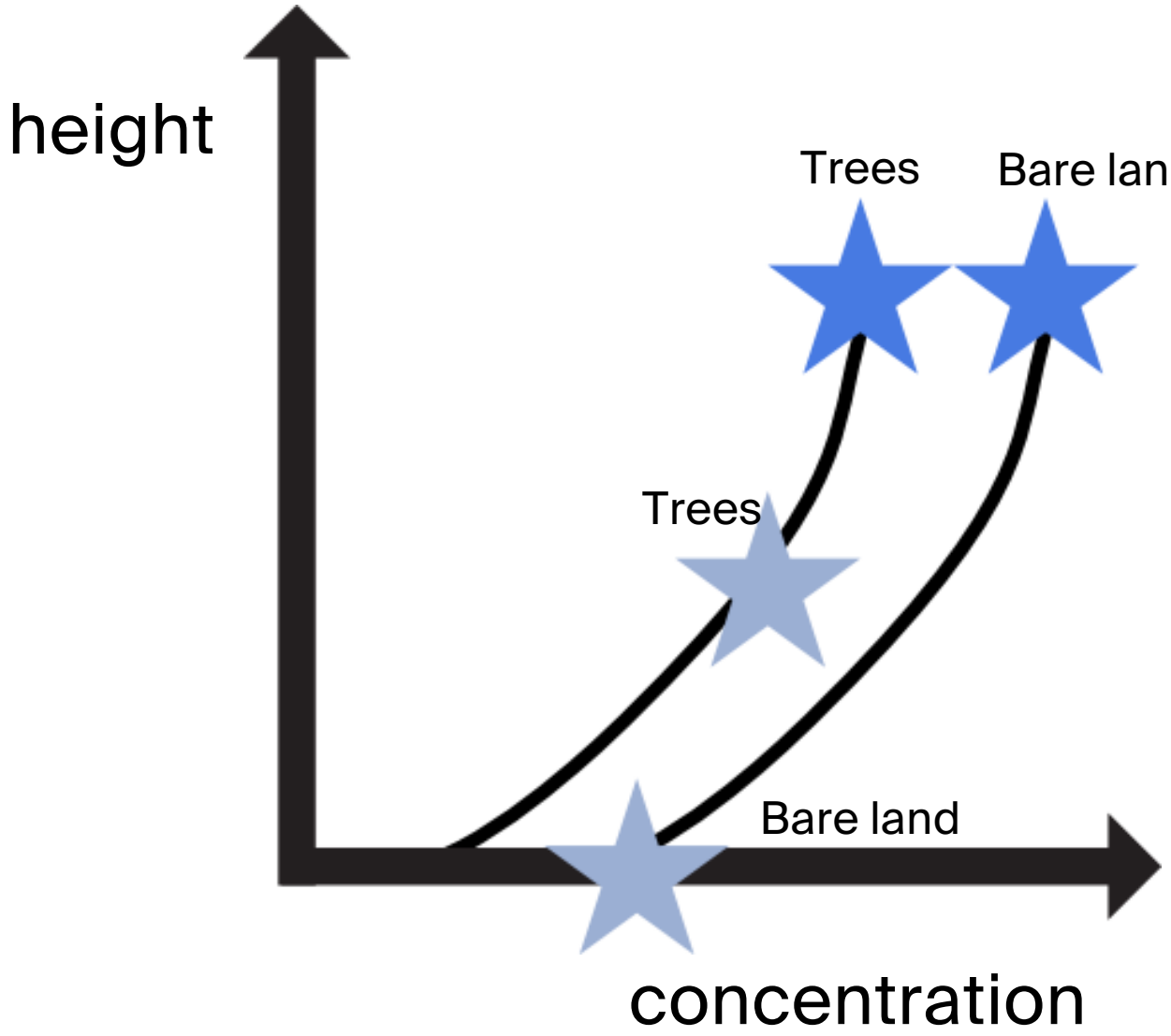
$$\chi^i(z) = \chi^i(z_{\text{ref}}) \frac{V_g^i(z_{\text{ref}})}{V_g^i(z)}$$

Extrapolated surface concentration =
3 m above displacement height d
$d = 0.7 * h_{veg}$

Vegetation height h_{veg}
Trees: 17 m
Sealed bare land: 0 m



Comparing results with different land covers



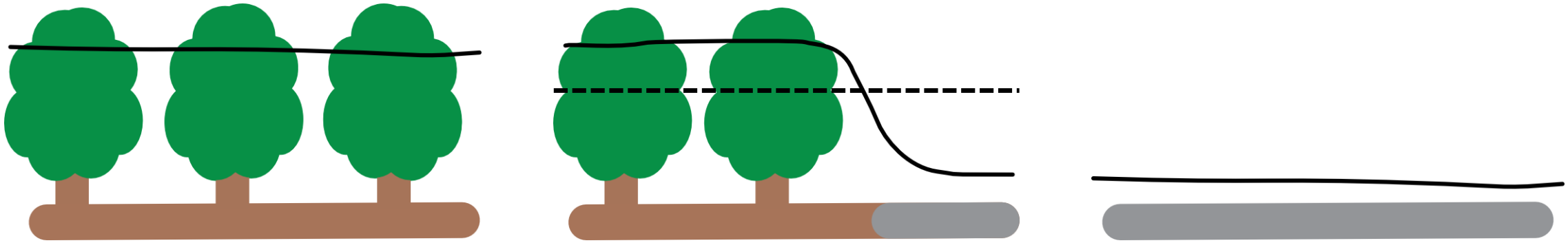
Mid-level concentration ~ 25 m

Surface concentration

Concentration at surface is valid for different heights

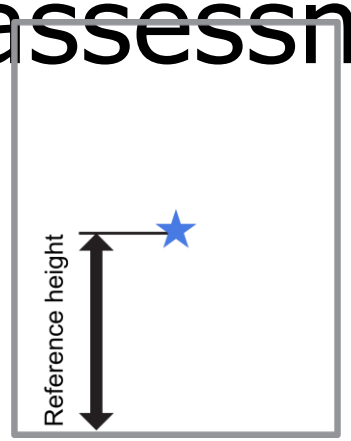
- useful for comparison with measurement
- useful for impact on vegetation
- not useful for impact on human health?

Grid cells with multiple land cover types



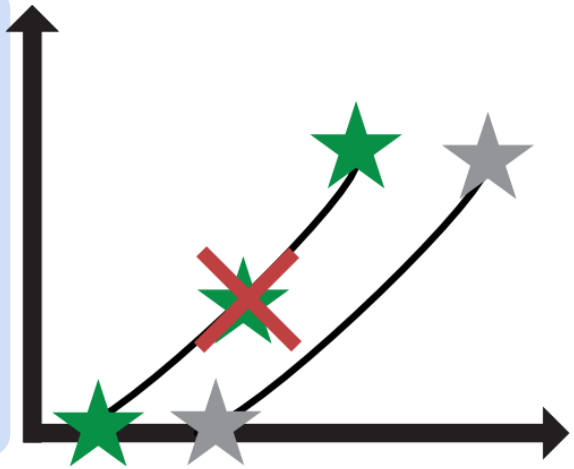
- The effect of extrapolation to surface concentration less pronounced with a mix of land cover classes in a grid cell
  => effect may be masked when large scale land covers are applied
- Our setup with extreme changes in land cover in single grid cells highlights the effect

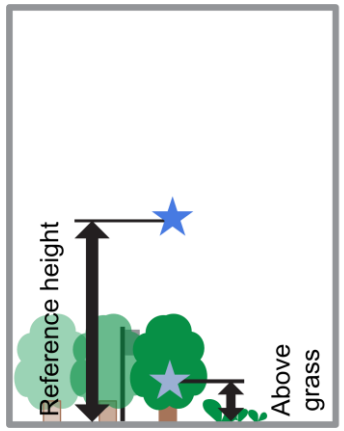
What best to do human impact assessment?



Use middle of lowest grid cell – other models don't extrapolate to surface either

Extrapolate concentration over trees to surface using Vg over trees?





Extrapolate to the ground using single landcover type more relevant to where people live, e.g. grass?

Any other idea?

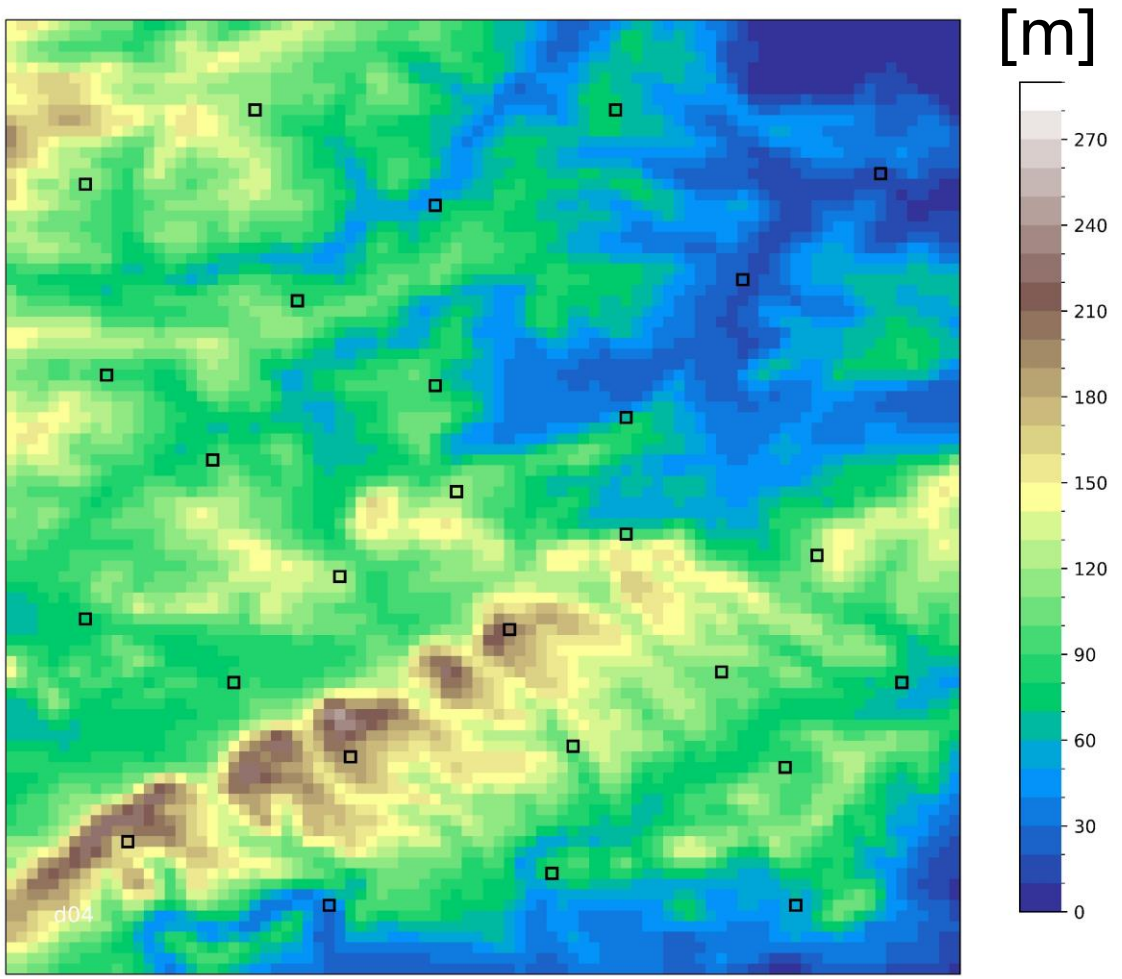
Thank you!

