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UNIVERSITA' DI ROMA

ENEA
Italian national agency for new technologies, energy and sustainable economic development

Ozone impacts on forest's productivity and health in Europe

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Aims

1. Effects of tropospheric ozone (O_3) on forests health conditions;

2. What are the most relevant factors affecting forests health conditions?

Gross Primary Production (GPP)

Crown Defoliation

Some insights:

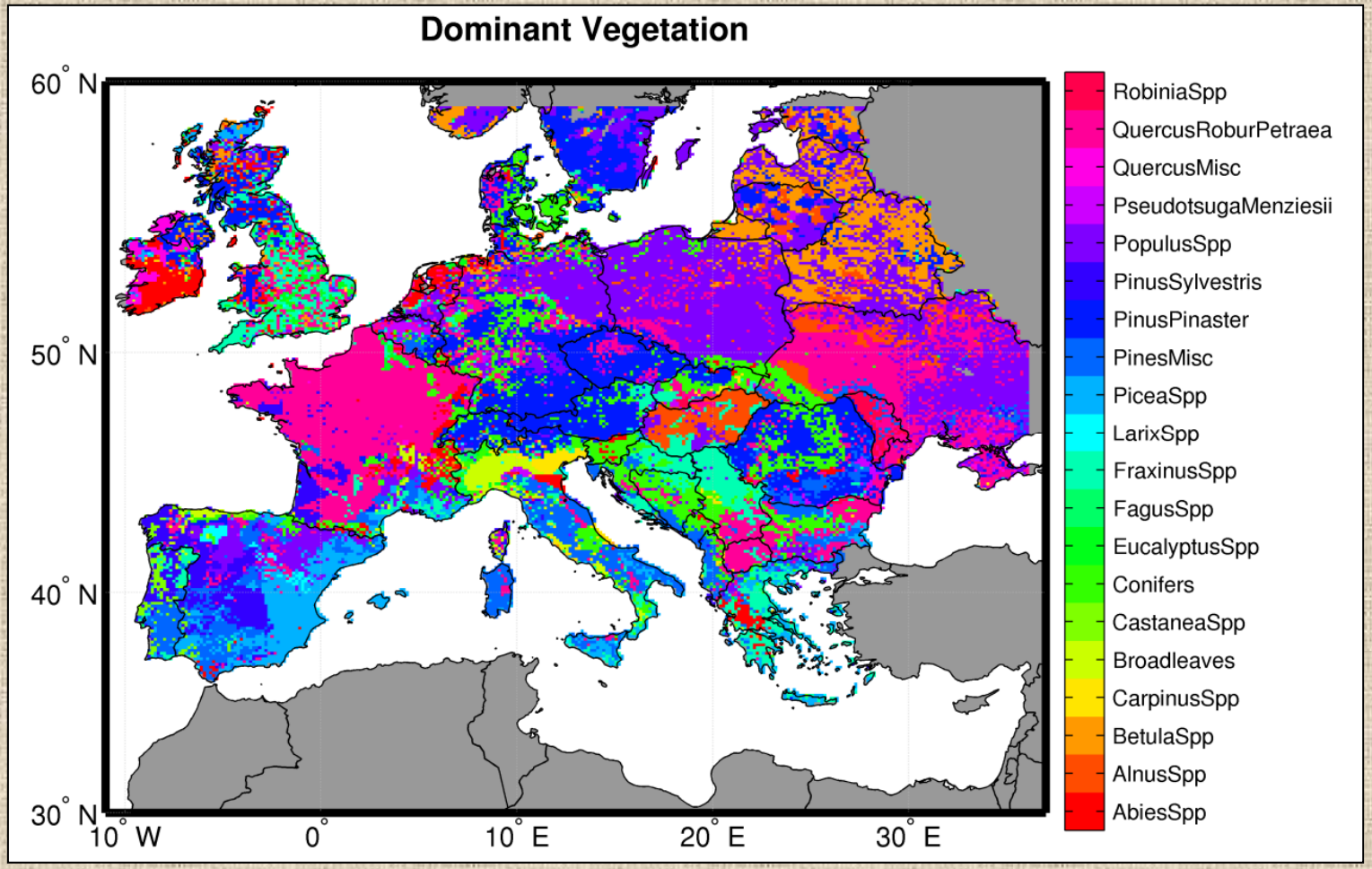
- Framework of mesoscale models at high spatial resolution (12 km) VS. EMEP model in the ICP Forests plots;
- Soil water limitations influence on ozone risk assessment to forests.

GPP-OZONE

Ozone impacts on forest's productivity and health in Europe

Methodology: building of the starting database (I)

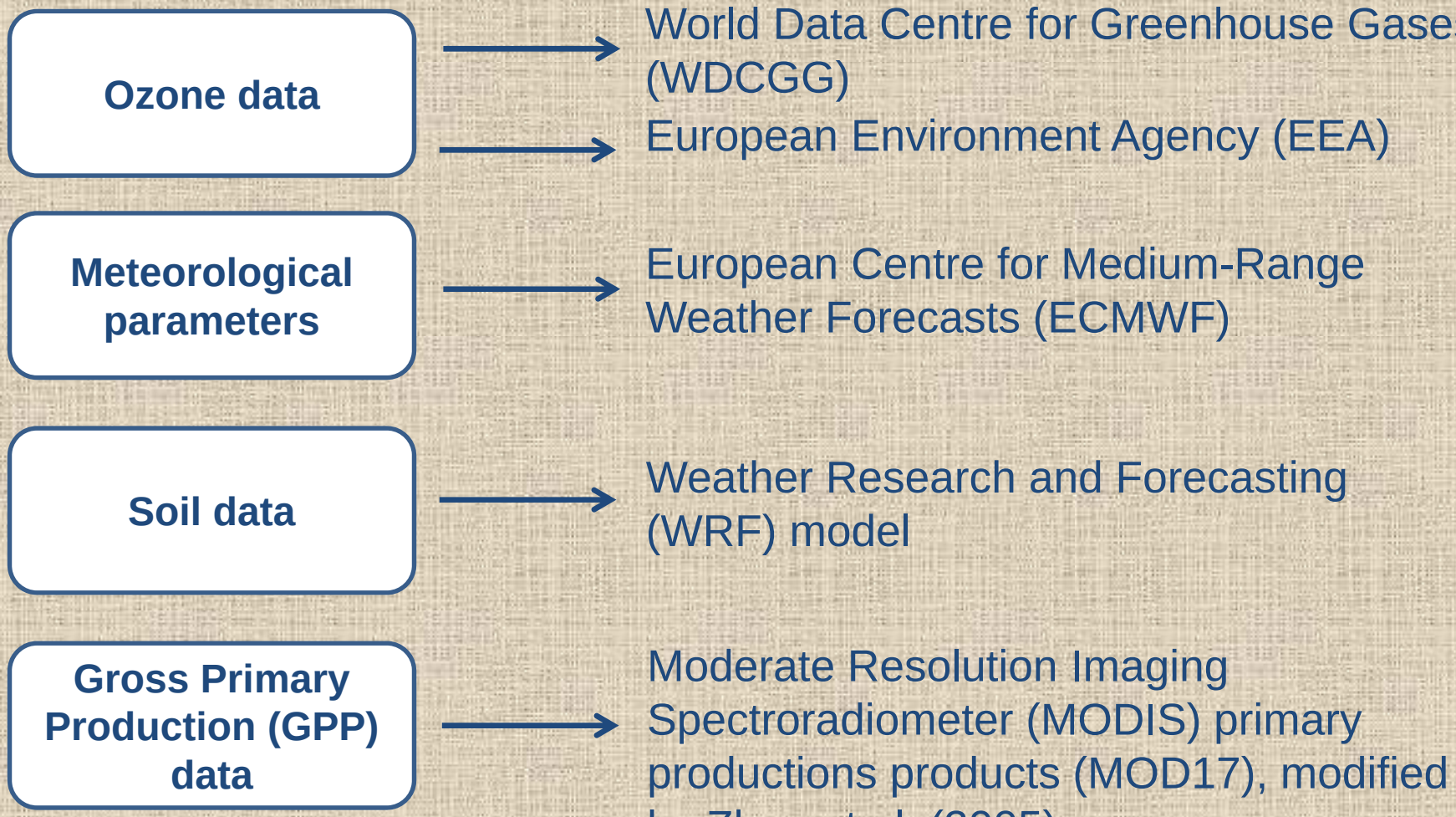
Effects of tropospheric ozone (O_3) on GPP



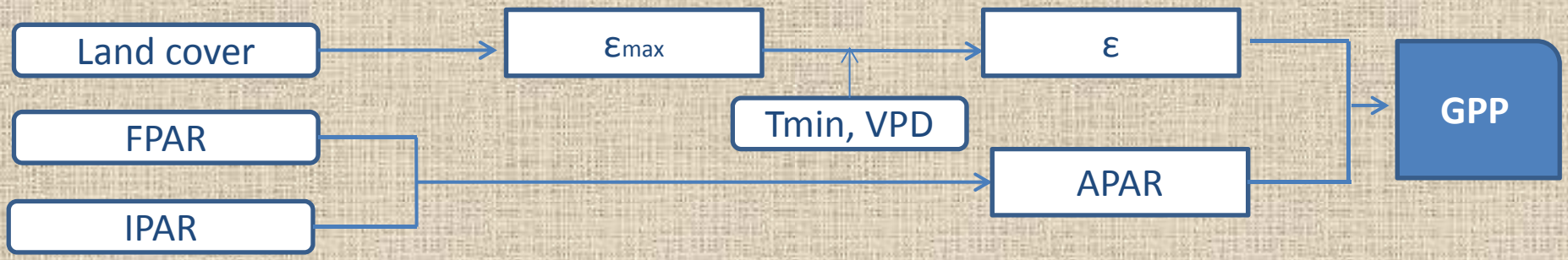
Tree species maps for European Forests (Brus et al., 2011; Tröltzsch et al., 2009)

Methodology: building of the starting database (I) (2000-2010)

Effects of tropospheric ozone (O_3) on GPP

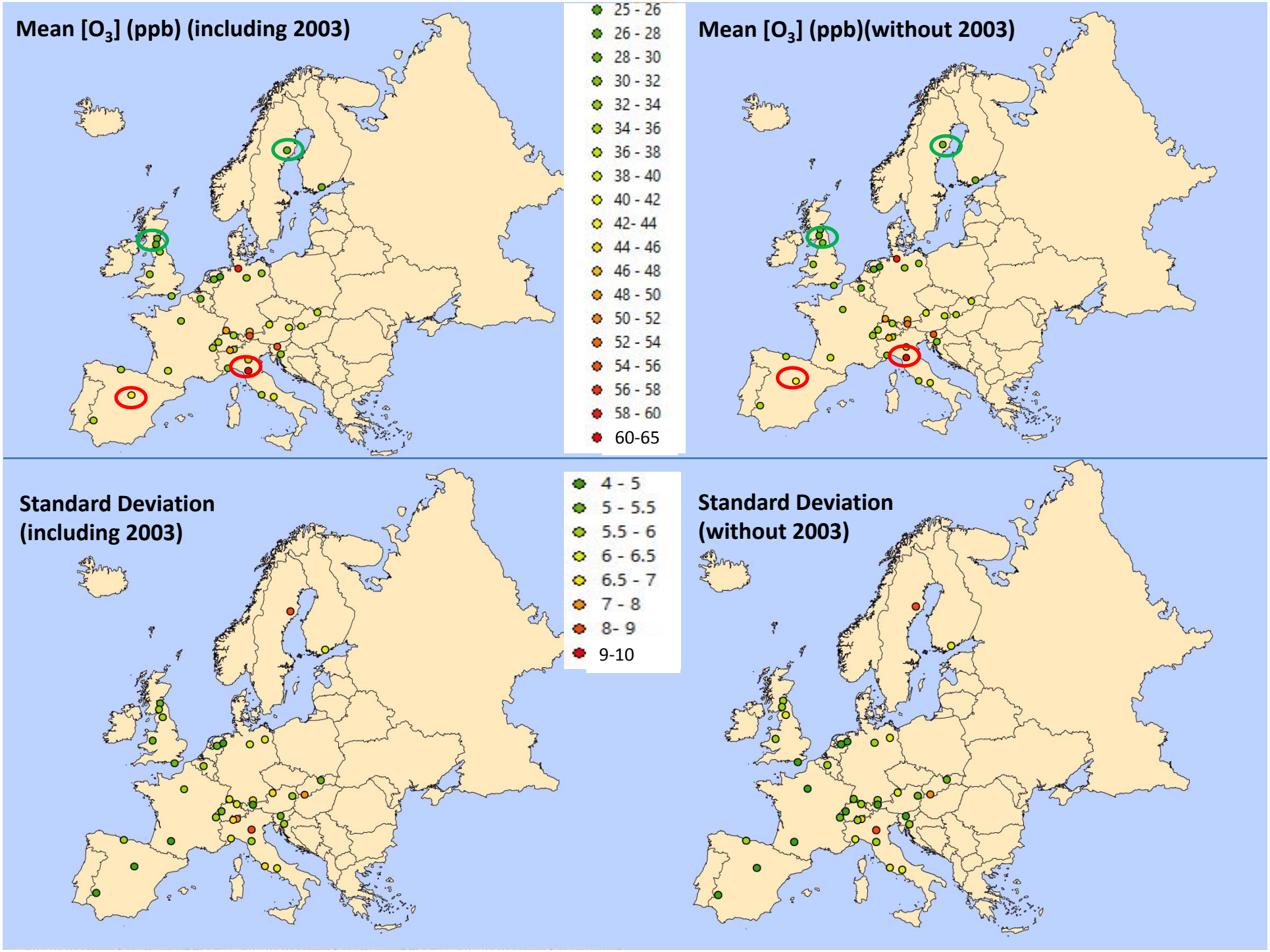


Gross Primary Production data



GPP was estimated by a light use efficiency model

Land cover	MODIS Land Cover Classification (MOD12Q1)
FPAR	Fraction of incident PAR absorbed by the surface (MOD15)
IPAR	PAR incident on the vegetative surface (DAO)
ε_{max}	The maximum radiation conversion efficiency (BIOME-BGC)
Tmin, VPD	NASA Data Assimilation Office (DAO)
APAR	Absorbed PAR


Mean [O3] (ppb) (including 2003)
25 - 26
26 - 28
28 - 30
30 - 32
32 - 34
34 - 36
36 - 38
38 - 40
40 - 42
42- 44
44 - 46
46 - 48
48 - 50
50 - 52
52 - 54
54 - 56
56 - 58
58 - 60
60-65
Mean [O3] (ppb)(without 2003)
Standard Deviation (including 2003)
4 - 5
5 - 5.5
5.5 - 6
6 - 6.5
6.5 - 7
7 - 8
8- 9
9-10
Standard Deviation (without 2003)

Ozone metrics

$$AOT40 = \int \max((C - 40), 0) dt$$

C is hourly ozone concentration (O_3)
Dt is day of the year during the growing season

AOT40 was estimated as sum of the exceedances above 40 ppb over the daylight hours during the growing season, according to the methodology for ozone risk assessment (UNECE, 2010)

$$g_{sto} = g_{\max} \times f_{light} \times \max(f_{\min}, f_{temp} \times f_{VPD} \times f_{SWC})$$