Any ideas? Please email me:

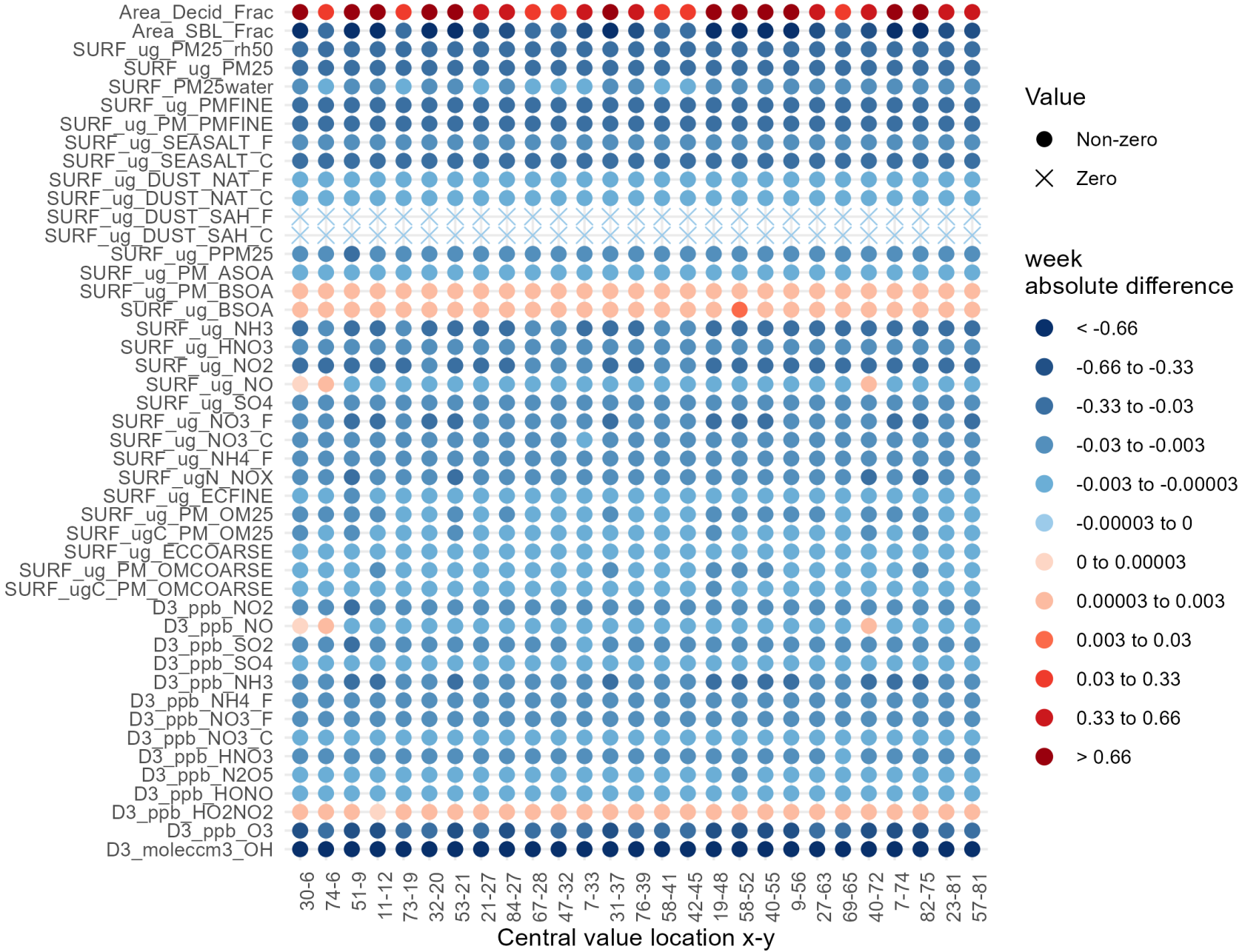
jansch@ceh.ac.uk

UKCEH Our planet. Decoded.

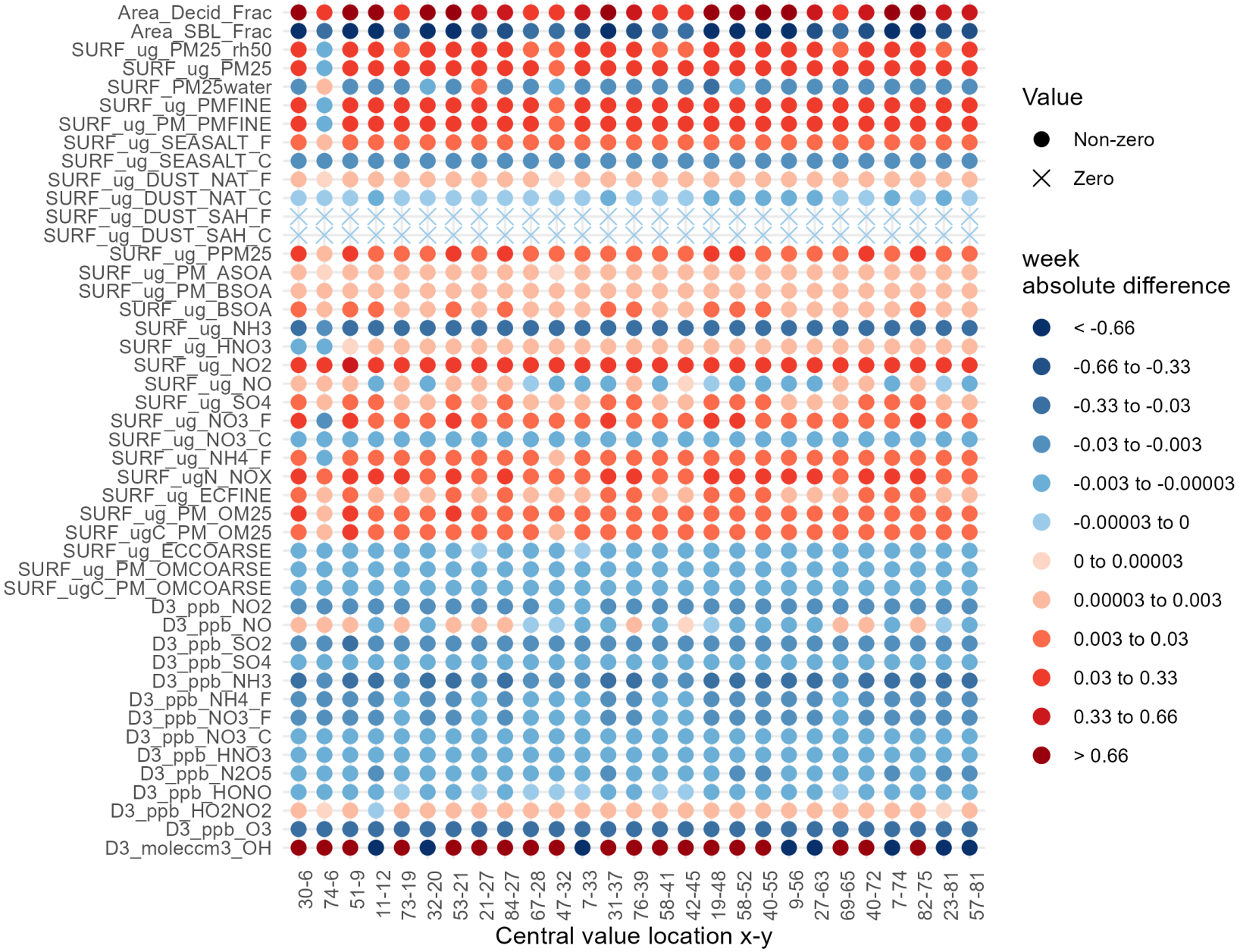
Elevation in innermost domain (BD)



May


Area_Decid_Frac
Area_SBL_Frac
SURF_ug_PM25_rh50
SURF_ug_PM25
SURF_PM25water
SURF_ug_PMFINE
SURF_ug_PM_PMFINE
SURF_ug_SEASALT_F
SURF_ug_SEASALT_C
SURF_ug_DUST_NAT_F
SURF_ug_DUST_NAT_C
SURF_ug_DUST_SAH_F
SURF_ug_DUST_SAH_C
SURF_ug_PPM25
SURF_ug_PM_ASOA
SURF_ug_PM_BSOA
SURF_ug_BSOA
SURF_ug_NH3
SURF_ug_HNO3
SURF_ug_NO2
SURF_ug_NO
SURF_ug_SO4
SURF_ug_NO3_F
SURF_ug_NO3_C
SURF_ug_NH4_F
SURF_ugN_NOX
SURF_ug_ECFINE
SURF_ug_PM_OM25
SURF_ugC_PM_OM25
SURF_ug_ECCOARSE
SURF_ug_PM_OMCOARSE
SURF_ugC_PM_OMCOARSE
D3_ppb_NO2
D3_ppb_NO
D3_ppb_SO2
D3_ppb_SO4
D3_ppb_NH3
D3_ppb_NH4_F
D3_ppb_NO3_F
D3_ppb_NO3_C
D3_ppb_HNO3
D3_ppb_N2O5
D3_ppb_HONO
D3_ppb_HO2NO2
D3_ppb_O3
D3_moleccm3_OH
30-6
74-6
51-9
11-12
73-19
32-20
53-21
21-27
84-27
67-28
47-32
7-33
31-37
76-39
58-41
42-45
19-48
58-52
40-55
9-56
27-63
69-65
40-72
7-74
82-75
23-81
57-81
Central value location x-y
Value
Non-zero
Zero
week
absolute difference
< -0.66
-0.66 to -0.33
-0.33 to -0.03
-0.03 to -0.003
-0.003 to -0.00003
-0.00003 to 0
0 to 0.00003
0.00003 to 0.003
0.003 to 0.03
0.03 to 0.33
0.33 to 0.66
> 0.66

Nov


Area_Decid_Frac
Area_SBL_Frac
SURF_ug_PM25_rh50
SURF_ug_PM25
SURF_PM25water
SURF_ug_PMFINE
SURF_ug_PM_PMFINE
SURF_ug_SEASALT_F
SURF_ug_SEASALT_C
SURF_ug_DUST_NAT_F
SURF_ug_DUST_NAT_C
SURF_ug_DUST_SAH_F
SURF_ug_DUST_SAH_C
SURF_ug_PPM25
SURF_ug_PM_ASOA
SURF_ug_PM_BSOA
SURF_ug_BSOA
SURF_ug_NH3
SURF_ug_HNO3
SURF_ug_NO2
SURF_ug_NO
SURF_ug_SO4
SURF_ug_NO3_F
SURF_ug_NO3_C
SURF_ug_NH4_F
SURF_ugN_NOX
SURF_ug_ECFINE
SURF_ug_PM_OM25
SURF_ugC_PM_OM25
SURF_ug_ECCOARSE
SURF_ug_PM_OMCOARSE
SURF_ugC_PM_OMCOARSE
D3_ppb_NO2
D3_ppb_NO
D3_ppb_SO2
D3_ppb_SO4
D3_ppb_NH3
D3_ppb_NH4_F
D3_ppb_NO3_F
D3_ppb_NO3_C
D3_ppb_HNO3
D3_ppb_N2O5
D3_ppb_HONO
D3_ppb_HO2NO2
D3_ppb_O3
D3_moleccm3_OH
30-6
74-6
51-9
11-12
73-19
32-20
53-21
21-27
84-27
67-28
47-32
7-33
31-37
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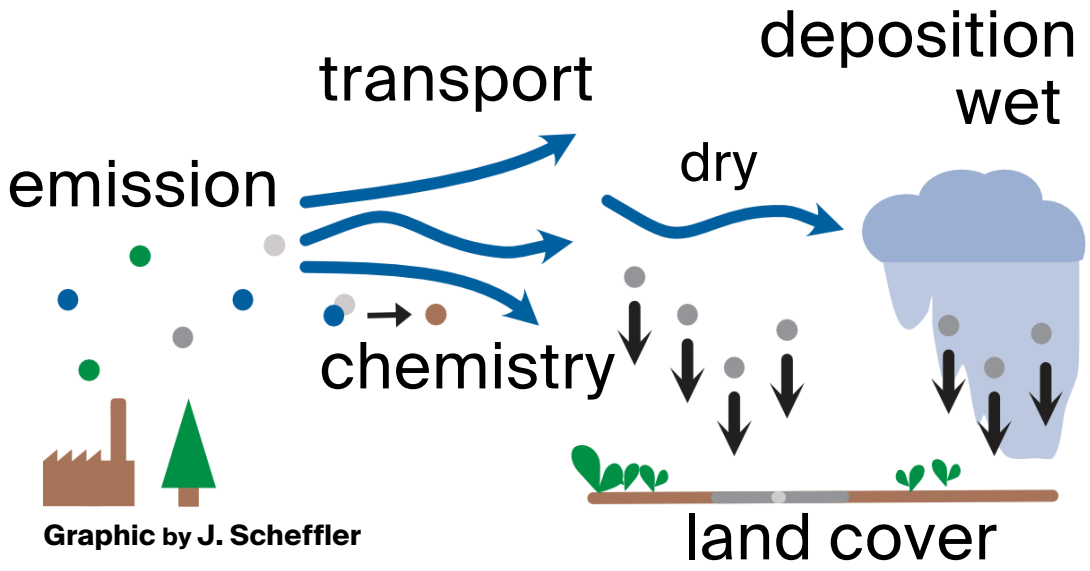
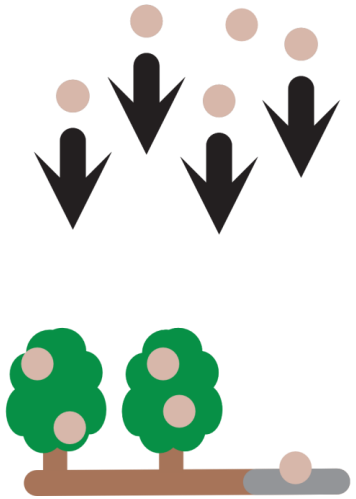
9-56
27-63
69-65
40-72
7-74
82-75
23-81
57-81
Central value location x-y
Value
Non-zero
Zero
week
absolute difference
< -0.66
-0.66 to -0.33
-0.33 to -0.03
-0.03 to -0.003
-0.003 to -0.00003
-0.00003 to 0
0 to 0.00003
0.00003 to 0.003
0.003 to 0.03
0.03 to 0.33
0.33 to 0.66
> 0.66

What impact does land cover have on air quality?

Atmospheric chemistry transport model

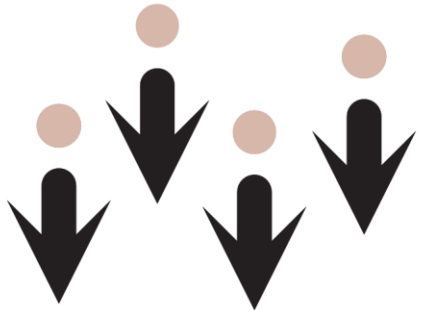


Depending on land cover more or less pollution can be removed from the atmosphere

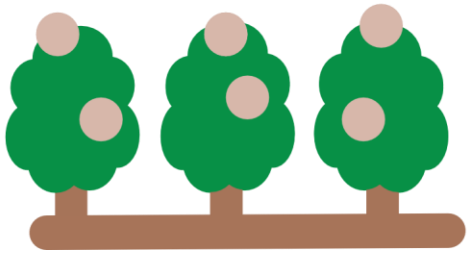


Pollution removal by dry deposition

concentration



deposition



All tree

concentration

deposition

All sealed bare land
= desert but w/o
re-suspension

Dry deposition in EMEP

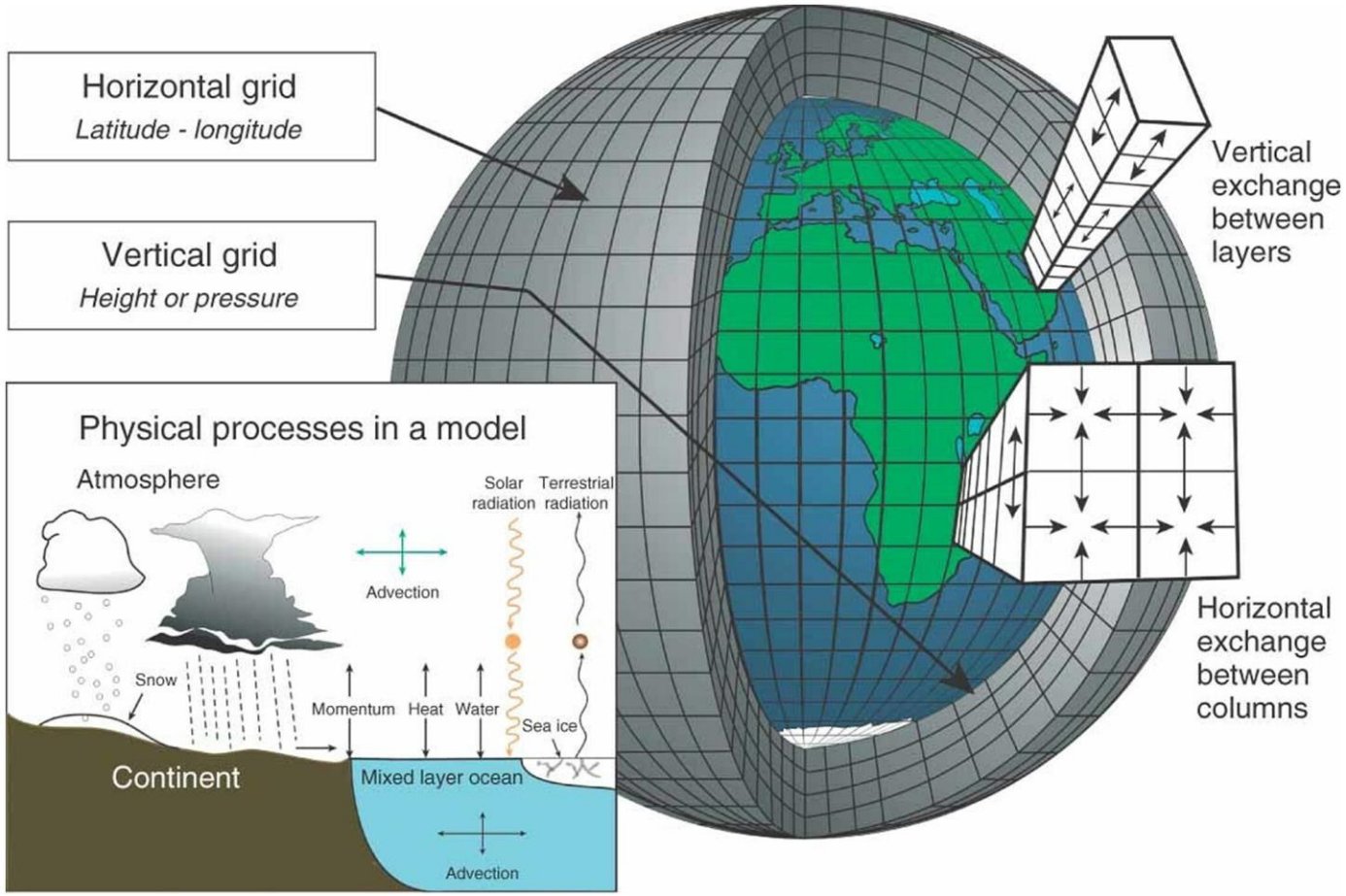
For particles, EMEP uses non-electrical-analogy formulation after Venkatram & Pleim (1999)