POD0= Σ [g_{sto}* [O3]*0.663]

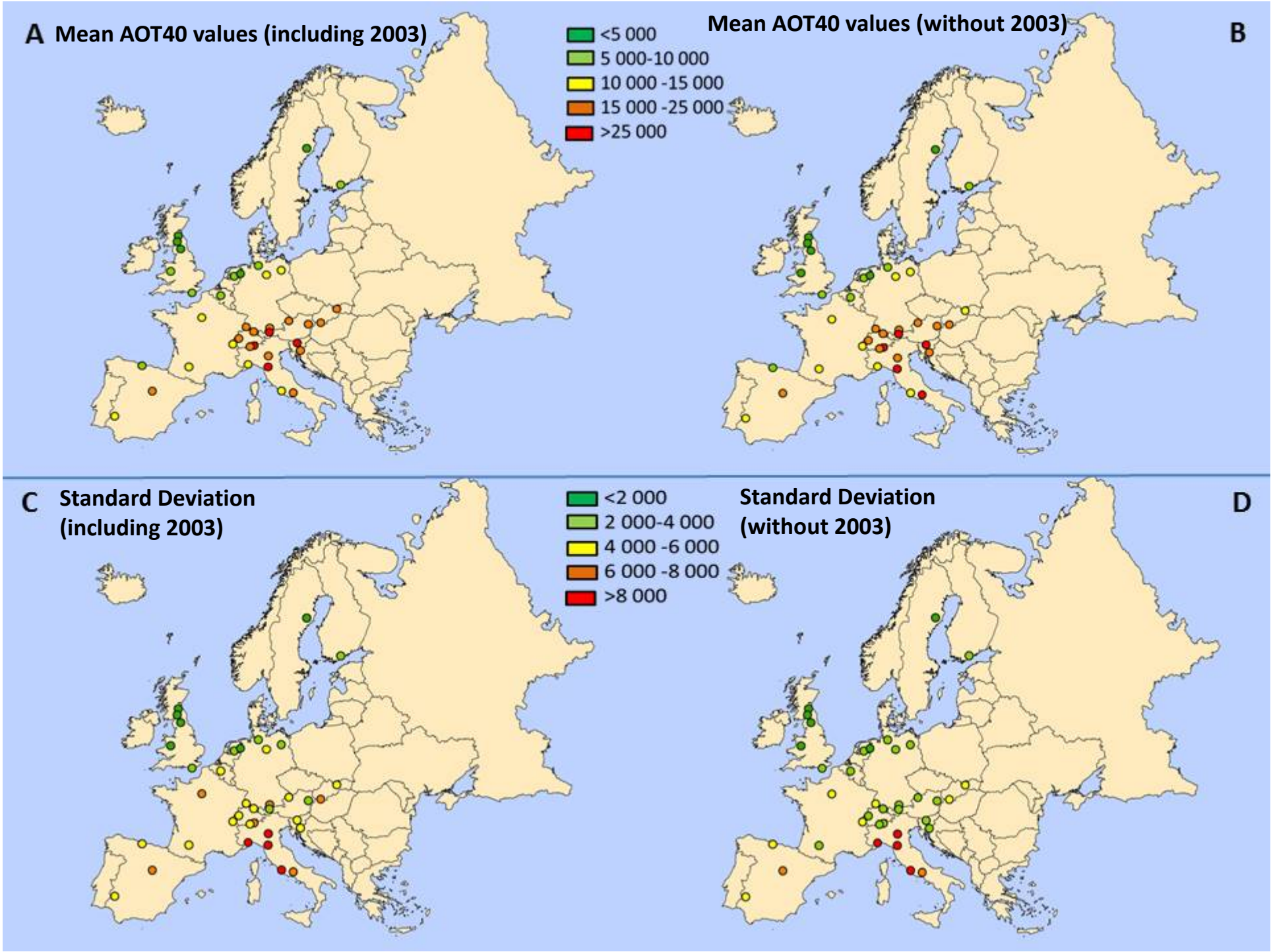
DO_3SE model

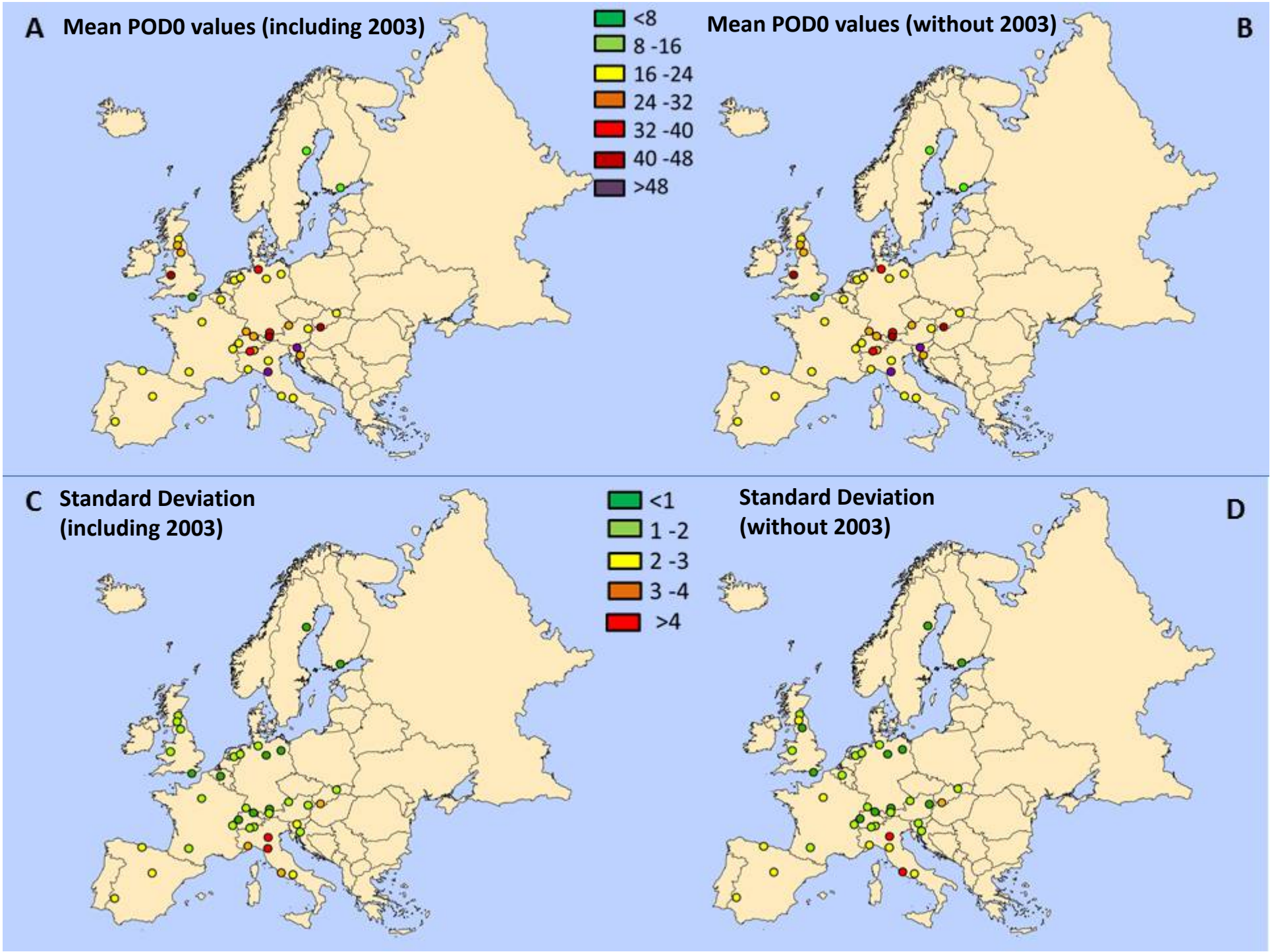
The stomatal flux-based model is based on the Jarvis' (1976) algorithm and describes species-specific effects of soil water availability (*fswc*), vapour pressure deficit (*fvpd*), air temperature (*ftemp*), radiation (*flight*) and O_3 concentration on stomatal functioning.

DO_3SE model

Climate	Mediterranean				Temperate			
Parameterization	Mediterranean Europe				Continental Central Europe			
Plant species	Generic deciduous	Generic evergreen	Pinus halepensis	Fagus sylvatica	Generic deciduous	Generic evergreen	Norway spruce	Fagus sylvatica
g_{max} [mmol.m^{-2}.s^{-1}]	150	175	215	145	150	125	125	150
$light_a$ [dl]	0.006	0.009	0.013	0.006	0.006	0.010	0.010	0.006
T_{opt} [°C]	21	23	27	21	21	14	14	16
T_{min} [°C]	0	2	10	4	0	0	0	5
T_{max} [°C]	35	38	38	37	35	35	35	33
VPD_{min} [kPa]	3.25	4	3.2	4.0	3.25	3.0	3.0	3.1
VPD_{max} [kPa]	1	2.2	1.0	1.0	1	0.5	0.5	1.0
f_{min} [mmol.m^{-2}.s^{-1}]	0.1	0.2	0.15	0.02	0.1	0.16	0.16	0.13

Climate				Atlantic			
Parameterization	Northern Europe			Atlantic Central Europe			
Plant species	Generic deciduous	Generic evergreen	Norway spruce	Generic deciduous	Generic evergreen	Scots pine	Fagus sylvatica
g_{max} [mmol.m^{-2}.s^{-1}]	150	112	112	150	180	180	150
$light_a$ [dl]	0.006	0.006	0.006	0.006	0.006	0.006	0.006
T_{opt} [°C]	21	20	20	21	20	20	21
T_{min} [°C]	0	0	0	0	0	0	0
T_{max} [°C]	35	200	200	35	36	36	35
VPD_{min} [kPa]	3.25	2.8	2.8	3.25	2.8	2.8	3.25
VPD_{max} [kPa]	1	0.8	0.8	1	0.6	0.6	1
f_{min} [mmol.m^{-2}.s^{-1}]	0.1	0.1	0.1	0.1	0.1	0.1	0.1


A Mean AOT40 values (including 2003)
<5 000
5 000-10 000
10 000 -15 000
15 000 -25 000
>25 000
Mean AOT40 values (without 2003)
B
C Standard Deviation (including 2003)
<2 000
2 000-4 000
4 000 -6 000
6 000 -8 000
>8 000
Standard Deviation (without 2003)
D


A
Mean POD0 values (including 2003)
<8
8 -16
16 -24
24 -32
32 -40
40 -48
>48
Mean POD0 values (without 2003)
B
C
Standard Deviation
(including 2003)
<1
1 -2
2 -3
3 -4
>4
Standard Deviation
(without 2003)
D

Partial correlation coefficients (controlling for: Photosynthetically Active Radiation (PAR) and air temperature (T)) and p-value (ns=not significant, p=0.001***, 0.01**, 0.05*) for correlation between Gross Primary Production (GPP) and ozone concentration (O_3).

Station name	r (GPP,O_3)	Station name	r (GPP,O_3)
Altendeich (DE)	-0.29*	Krvavec (SI)	-0.64***
Anières (CH)	-0.53***	Lullington Heath (UK)	ns
Aston Hill (UK)	ns	Luukki (FI)	-0.42**
Barcarrota (ES)	ns	Magadino (CH)	-0.28*
Barsbeek-De Veenen (UK)	-0.55***	Monte Cimone (IT)	-0.55***
Bosco Fontana (IT)	ns	Neuglobsow (DE)	-0.38**
Bush Estate (UK)	-0.41**	Niembro (ES)	ns
Campisabalos (ES)	-0.47***	Payerne (CH)	-0.59***
Castel di Guido (IT)	ns	Rigi (CH)	-0.52***
Cengio (IT)	ns	Rur S-O/Foret RAMB (FR)	ns
Enzenkirchen im Sauwald (AT)	-0.55***	Schauinsland (DE)	-0.63***
Eskdalemuir (UK)	ns	St.P. Leeuw (BE)	ns
Fontechiari (IT)	-0.49***	Tänikon (CH)	-0.34**
Gainfarn (AT)	-0.54***	Topolniky (SK)	-0.32*
Ganovce (SK)	-0.41**	Valthermond-Noorderdiep (NL)	-0.61***
Gaudonville (FR)	-0.40**	Vindeln (SE)	-0.51***
Great Dun Fell (UK)	0.37*	Waldhof (DE)	-0.56***
Hohenpeissenberg (DE)	-0.68***	Zugspitze (DE)	-0.39**
Iskrba (SI)	-0.51***		

Correlation coefficients and p-value (ns=not significant, p=0.001***,0.01**,0.05*) for correlation between Gross Primary Production (GPP) and ozone fluxes (F_{O3}).

Station name	r (GPP, F_{O3})
Altendeich (DE)	0.57***
Anières (CH)	ns
Aston Hill (UK)	ns
Barcarrota (ES)	0.87***
Barsbeek-De Veenen (UK)	0.62***
Bosco Fontana (IT)	ns
Bush Estate (UK)	0.36**
Campisabalos (ES)	ns
Castel di Guido (IT)	0.57***
Cengio (IT)	ns
Enzenkirchen im Sauwald (AT)	ns
Eskdalemuir (UK)	ns
Fontechiari (IT)	ns
Gainfarn (AT)	ns
Ganovce (SK)	ns
Gaudonville (FR)	ns
Great Dun Fell (UK)	0.49***
Hohenpeissenberg (DE)	0.43**
Iskrba (SI)	ns

Station name	r (GPP, F_{O3})
Krvavec (SI)	0.88***
Lullington Heath (UK)	ns
Luukki (FI)	0.72***
Magadino (CH)	0.40**
Monte Cimone (IT)	0.41***
Neuglobsow (DE)	ns
Niembro (ES)	0.27*
Payerne (CH)	ns
Rigi (CH)	0.68***
Rur S-O/Foret RAMB (FR)	0.33**
Schauinsland (DE)	-0.53***
St.P. Leeuw (BE)	ns
Tänikon (CH)	ns
Topolniky (SK)	0.70***
Valthermond-Noorderdiep (NL)	ns
Vindeln (SE)	0.48***
Waldhof (DE)	ns
Zugspitze (DE)	0.48***

What are the most relevant factors affecting GPP?

Random Forests Analysis (RFA)

(Breiman et al. 1984, 2001)

RFA is a collection of simple tree predictors, each capable of producing a response when evaluated in relation to a set of predictor values.

The final predictor importance values are computed by normalizing those averages so that to the highest average is assigned the value of 1, and the importance of all other predictors is expressed in terms of the relative magnitudes (Svetnik et al., 2003).