$$v_{\mathrm{d}} = \frac{v_{\mathrm{s}}}{(1 - \mathrm{e}^{-rv_{\mathrm{s}}})}.$$

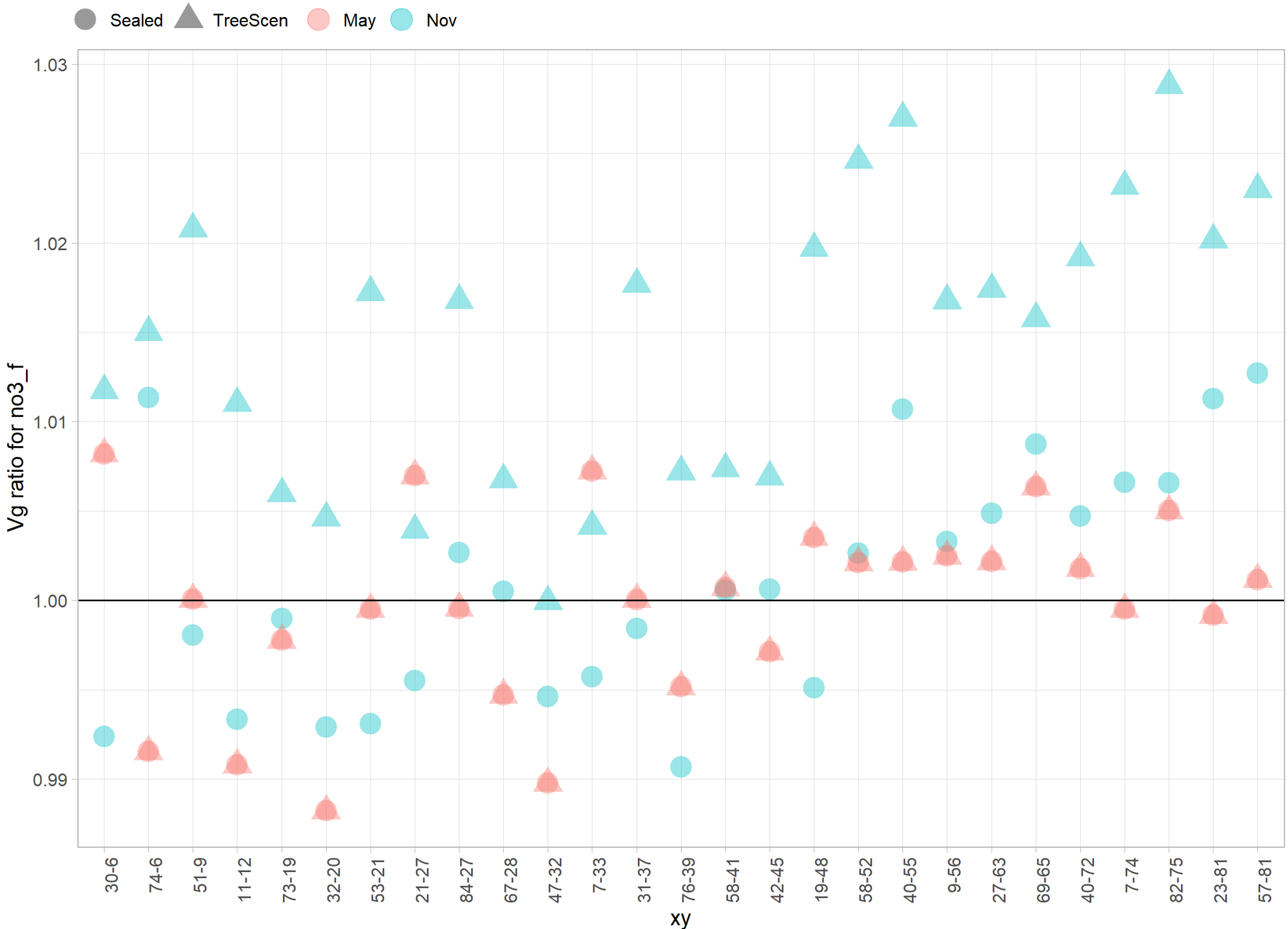
V_s – gravitational settling velocity

r – total resistance = $R_a + \frac{1}{V_{ds}}$

Atmospheric modelling on a 3D grid



From Edwards (2010): Schematic representation of the Cartesian grid structure used in finite-difference GCMs. Graphic by Courtney Ritz and Trevor Burnham.


Sealed
TreeScen
May
Nov
Vg ratio for no3_f
1.03
1.02
1.01
1.00
0.99
30-6
74-6
51-9
11-12
73-19
32-20
53-21
21-27
84-27
67-28
47-32
7-33
31-37
76-39
58-41
42-45
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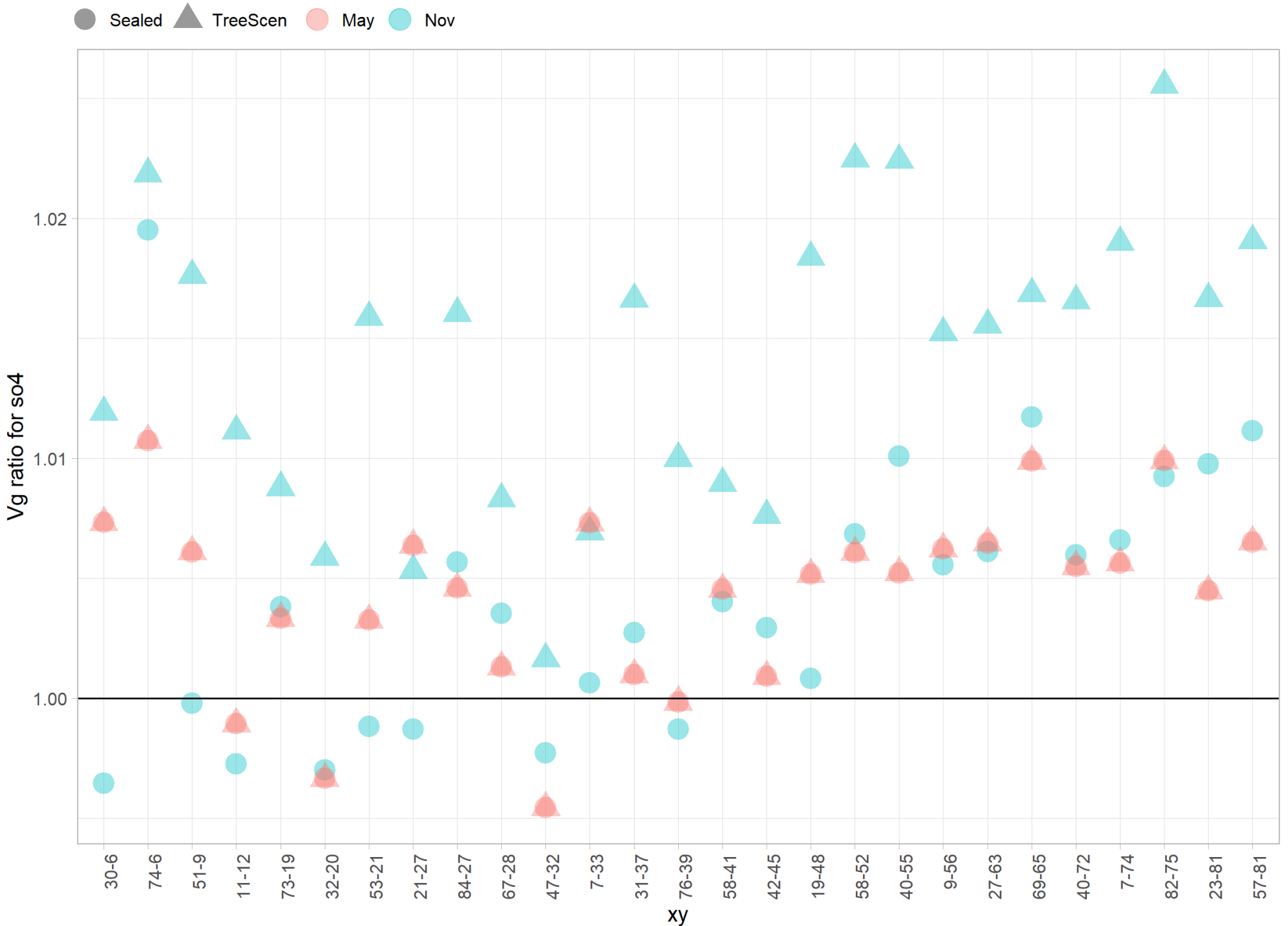
40-72
7-74
82-75
23-81
57-81
xy


Sealed
TreeScen
May
Nov
Vg ratio for so4
1.02
1.01
1.00
30-6
74-6
51-9
11-12
73-19
32-20
53-21
21-27
84-27
67-28
47-32
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40-72
7-74
82-75
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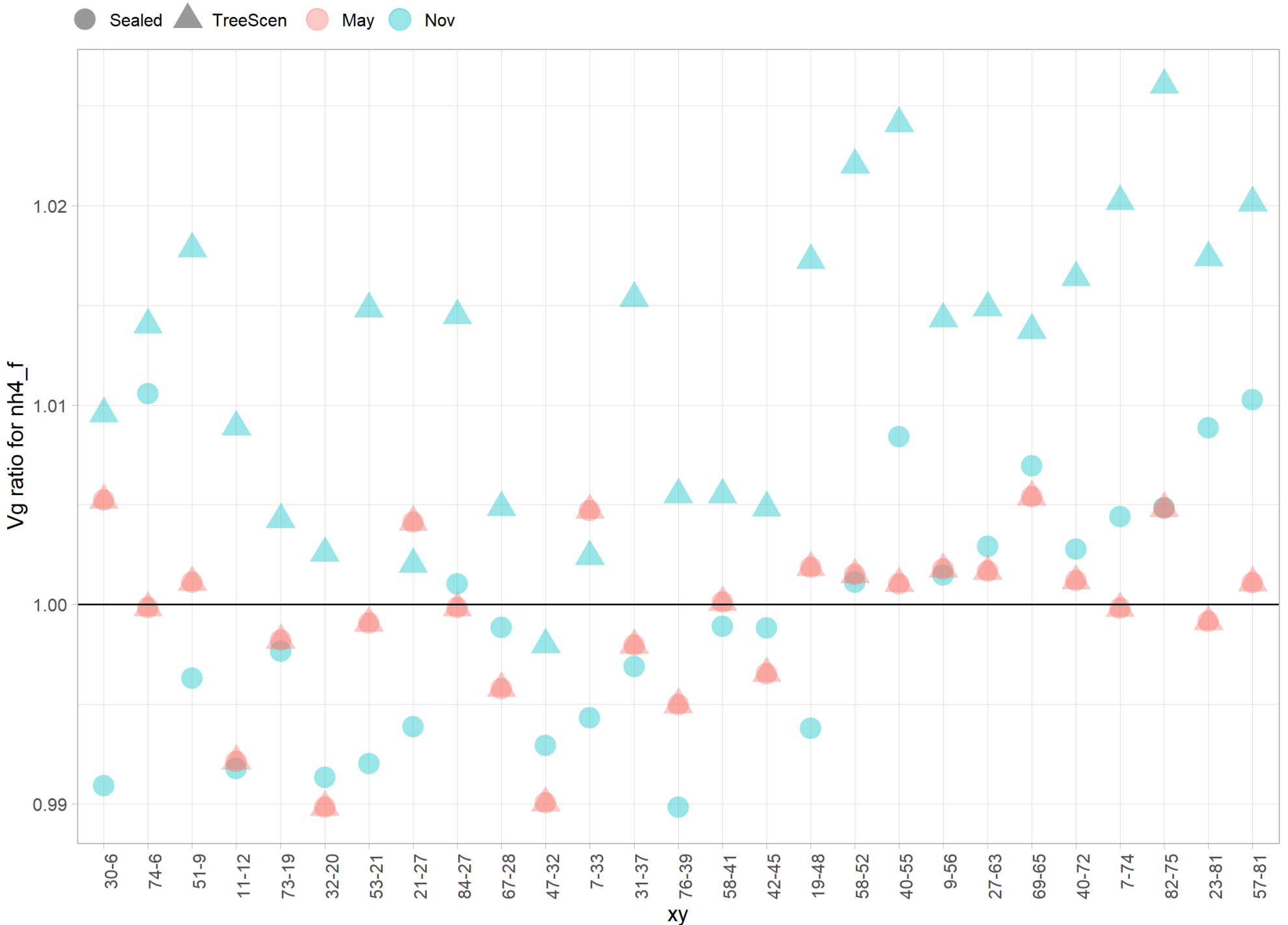
57-81
xy


Sealed
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1.02
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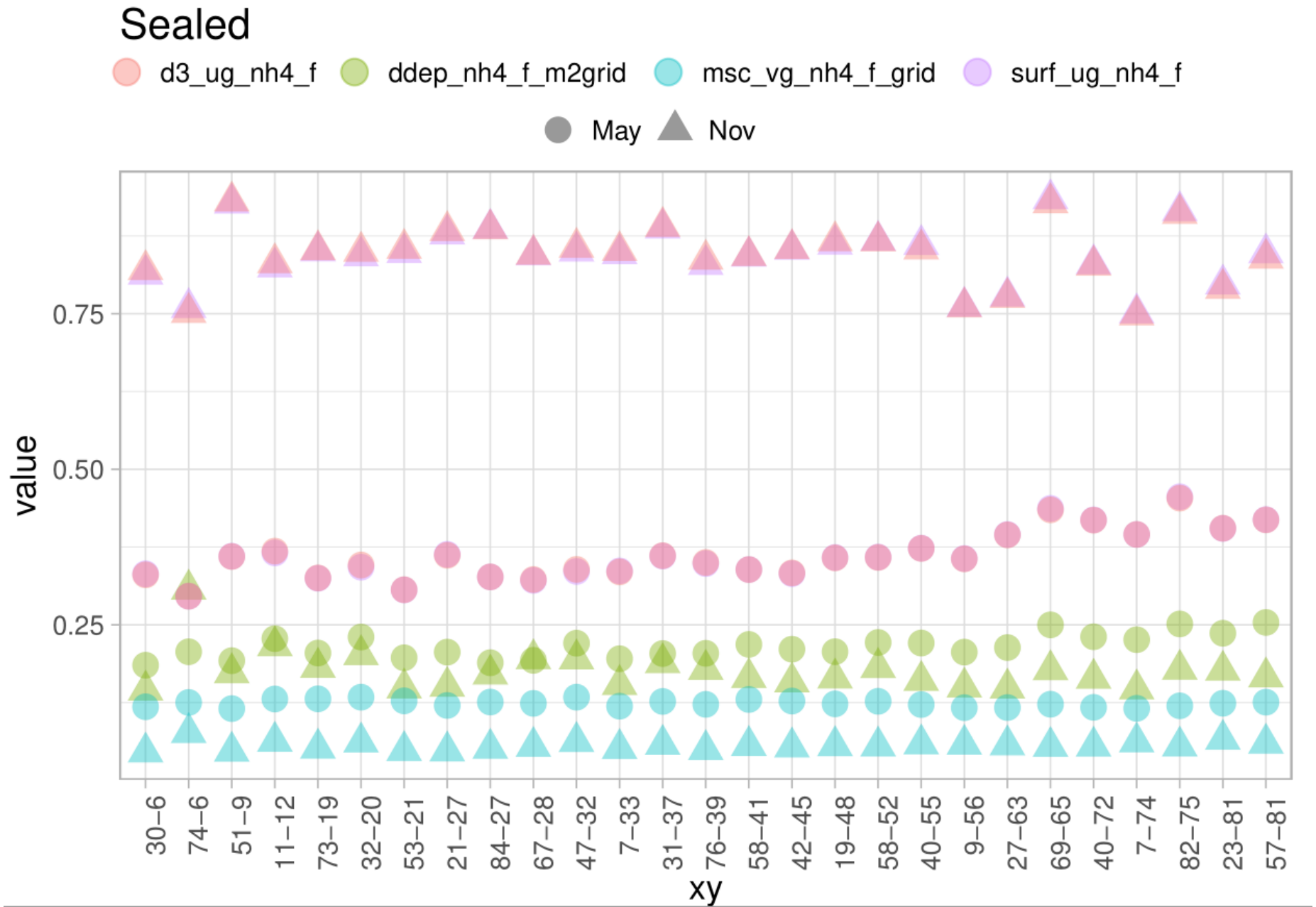
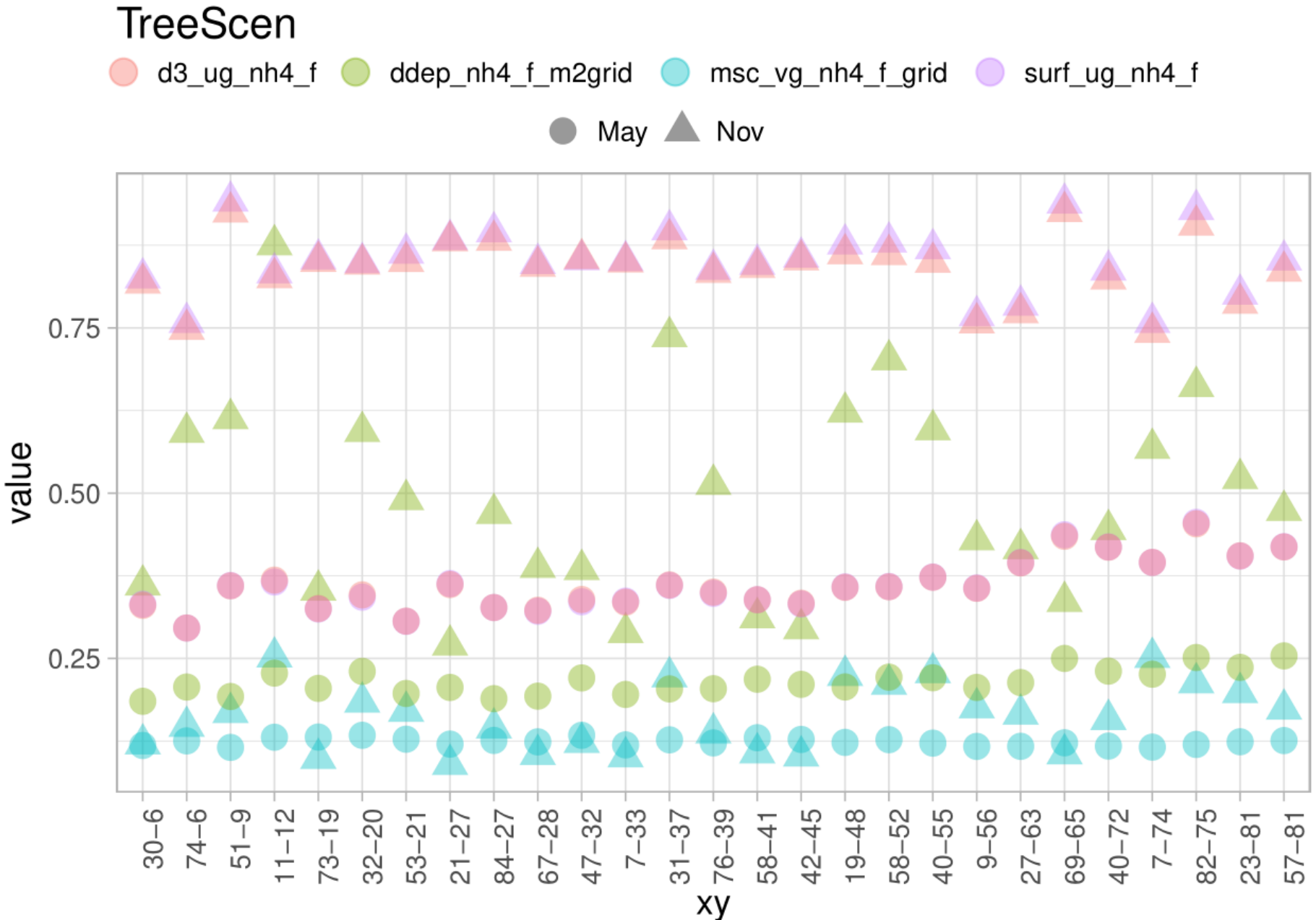
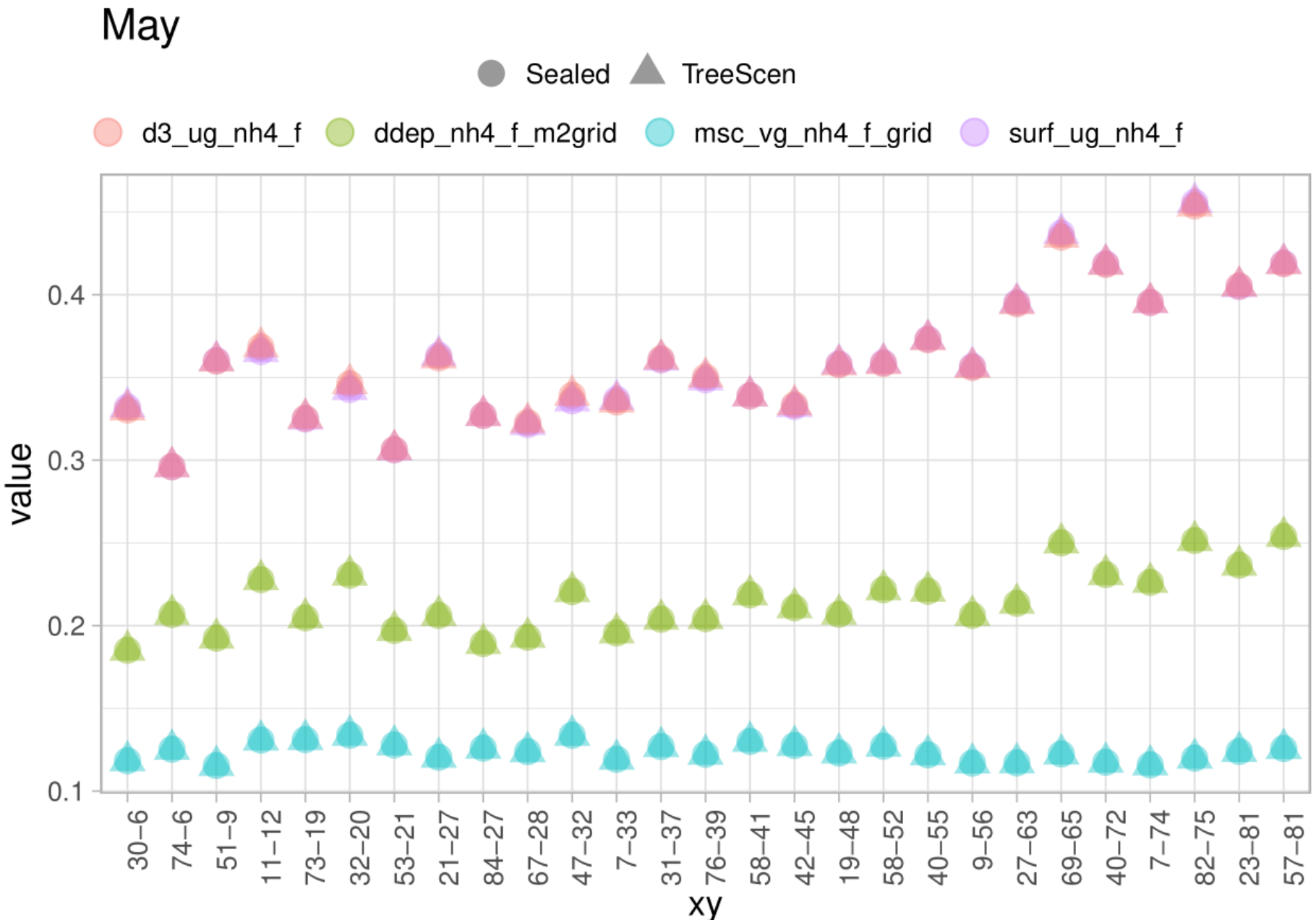
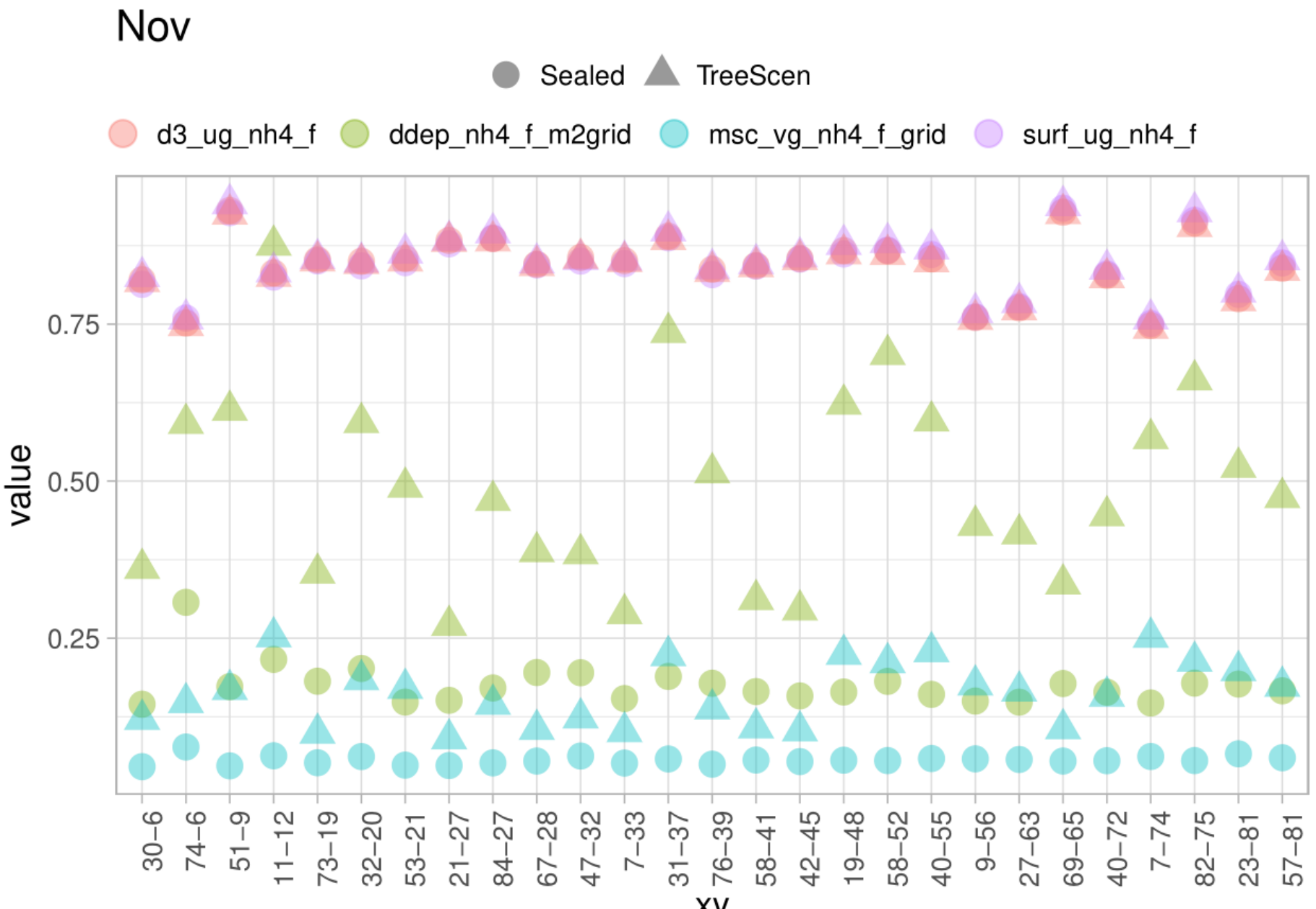
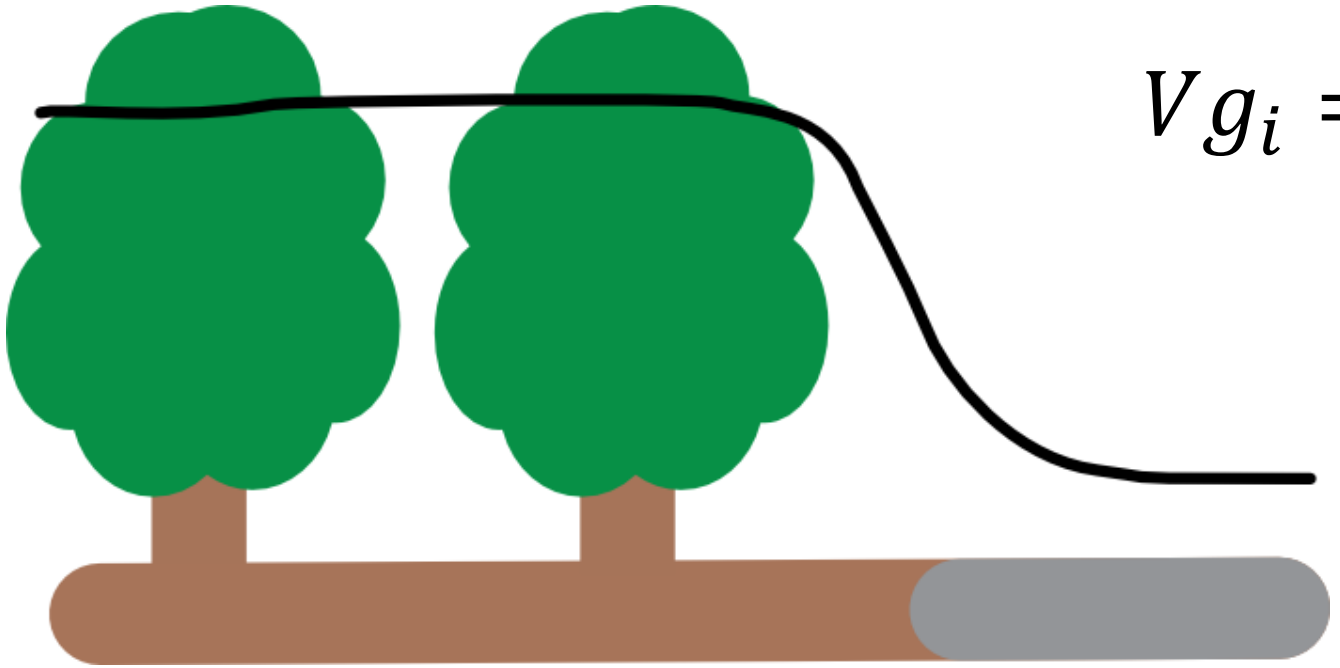
58-41
42-45
19-48
58-52
40-55
9-56
27-63
69-65
40-72
7-74
82-75
23-81
57-81
xy