RFA was performed including and not including the Photosynthetically Active Radiation (PAR)

To test the ability of the RFA to discern the predictor's importance

To select the most important predictors affecting GPP

RANDOM FORESTS ANALYSIS INCLUDING PAR

Station name	O_3	O_3 flux	PAR	RH	SWC	Temperature
Altendeich	0.56	0.39	**1.00**	0.35	0.56	0.38
Anières	0.31	0.38	**1.00**	0.63	0.37	0.66
Aston Hill	0.52	0.44	**1.00**	0.85	0.46	0.73
Barcarrota	0.33	0.87	0.66	0.63	0.75	1.00
Barsbeek-De Veenen	0.26	0.59	**1.00**	0.89	0.47	0.58
Bosco Fontana	0.46	0.32	0.79	0.98	0.59	1.00
Bush Estate	0.57	0.58	0.89	0.67	0.32	1.00
Campisabalos	0.69	0.74	**1.00**	0.55	0.81	0.61
Castel di Guido	0.25	0.88	0.44	0.63	1.00	0.56
Cengio	0.32	0.50	0.95	0.69	0.21	1.00
Enzenkirchen im Sauwald	0.26	0.37	0.92	1.00	0.34	0.95
Eskdalemuir	0.40	0.34	**1.00**	0.57	0.54	0.89
Fontechiari	0.45	0.40	**1.00**	0.49	0.55	0.68
Gainfarn	0.23	0.19	**1.00**	0.41	0.23	0.44
Ganovce	0.40	0.33	0.78	1.00	0.57	0.76
Gaudonville	0.29	0.44	**1.00**	0.51	0.47	0.46
Great Dun Fell	1.00	0.65	0.78	0.66	0.34	0.74
Hohenpeissenberg	0.36	0.49	0.63	0.79	0.38	1.00
Krvavec	0.17	0.81	0.62	0.71	0.20	1.00
Lullington Heath	0.33	0.26	**1.00**	0.32	0.24	0.21
Luukki	0.36	0.95	0.88	0.90	0.60	1.00
Magadino	0.30	0.55	**1.00**	0.79	0.77	0.81
Monte Cimone	0.29	0.62	**1.00**	0.61	0.60	0.89
Neuglobsow	0.37	0.57	**1.00**	0.86	0.45	0.96
Niembro	0.33	0.57	**1.00**	0.66	0.39	0.54
Payerne	0.49	0.29	0.99	0.79	0.56	1.00
Rigi	0.29	0.71	0.63	0.76	0.42	1.00
Rur S-O/Foret RAMB	0.64	1.00	0.75	0.44	0.76	0.49
Schauinsland	0.32	1.00	0.88	0.98	0.42	0.92
St.P. Leeuw	0.42	0.44	0.91	0.73	0.37	1.00
Tänikon	0.29	0.41	0.68	1.00	0.40	0.99
Topolniky	0.29	0.69	0.81	1.00	0.32	0.91
Valthermond-Noorderdiep	0.29	0.37	0.81	0.82	0.25	1.00
Vindeln	0.56	0.64	0.44	0.84	0.65	1.00
Waldhof	0.27	0.52	**1.00**	0.60	0.35	0.81
Zugspitze	0.29	0.69	0.46	0.85	0.44	1.00

RANDOM FORESTS ANALYSIS WITHOUT PAR

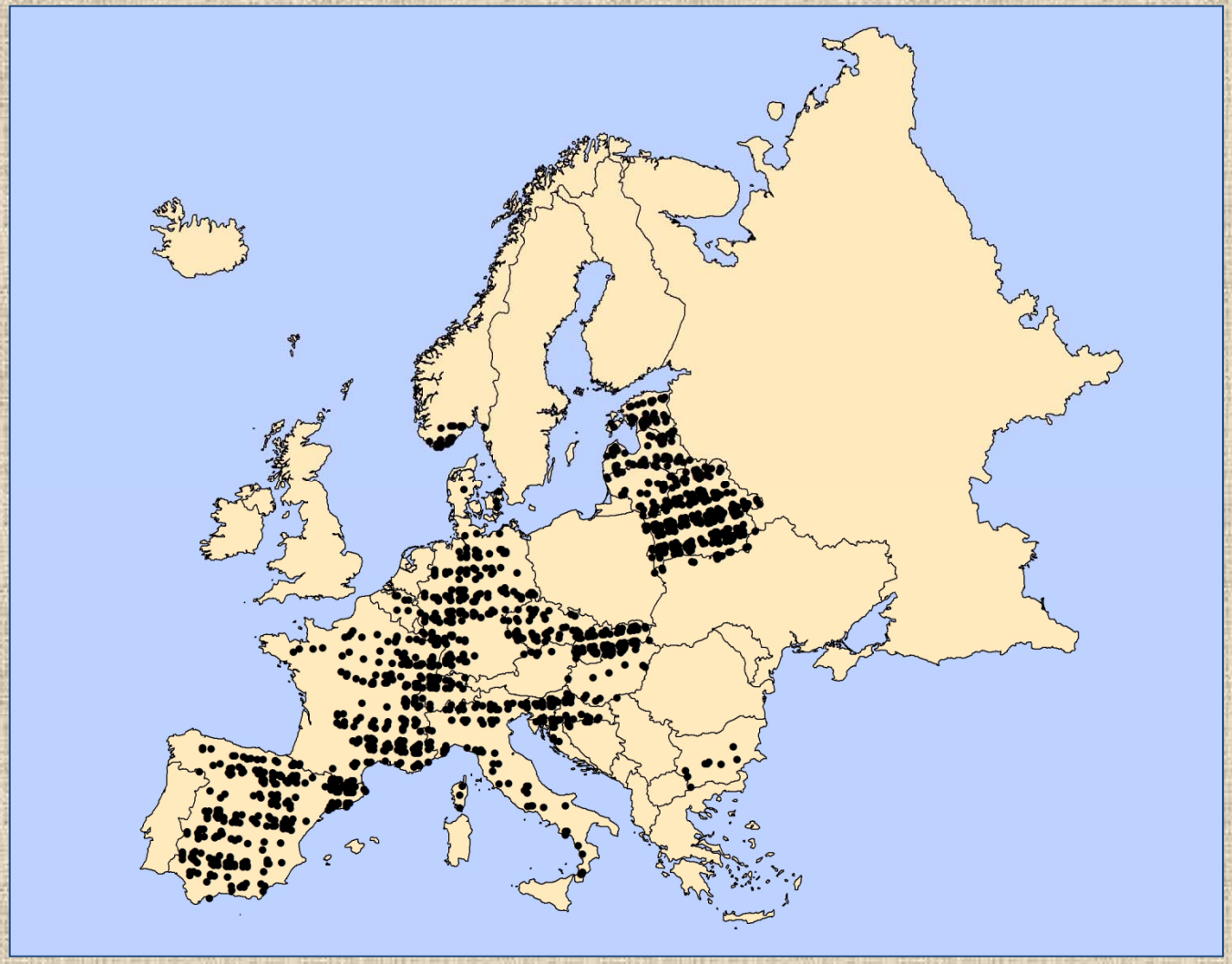
Station name	O_3	O_3 flux	RH	SWC	Temperature
Altendeich	1.00	0.93	0.62	0.61	0.47
Anières	0.76	0.67	0.86	0.68	**1.00**
Aston Hill	0.33	0.60	**1.00**	0.35	0.73
Barcarrota	0.45	0.82	**1.00**	0.86	0.98
Barsbeek-De Veenen	0.26	1.00	0.57	0.29	0.57
Bosco Fontana	0.62	0.41	**1.00**	0.57	0.93
Bush Estate	0.53	0.61	**1.00**	0.58	0.87
Campisabalos	0.81	0.68	0.78	**1.00**	0.57
Castel di Guido	0.48	0.89	0.59	**1.00**	0.84
Cengio	0.79	0.51	**1.00**	0.57	0.74
Enzenkirchen im Sauwald	0.57	0.24	0.74	0.47	**1.00**
Eskdalemuir	0.47	0.56	0.93	0.91	**1.00**
Fontechiari	0.67	0.68	0.76	0.51	**1.00**
Gainfarn	0.78	0.56	0.87	0.41	**1.00**
Ganovce	0.45	0.29	0.81	0.38	**1.00**
Gaudonville	0.70	0.57	0.85	**1.00**	0.98
Great Dun Fell	1.00	0.54	0.88	0.36	0.61
Hohenpeissenberg	0.34	0.66	1.00	0.38	0.94
Krvavec	0.20	1.00	0.81	0.23	0.84
Lullington Heath	0.72	1.00	0.71	0.58	0.54
Luukki	0.32	0.78	0.95	0.62	**1.00**
Magadino	0.52	0.42	0.89	0.88	**1.00**
Monte Cimone	0.28	0.25	**1.00**	0.58	0.85
Neuglobsow	0.49	0.76	0.93	0.68	**1.00**
Niembro	0.61	0.79	**1.00**	0.51	0.96
Payerne	0.71	0.36	0.94	0.62	**1.00**
Rigi	0.30	0.54	0.98	0.52	**1.00**
Rur S-O/Foret RAMB	0.52	1.00	0.26	0.55	0.36
Schauinsland	0.25	0.47	**1.00**	0.38	0.98
St.P. Leeuw	0.57	0.60	**1.00**	0.39	0.93
Tänikon	0.50	0.53	0.81	0.74	**1.00**
Topolniky	0.36	0.91	0.95	0.42	**1.00**
Valthermond-Noorderdiep	0.43	0.37	**1.00**	0.42	0.79
Vindeln	0.49	0.62	0.98	0.53	**1.00**
Waldhof	0.62	0.46	0.89	0.41	**1.00**
Zugspitze	0.32	0.32	0.97	0.42	**1.00**

DEFOLIATION-OZONE

Ozone impacts on forest's productivity and health in Europe

Methodology: building of the starting database (II)

Effects of tropospheric ozone (O_3) on Crown Defoliation



Abies alba

Fagus sylvatica

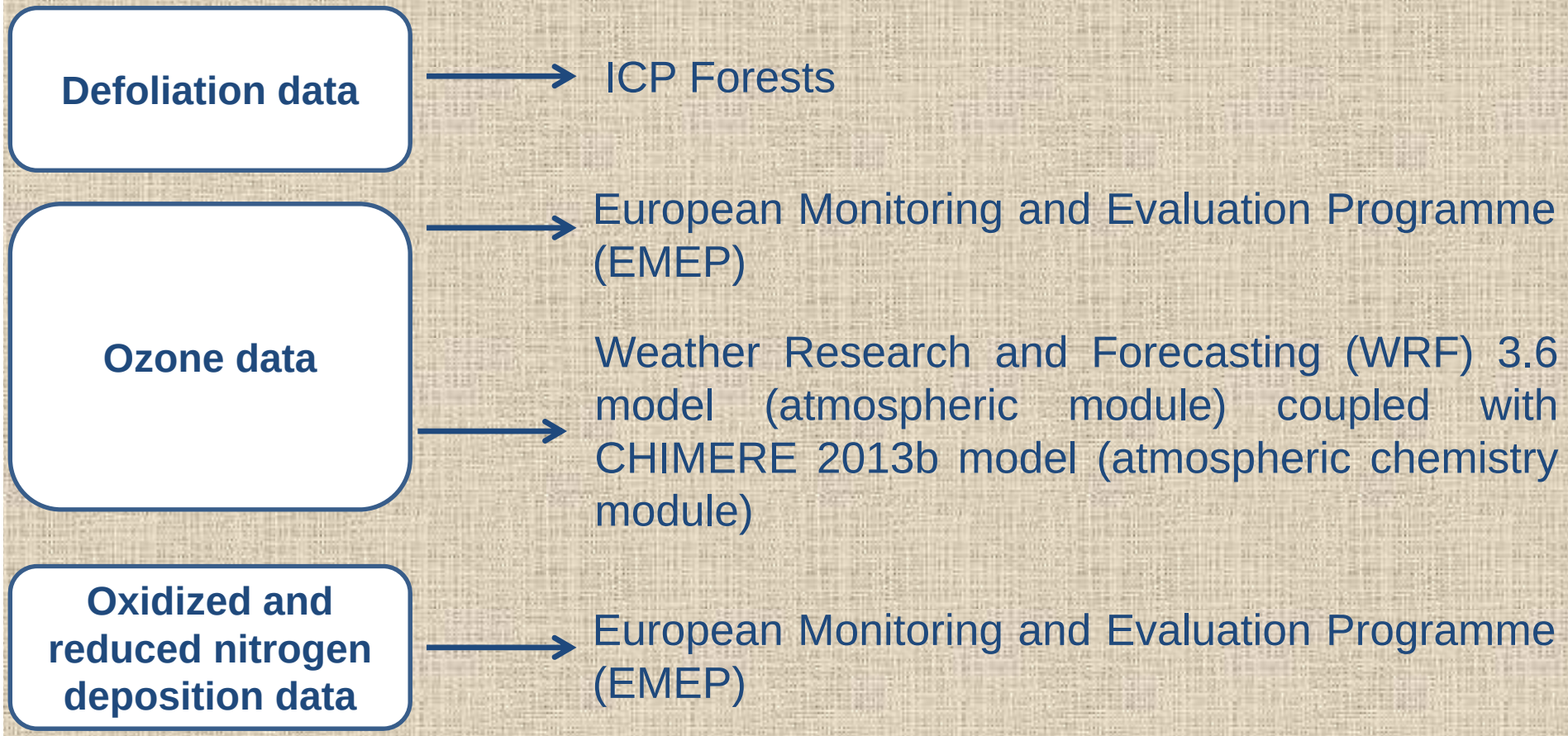
Pinus sylvestris

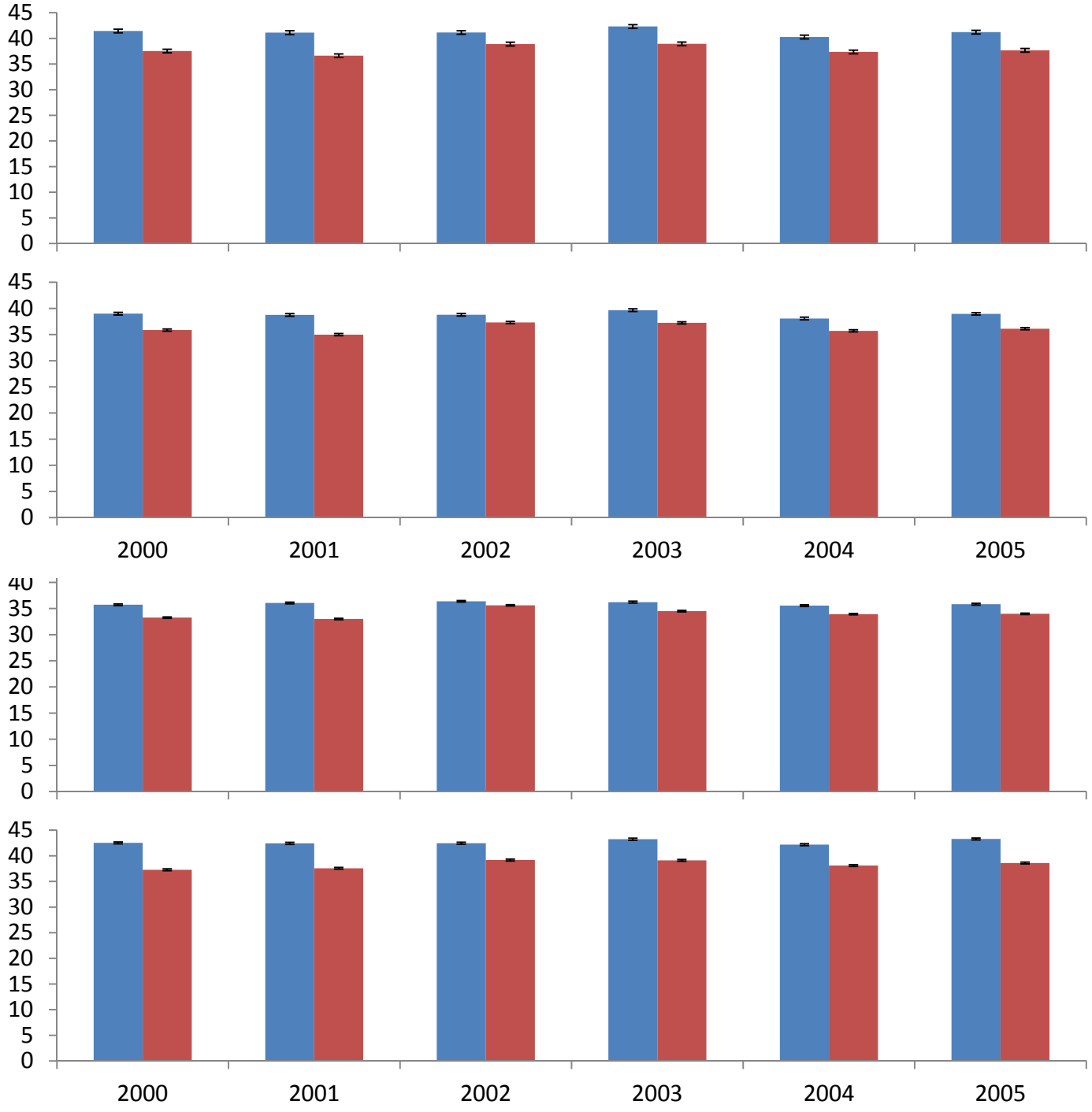
Quercus ilex

Total number of plots= 1511

Methodology: building of the starting database (II) (2000-2005)