Sealed
d3_ug_nh4_f
ddep_nh4_f_m2grid
msc_vg_nh4_f_grid
surf_ug_nh4_f
May
Nov
value
0.75
0.50
0.25
30–6
74–6
51–9
11–12
73–19
32–20
53–21
21–27
84–27
67–28
47–32
7–33
31–37
76–39
58–41
42–45
19–48
58–52
40–55
9–56
27–63
69–65
40–72
7–74
82–75
23–81
57–81
xy


TreeScen
d3_ug_nh4_f
ddep_nh4_f_m2grid
msc_vg_nh4_f_grid
surf_ug_nh4_f
May
Nov
value
0.75
0.50
0.25
30–6
74–6
51–9
11–12
73–19
32–20
53–21
21–27
84–27
67–28
47–32
7–33
31–37
76–39
58–41
42–45
19–48
58–52
40–55
9–56
27–63
69–65
40–72
7–74
82–75
23–81
57–81
xy


May
Sealed
TreeScen
d3_ug_nh4_f
ddep_nh4_f_m2grid
msc_vg_nh4_f_grid
surf_ug_nh4_f
value
0.4
0.3
0.2
0.1
30–6
74–6
51–9
11–12
73–19
32–20
53–21
21–27
84–27
67–28
47–32
7–33
31–37
76–39
58–41
42–45
19–48
58–52
40–55
9–56
27–63
69–65
40–72
7–74
82–75
23–81
57–81
xy


Nov
Sealed
TreeScen
d3_ug_nh4_f
ddep_nh4_f_m2grid
msc_vg_nh4_f_grid
surf_ug_nh4_f
value
0.75
0.50
0.25
30–6
74–6
51–9
11–12
73–19
32–20
53–21
21–27
84–27
67–28
47–32
7–33
31–37
76–39
58–41
42–45
19–48
58–52
40–55
9–56
27–63
69–65
40–72
7–74
82–75
23–81
57–81
xy