Effects of tropospheric ozone (O_3) on Crown Defoliation

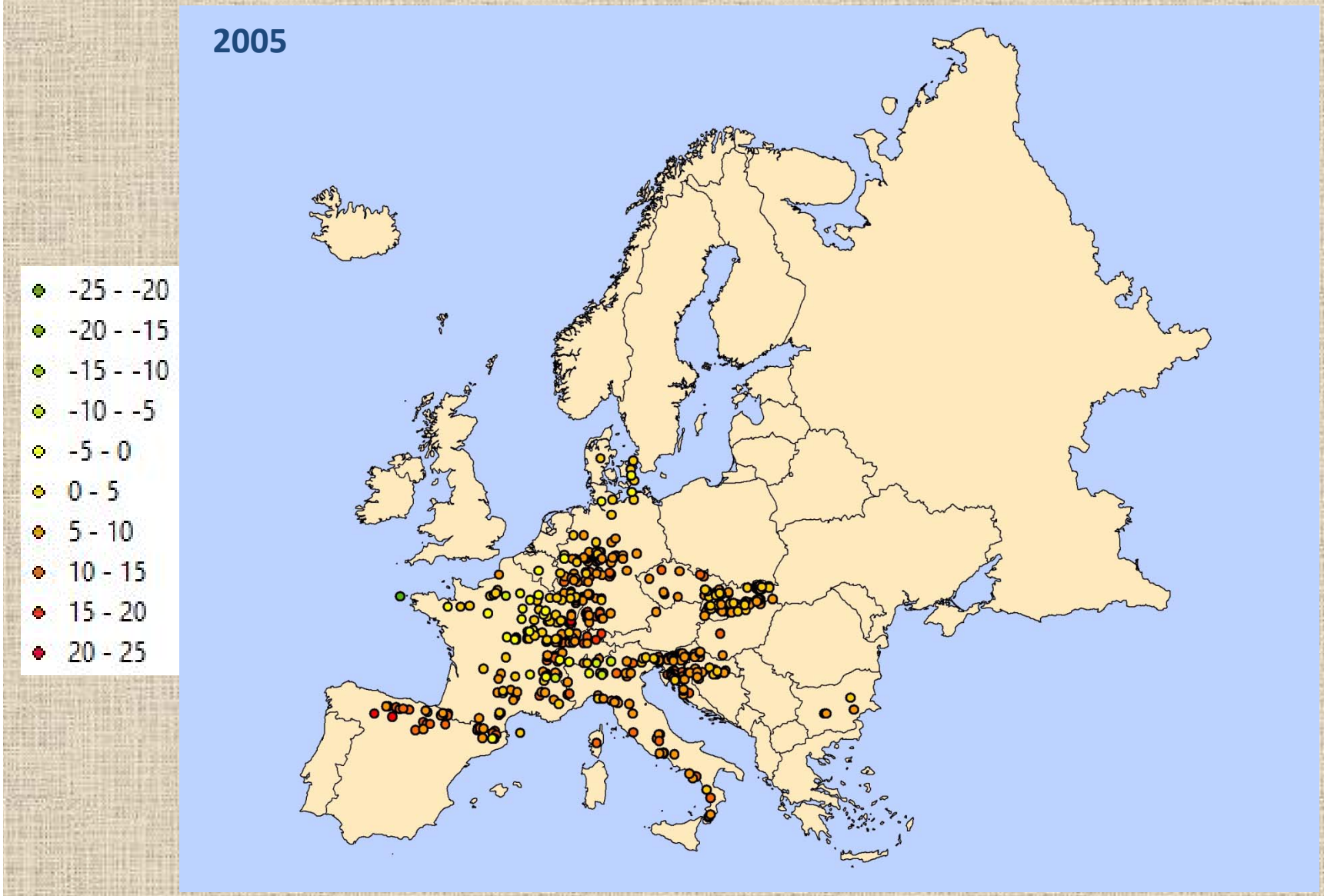




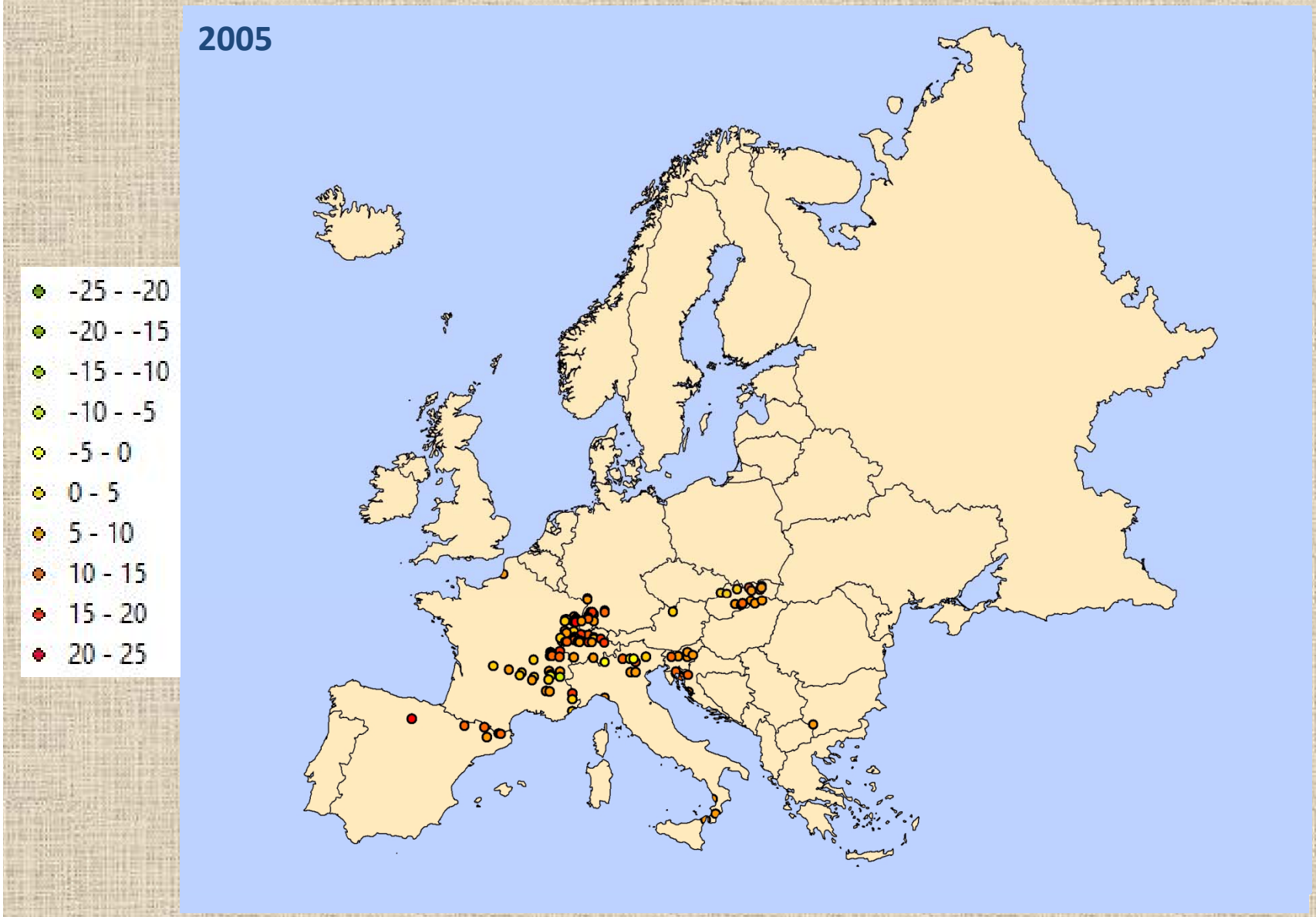
O3 CONCENTRATION ppb

Mean ± S.E.

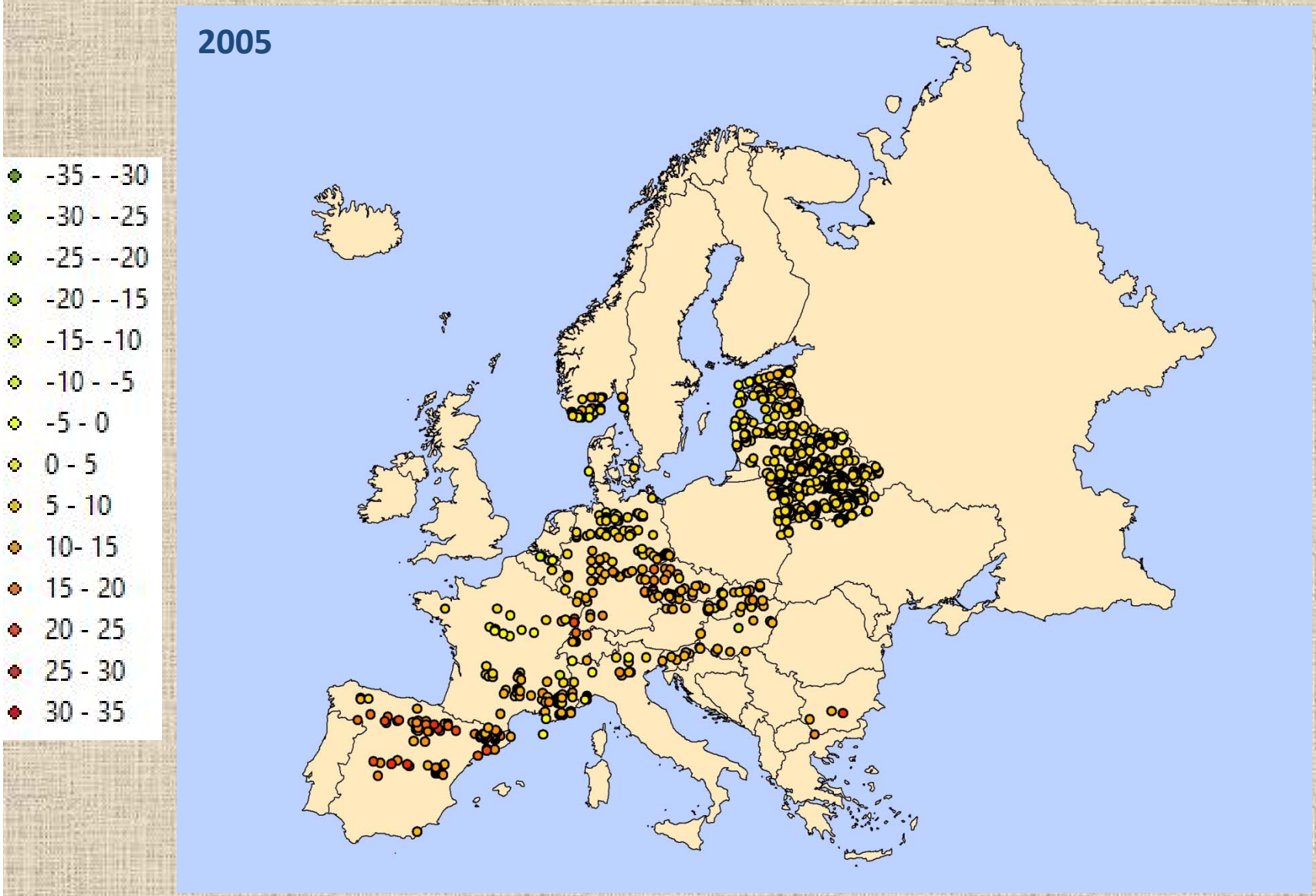
WRF/CHIMERE - EMEP (%), O_3 CONCENTRATION (ppb), *FAGUS SYLVATICA PLOTS*



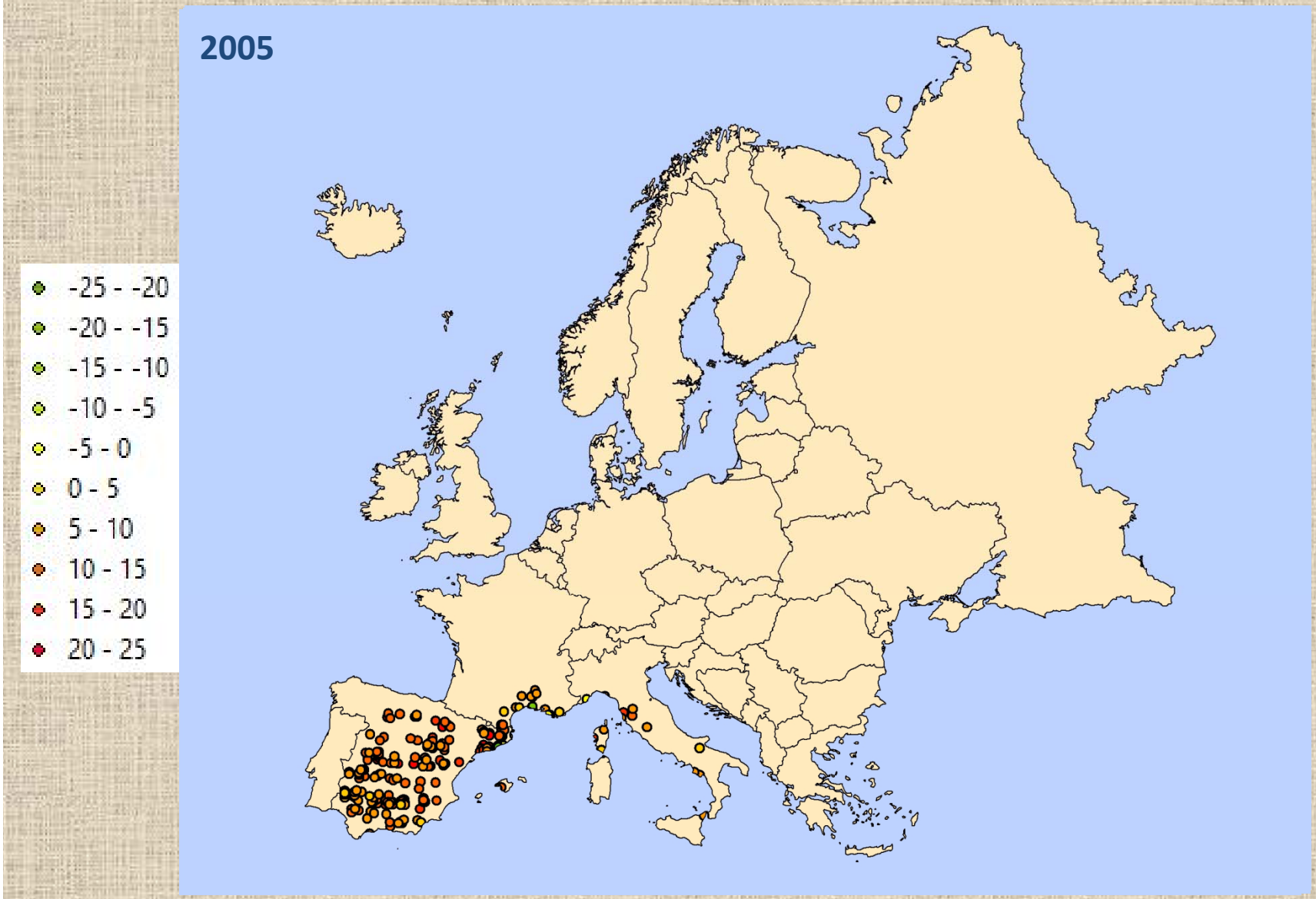
WRF/CHIMERE - EMEP (%), O_3 CONCENTRATION (ppb), *ABIES ALBA PLOTS*

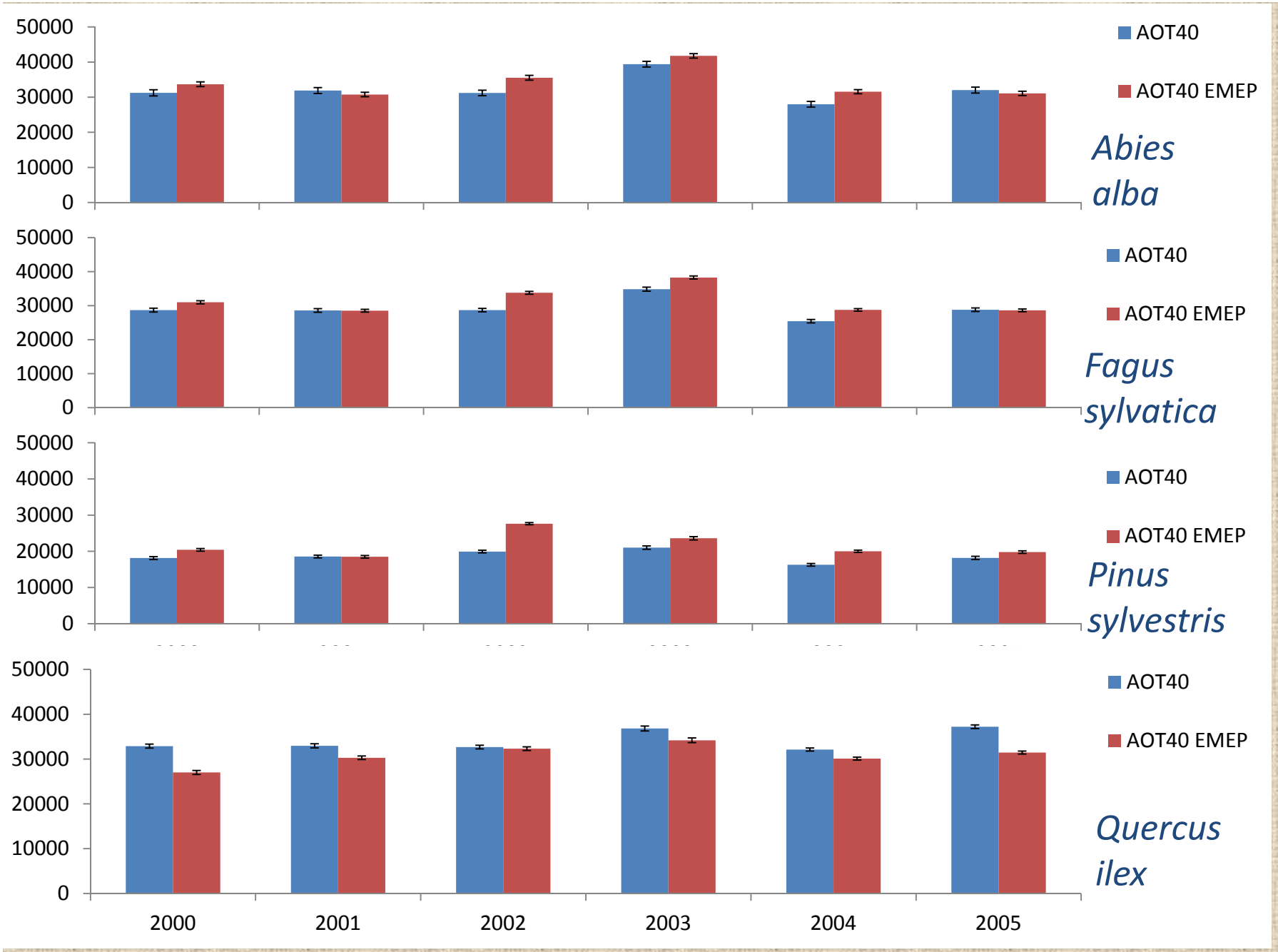


WRF/CHIMERE - EMEP (%), O_3 CONCENTRATION (ppb), *PINUS SYLVESTRIS PLOTS*



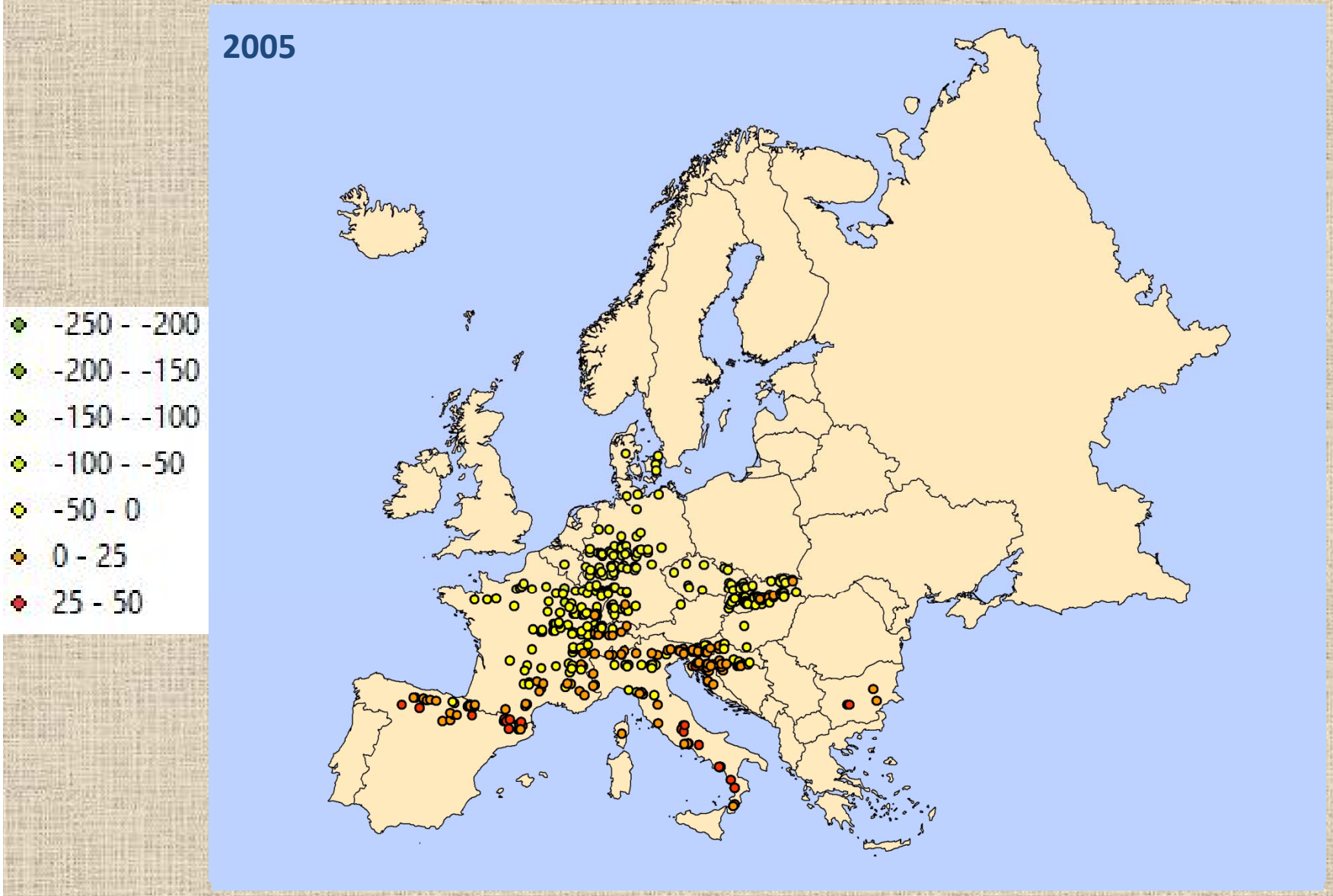
WRF/CHIMERE - EMEP (%), O_3 CONCENTRATION (ppb), *QUERCUS ILEX PLOTS*



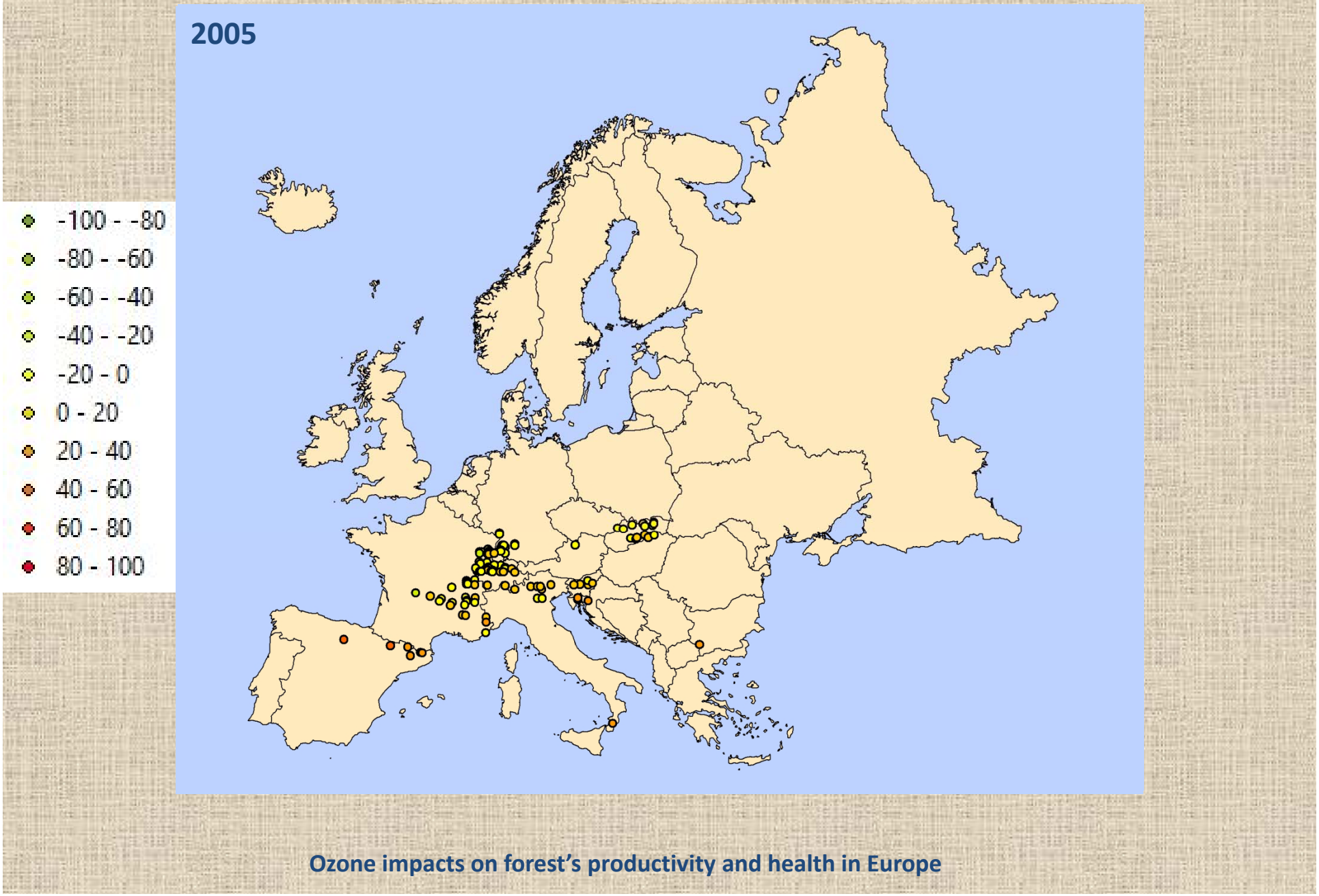

50000
40000
30000
20000
10000
0
AOT40
AOT40 EMEP
Abies alba
Fagus sylvatica
Pinus sylvestris
Quercus ilex
2000
2001
2002
2003
2004
2005
AOT40
ppb*h

Mean ± S.E.