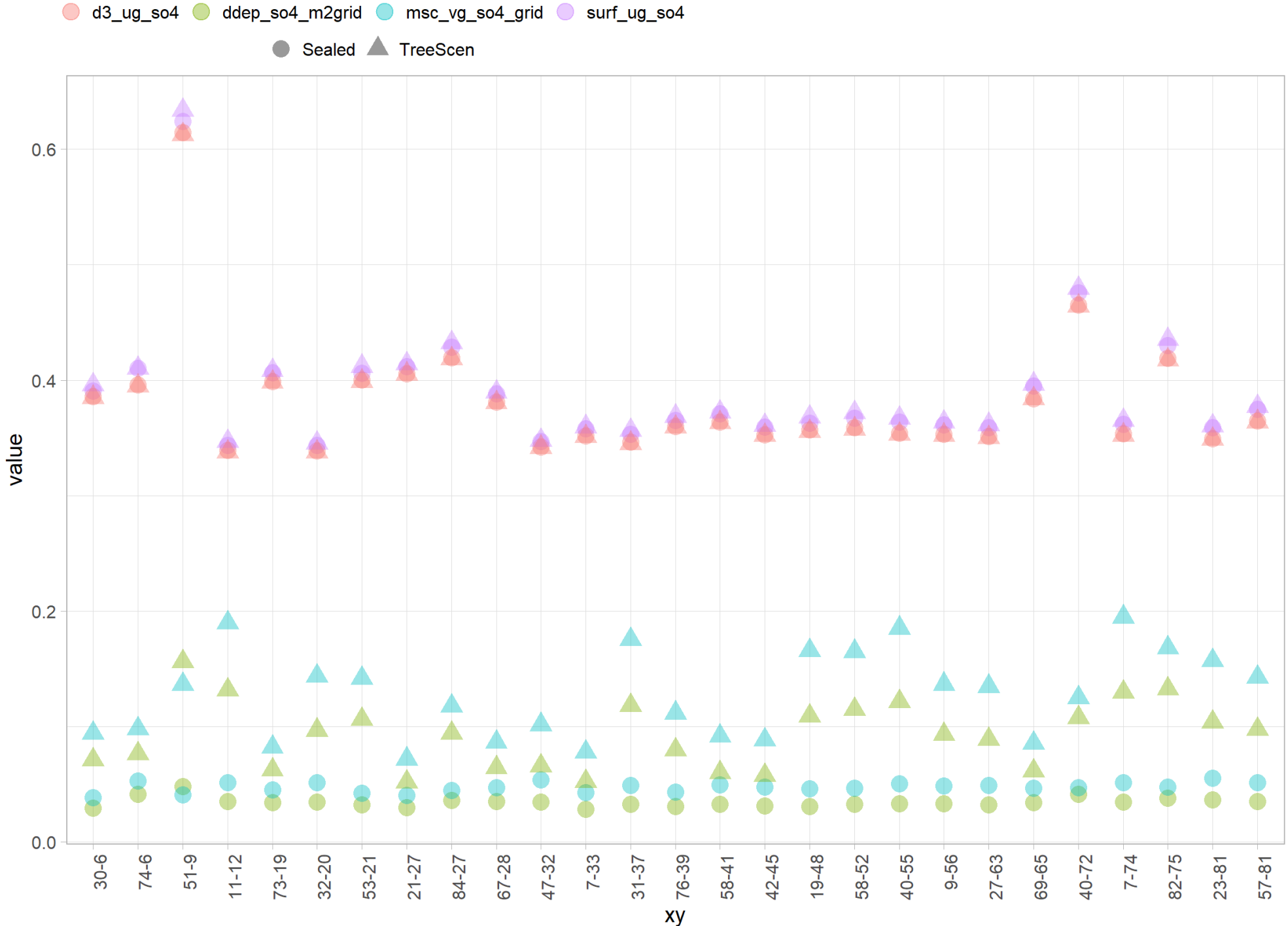
$$Vg_i = Vs_i/(1 - e^{-\{\left(Ra + \frac{1}{Vds}\right) * Vs_i\}})$$

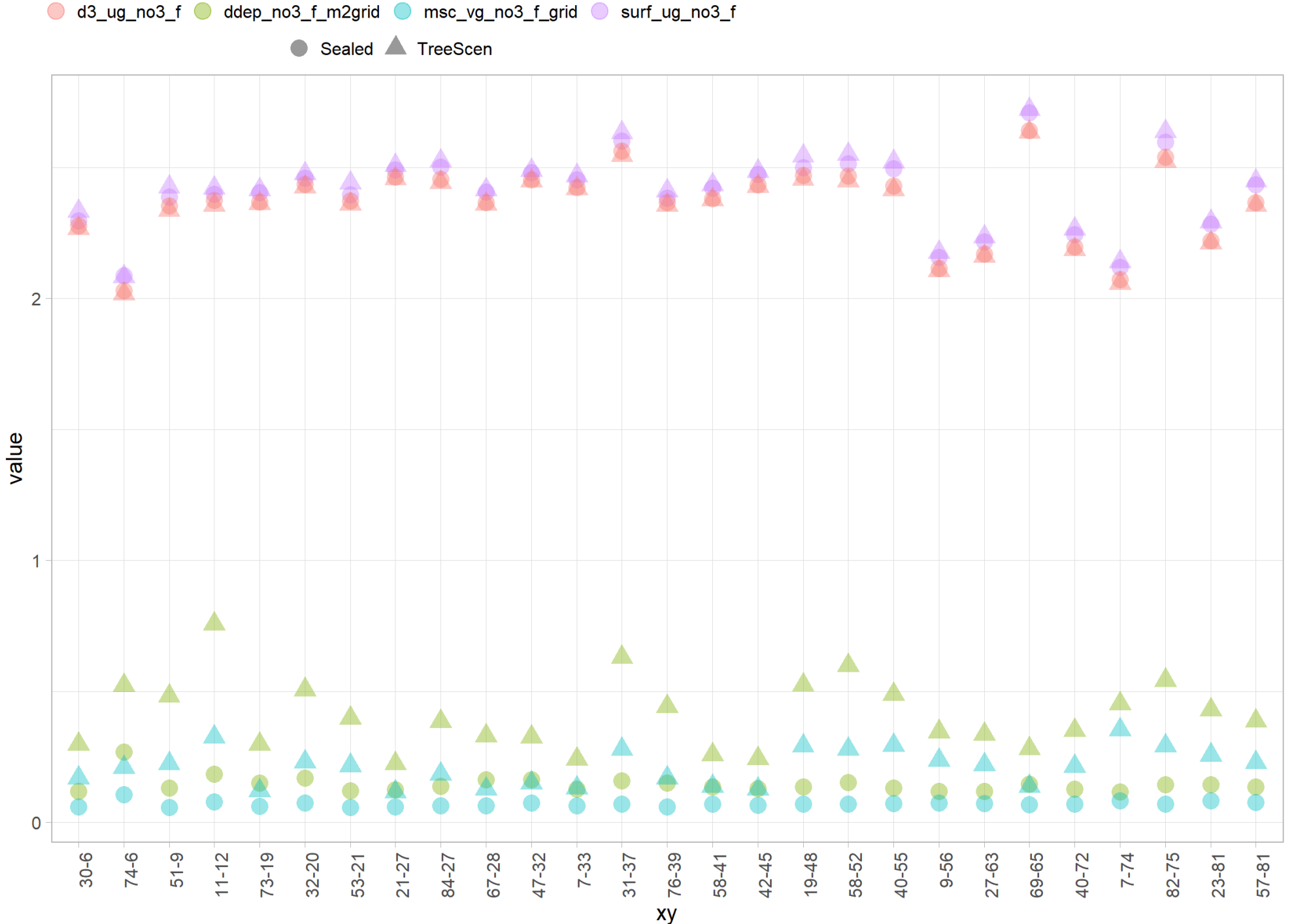
Vds = f(LAI)
If LAI = 0
Vds (forest) = Vds (non-forest)

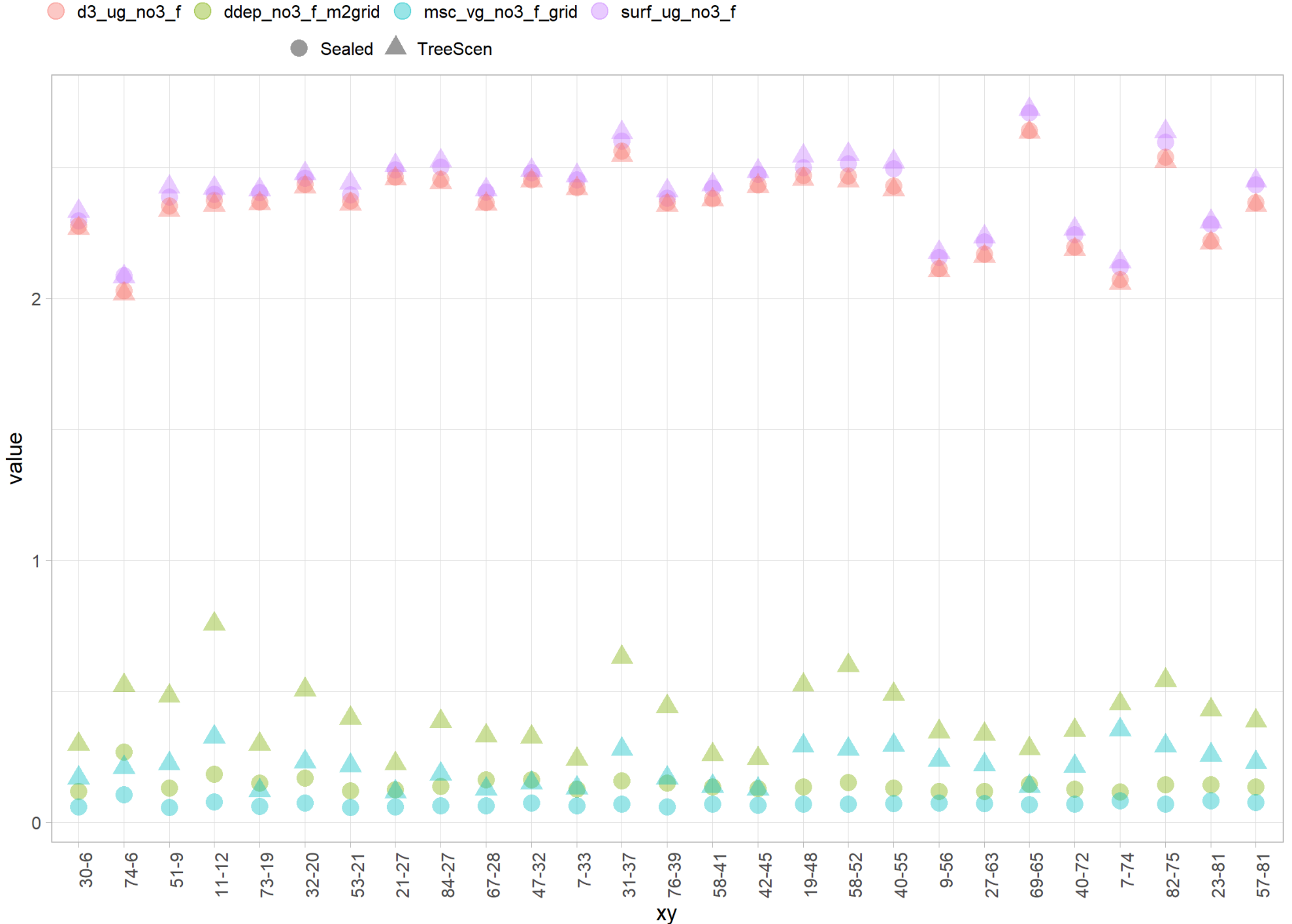
```
! Use non-electrical-analogy version of Venkatram+Pleim (AE,1999)
! ACP70

  Vg_ref(icmp) = BL(icmp)%Vs/ &
           ( 1.0 - exp( -( L%Ra_ref + 1.0/Vds)* BL(icmp)%Vs))
  Vg_3m (icmp) = BL(icmp)%Vs/ &
           ( 1.0 - exp( -( L%Ra_3m  + 1.0/Vds)* BL(icmp)%Vs))

  Vg_eff(icmp) = Vg_ref(icmp) !PW
```


d3_ug_so4
ddep_so4_m2grid
msc_vg_so4_grid
surf_ug_so4
Sealed
TreeScen
value
0.0
0.2
0.4
0.6
xy
30-6
74-6
51-9
11-12
73-19
32-20
53-21
21-27
84-27
67-28
47-32
7-33
31-37
76-39
58-41
42-45
19-48
58-52
40-55
9-56
27-63
69-65
40-72
7-74
82-75
23-81
57-81


d3_ug_no3_f
ddep_no3_f_m2grid
msc_vg_no3_f_grid
surf_ug_no3_f
Sealed
TreeScen
value
0
1
2
xy
30-6
74-6
51-9
11-12
73-19
32-20
53-21
21-27
84-27
67-28
47-32
7-33
31-37
76-39
58-41
42-45
19-48
58-52
40-55
9-56
27-63
69-65
40-72
7-74
82-75
23-81
57-81


d3_ug_no3_f
ddep_no3_f_m2grid
msc_vg_no3_f_grid
surf_ug_no3_f
Sealed
TreeScen
value
0
1
2
xy
30-6
74-6
51-9
11-12
73-19
32-20
53-21
21-27
84-27
67-28
47-32
7-33
31-37
76-39
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42-45
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58-52
40-55
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27-63
69-65
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7-74
82-75
23-81
57-81

The monetary value of air pollution removal by urban vegetation

Existing urban and peri-urban vegetation & possible changes to them

↓

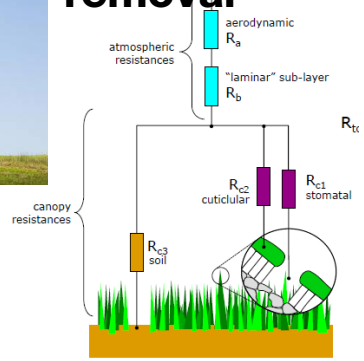
Atmospheric chemistry transport modelling → dry deposition of pollutants depends on surface (e.g. trees or bare soil)

↓

Impact of $PM_{2.5}$ on mortality and morbidity on the population
Health functions for 4 pollutants:
$PM_{2.5}$, SO_2, NO_2, O_3

Natural Capital

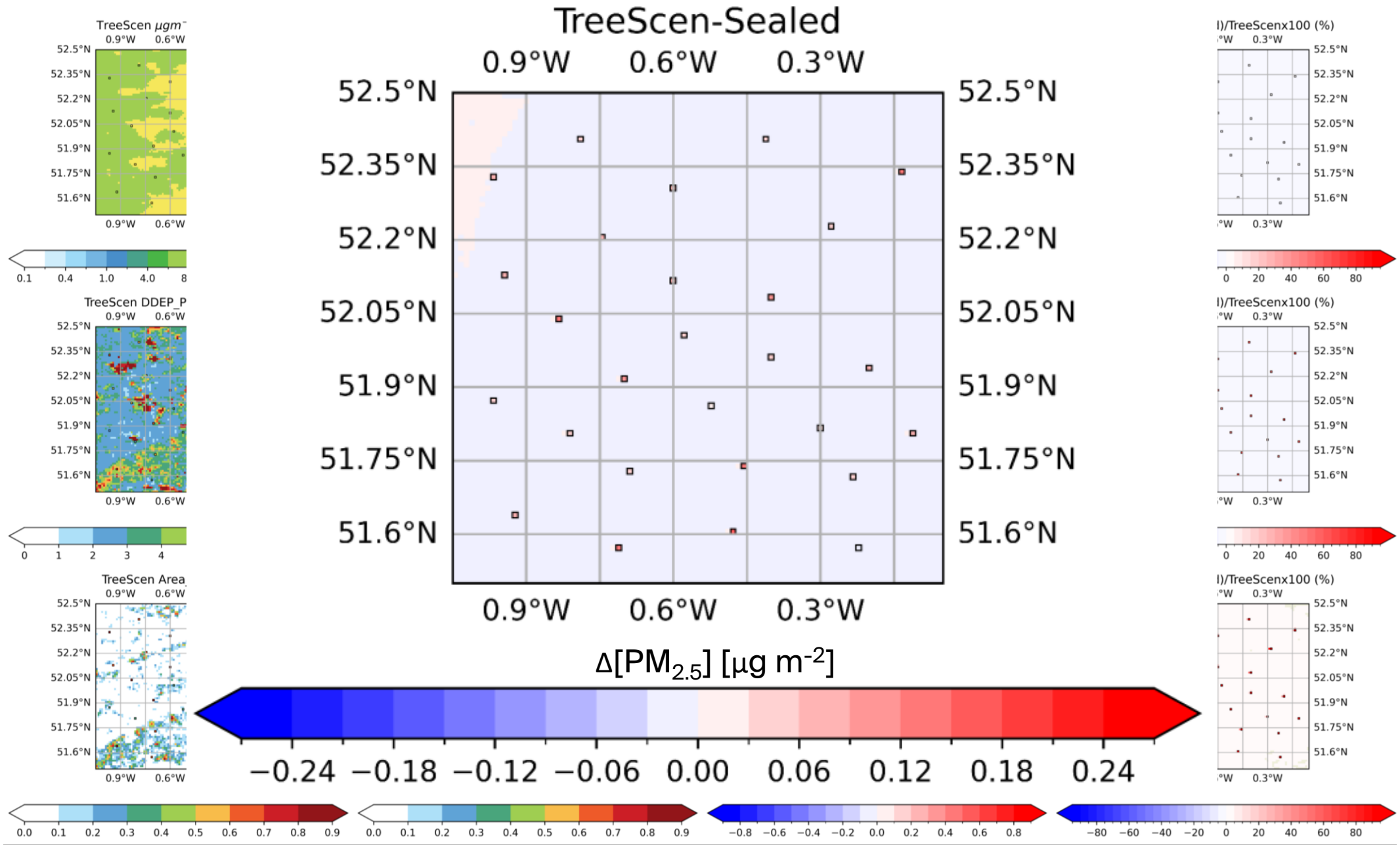
Provides a service:
Pollution removal



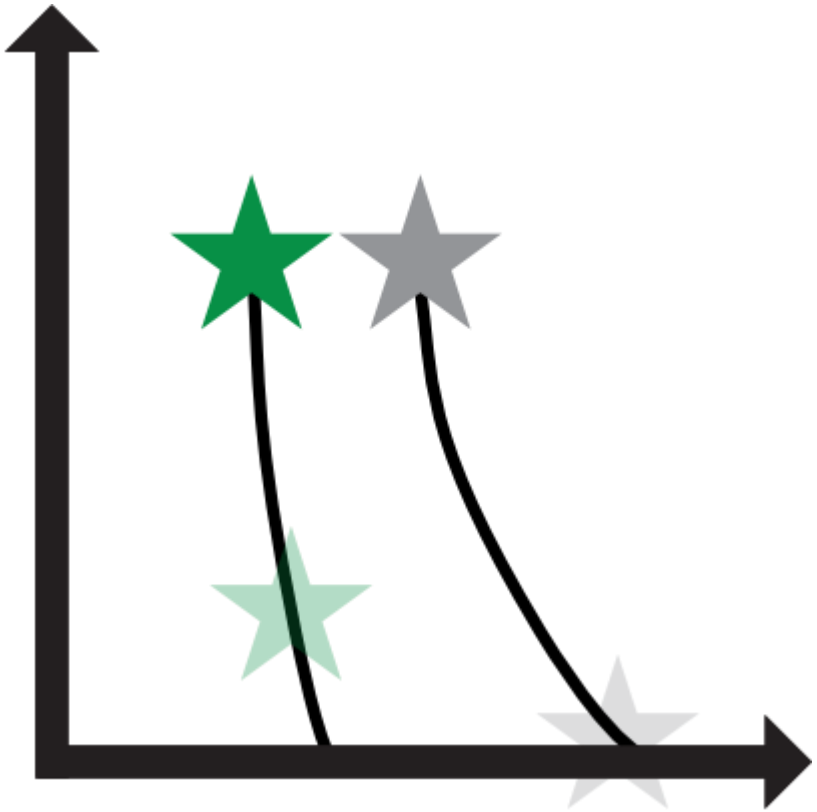
Provides a 'Good':
Clean air

Our benefit:
Improved health
Fewer hospital admissions

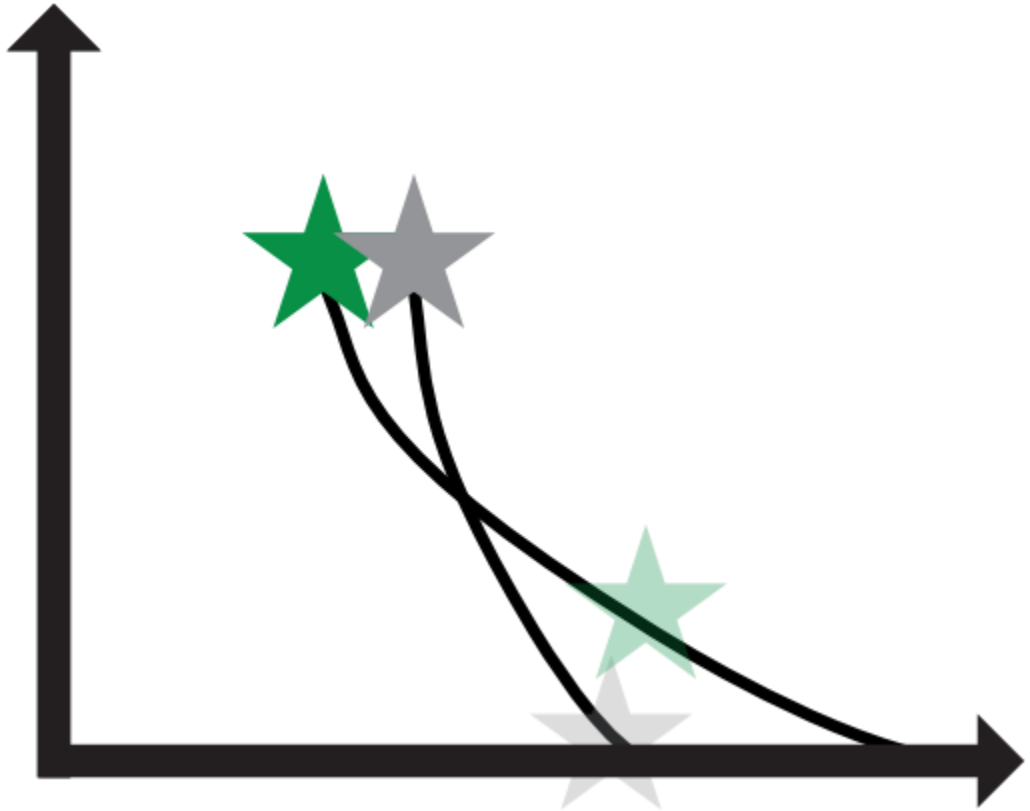
(Monetary value)


TreeScen-Sealed
0.9°W
0.6°W
0.3°W
52.5°N
52.35°N
52.2°N
52.05°N
51.9°N
51.75°N
51.6°N
Δ[PM2.5] [µg m-2]
−0.24 −0.18 −0.12 −0.06 0.00 0.06 0.12 0.18 0.24
TreeScen µgm
TreeScen DDEP_P
TreeScen Area
)/TreeScenx100 (%)

Leaf-on period



Leaf-off period



Tree cover

Sealed bare land

How do we best assess the impact of land cover change on air quality?

- Use lowest grid concentration instead of surface grid concentration?
- Extrapolate all land covers to 3 m above ground even for higher elevated land covers?
- Extrapolate concentration to the ground based on one single landcover type that is more relevant to where people live, e.g. grass?
- Any other ideas?