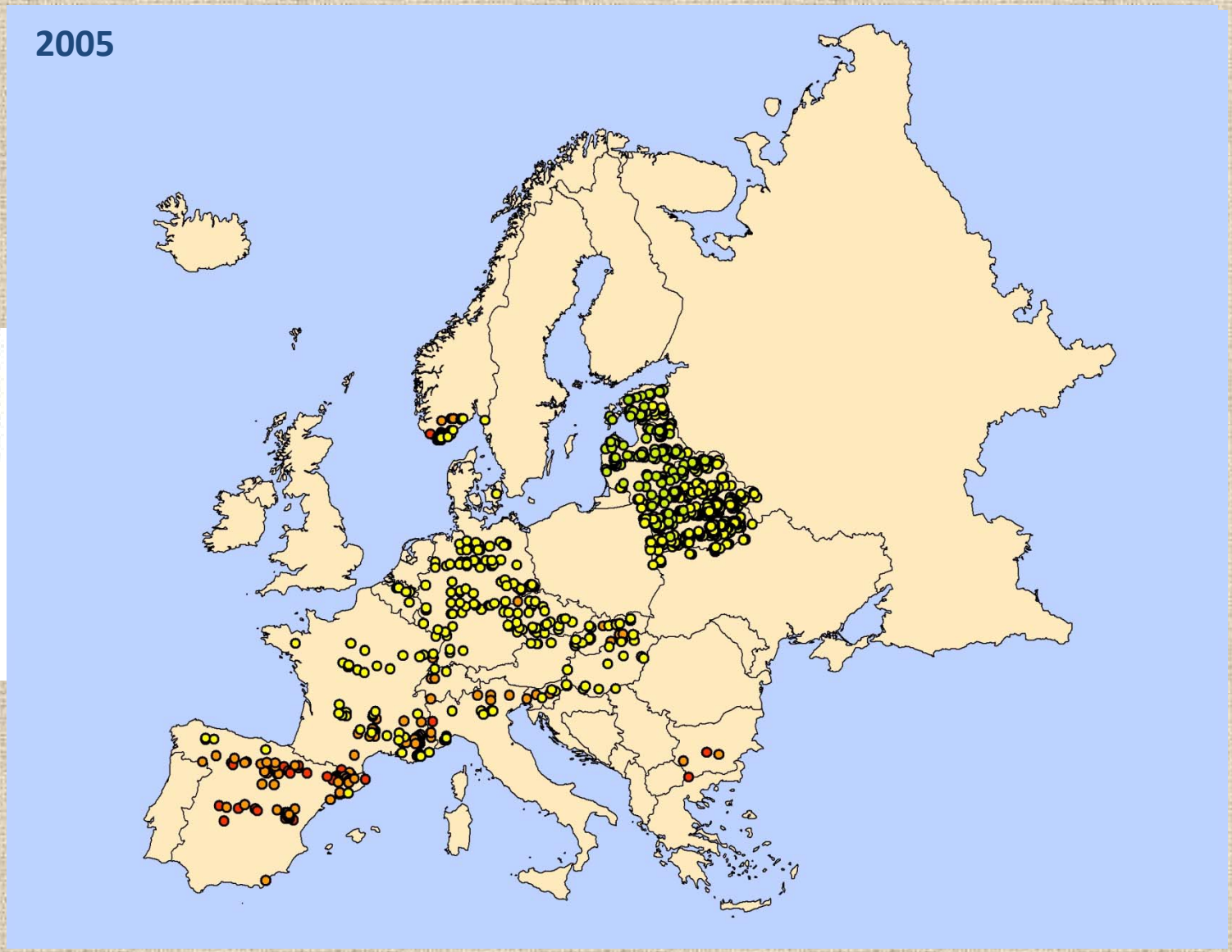
WRF/CHIMERE - EMEP (%), AOT40 (ppb*h), *FAGUS SYLVATICA PLOTS*



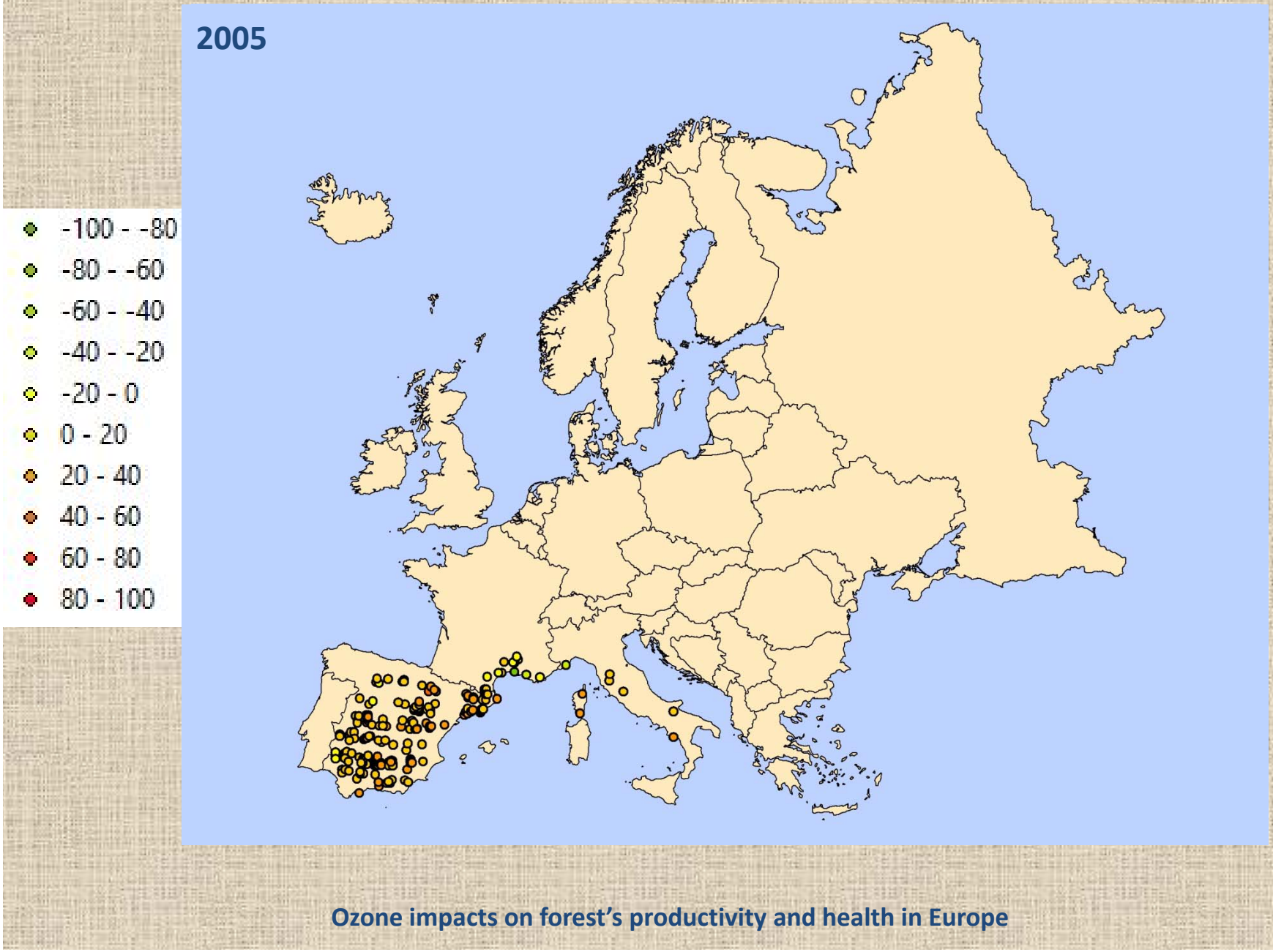
WRF/CHIMERE - EMEP (%), AOT40 (ppb*h), *ABIES ALBA PLOTS*

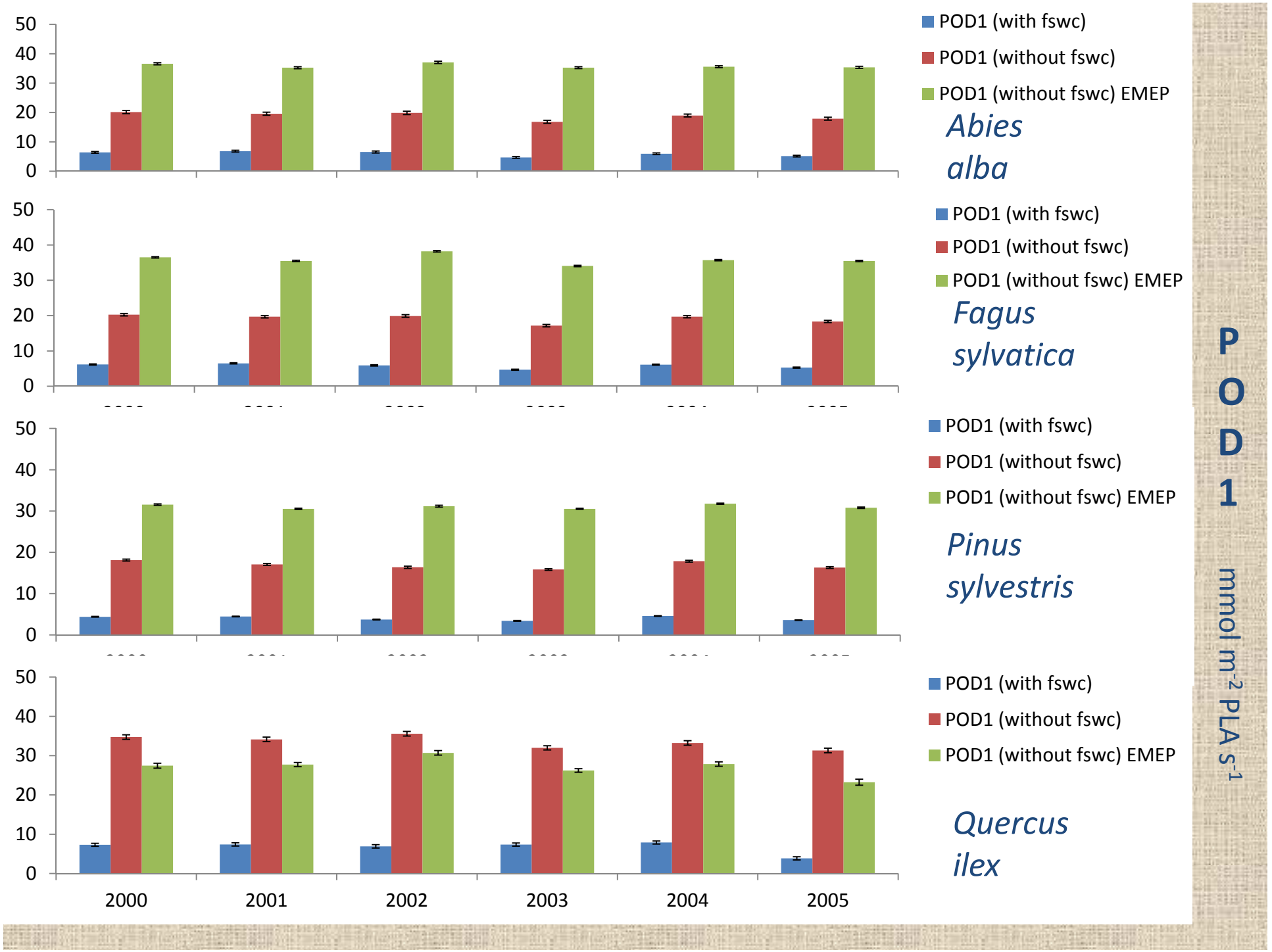


WRF/CHIMERE - EMEP (%), AOT40 (ppb*h), *PINUS SYLVESTRIS PLOTS*

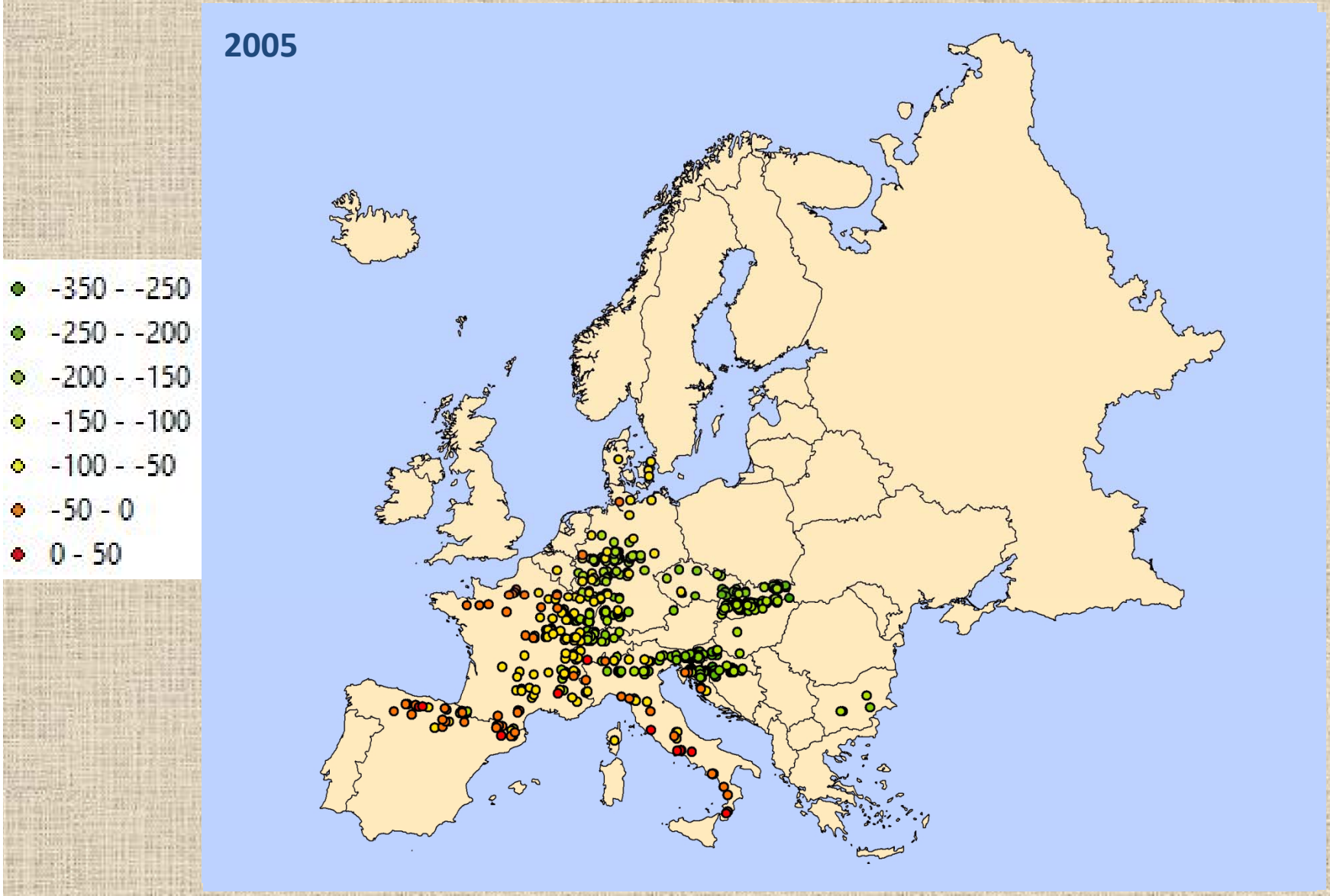


WRF/CHIMERE - EMEP (%), AOT40 (ppb*h), *QUERCUS ILEX PLOTS*

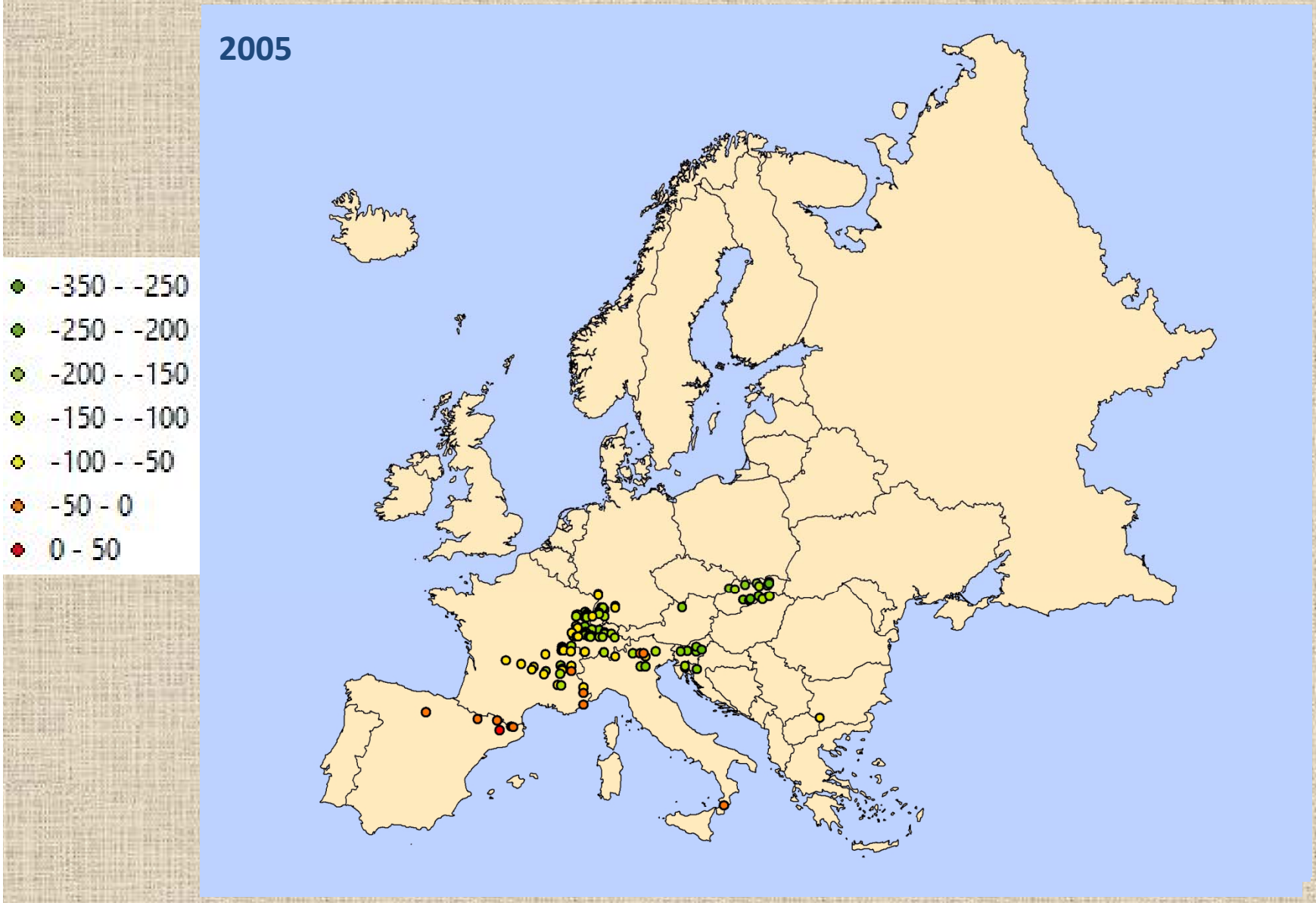



50
40
30
20
10
0
POD1 (with fswc)
POD1 (without fswc)
POD1 (without fswc) EMEP
Abies alba
Fagus sylvatica
Pinus sylvestris
Quercus ilex
2000
2001
2002
2003
2004
2005
POD1
mmol m-2 PLA s-1

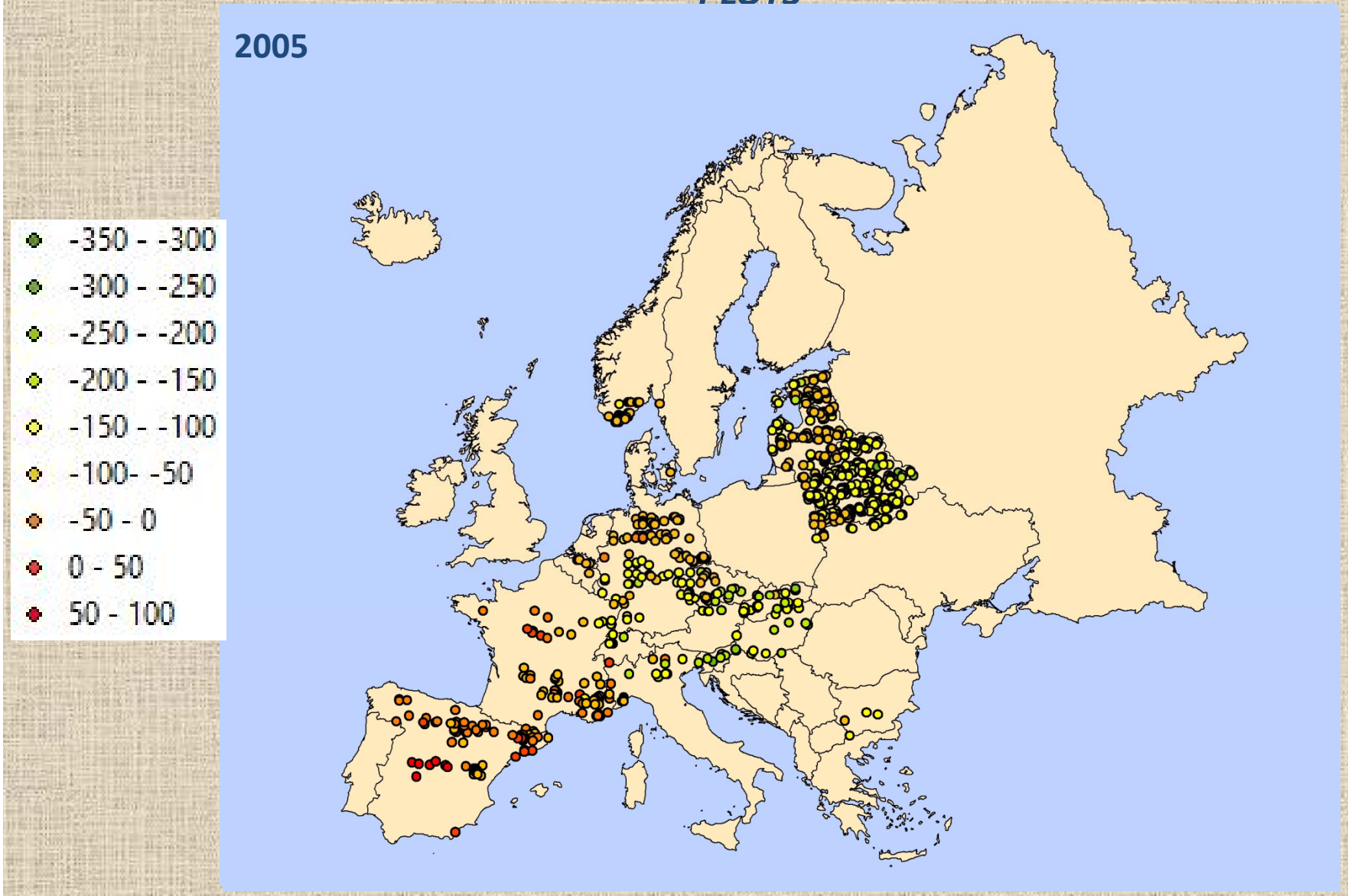
WRF/CHIMERE - EMEP (%), POD1 (mmol m^{-2} PLA s^{-1}) FAGUS SYLVATICA PLOTS



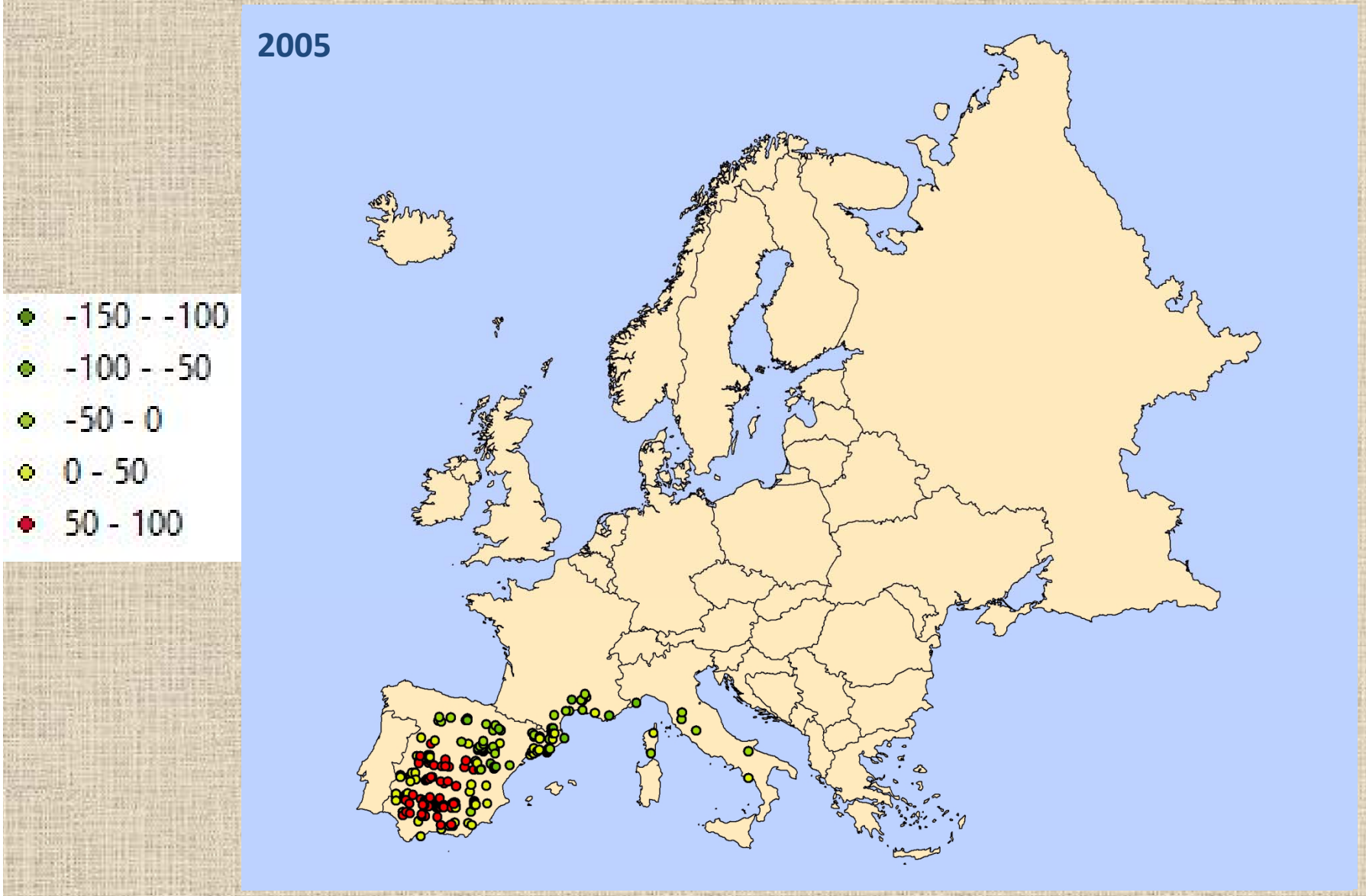
WRF/CHIMERE - EMEP (%), POD1 (mmol m^{-2} PLA s^{-1}), *ABIES ALBA PLOTS*



WRF/CHIMERE - EMEP (%), POD1 (mmol m^{-2} PLA s^{-1}), *PINUS SYLVESTRIS PLOTS*

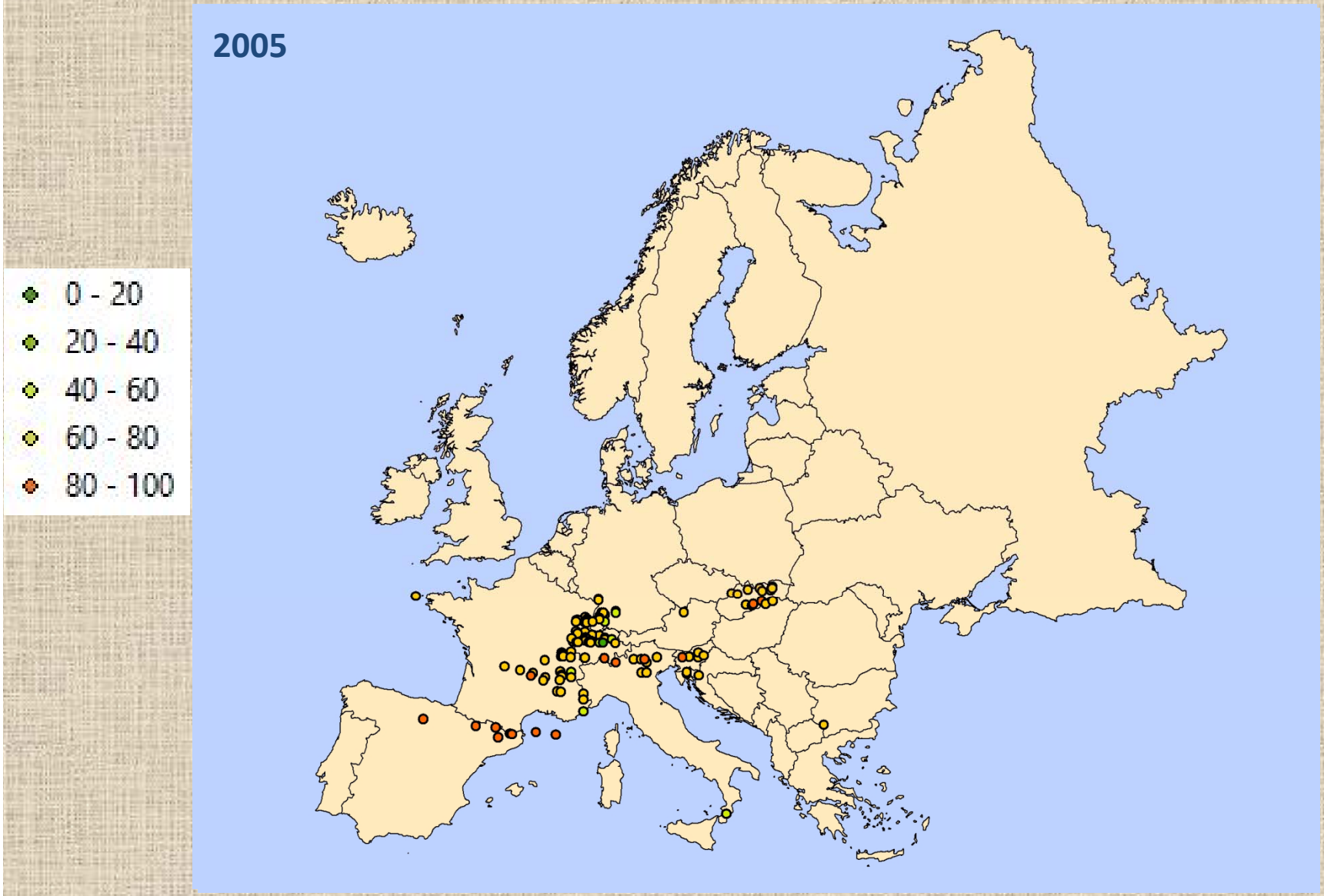


WRF/CHIMERE - EMEP (%), POD1 (mmol m^{-2} PLA s^{-1}), *QUERCUS ILEX PLOTS*

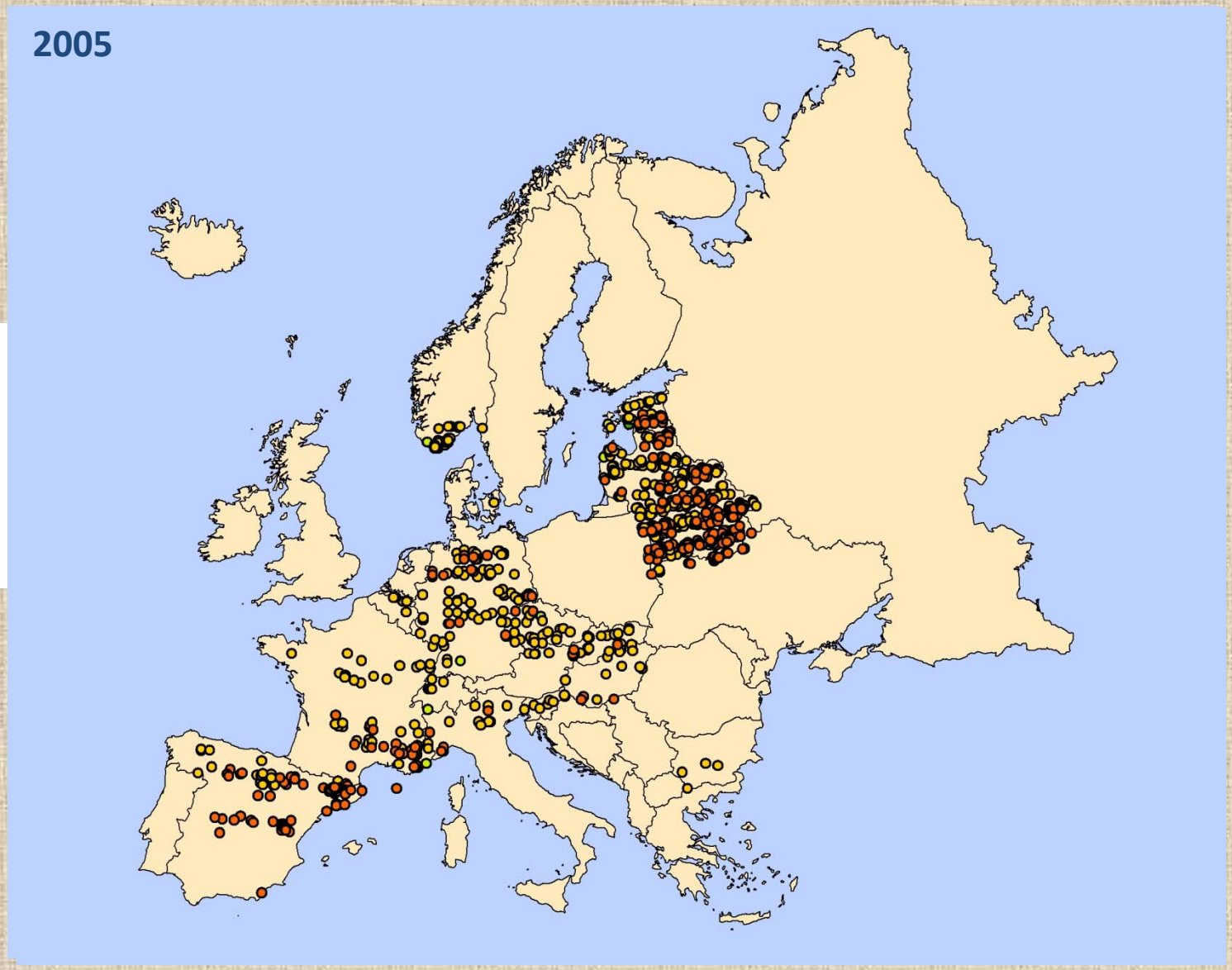


WRF/CHIMERE POD1 (NO SWC)- WRF/CHIMERE POD1 (WITH SWC) (%), *FAGUS SYLVATICA PLOTS* (mmol m^{-2} PLA s^{-1})

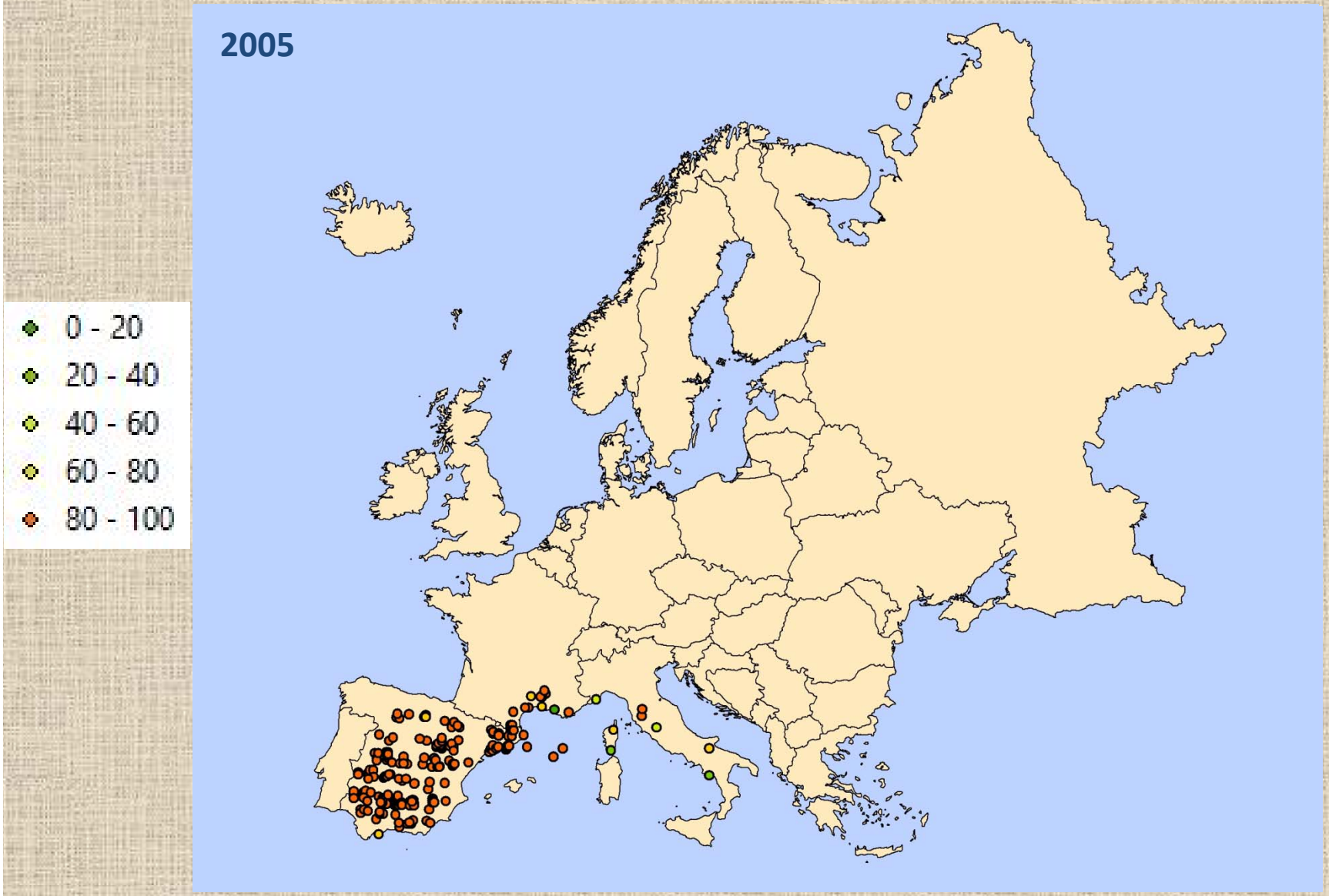
WRF/CHIMERE POD1 (NO SWC)- WRF/CHIMERE POD1 (WITH SWC) (%), *ABIES ALBA PLOTS* (mmol m^{-2} PLA s^{-1})



WRF/CHIMERE POD1 (NO SWC)- WRF/CHIMERE POD1 (WITH SWC) (%), *PINUS SYLVESTRIS PLOTS* (mmol m^{-2} PLA s^{-1})



WRF/CHIMERE POD1 (NO SWC)- WRF/CHIMERE POD1 (WITH SWC) (%), *QUERCUS ILEX PLOTS* (mmol m^{-2} PLA s^{-1})



Some considerations:

Strong inconsistency between WRF-Chimere model and EMEP model in the ICP Forests plots;

The mean annual ozone concentration simulated by CHIMERE is higher than EMEP ; it is remarkable and unexpected how this latter shows a higher AOT40 than CHIMERE

Large difference in POD1 magnitude when including soil water content function (especially in Mediterranean area)

Analyse the effect of ozone simulated by WRF-CHIMERE and EMEP model on crown defoliation

$$AOT\,40 = \begin{cases} \int_{t=01-Jan}^{31-Dec} \max([O_3]-40,0)dt; g_{sto} > 0 \\ 0; g_{sto} = 0 \end{cases}$$

gs

where $[O_3]$ is the hourly O_3 concentration (ppb), t is the integration time (1 hour) and g_{sto} is the stomatal conductance

Correlation analysis

Defoliation 2000

	AOT40	AOT40 GS	POD1 (with fswc)	POD1 (without fswc)	O3 concentration
Abies alba	0.279808	0.334400	-0.251635	-0.289300	
Fagus sylvatica					-0.200479
Pinus sylvestris			-0.125706	-0.080439	
Quercus ilex				0.252089	
	AOT40 EMEP	Oxidized nitrogen	Reduced nitrogen	POD1 (without fswc) EMEP	O3 concentration EMEP
Abies alba				0.229943	
Fagus sylvatica		0.266086	0.160539		-0.169762
Pinus sylvestris				0.110171	-0.138628
Quercus ilex					

$p<0.05$

Correlation analysis

Defoliation 2003

2002 data

	AOT40	AOT40 GS	POD1 (with fswc)	POD1 (without fswc)	O3 concentration
Abies alba		0.216510	-0.302851	-0.399549	
Fagus sylvatica					
Pinus sylvestris	0.243579	0.285641	0.099715	0.110922	0.120642
Quercus ilex					
	AOT40 EMEP	Oxidized nitrogen	Reduced nitrogen	POD1 (without fswc) EMEP	O3 concentration EMEP
Abies alba				0.219017	
Fagus sylvatica	0.154131	0.145795	0.104713	0.159485	-0.062849
Pinus sylvestris		0.245729	0.204544	0.299978	0.073472
Quercus ilex		0.173950	0.151180		

2003 data

	AOT40	AOT40 GS	POD1 (with fswc)	POD1 (without fswc)	O3 concentration
Abies alba			-0.282501	-0.364972	
Fagus sylvatica					
Pinus sylvestris	0.254592	0.291686	0.097503		0.149163
Quercus ilex					
	AOT40 EMEP	Oxidized nitrogen	Reduced nitrogen	POD1 (without fswc) EMEP	O3 concentration EMEP
Abies alba				0.228459	
Fagus sylvatica	0.109094	0.138925			
Pinus sylvestris		0.253401	0.205220	0.228328	0.126090
Quercus ilex		0.184335			

$p<0.05$

Correlation analysis

Defoliation 2005

2004 data

	AOT40	AOT40 GS	POD1 (with fswc)	POD1 (without fswc)	O3 concentration
Abies alba	0.269528	0.293519		-0.228349	0.207111
Fagus sylvatica	-0.101052	-0.101624			-0.108026
Pinus sylvestris	0.218153	0.272580	0.159492	0.155700	0.116056
Quercus ilex					

	Oxidized nitrogen	Reduced nitrogen	AOT40 EMEP	O3 concentration EMEP	POD1 (without fswc) EMEP
Abies alba	0.314229				
Fagus sylvatica				-0.115819	-0.110585
Pinus sylvestris	0.255910	0.149633	0.308474	0.077323	0.289296
Quercus ilex	0.210579	0.149401	0.121656	0.072327	0.190408

2005 data

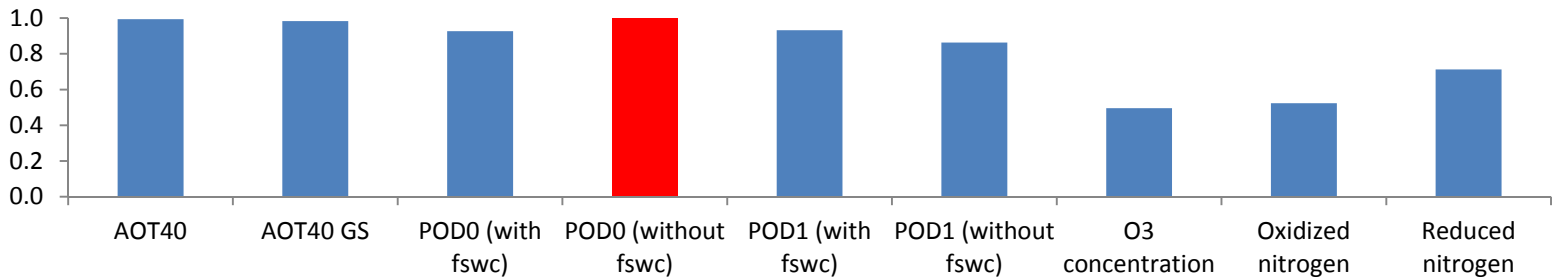
	AOT40	AOT40 GS	POD1 (with fswc)	POD1 (without fswc)	O3 concentration
Abies alba	0.258619	0.269542	-0.198894	-0.258554	
Fagus sylvatica					
Pinus sylvestris	0.234271	0.282363	0.124338	0.153082	0.144075
Quercus ilex					

	Oxidized nitrogen	Reduced nitrogen	AOT40 EMEP	O3 concentration EMEP	POD1 (without fswc) EMEP
Abies alba					
Fagus sylvatica	0.121227	0.102801		-0.107306	
Pinus sylvestris	0.266849	0.158908	0.308820	0.103882	0.297265
Quercus ilex	0.217302	0.157760			0.172487

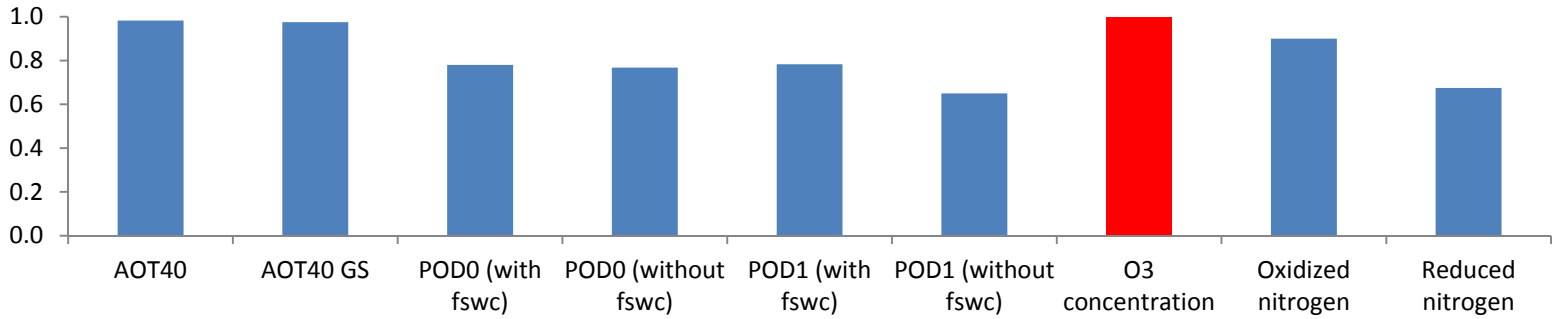
$p<0.05$

Random Forests Analysis (RFA)

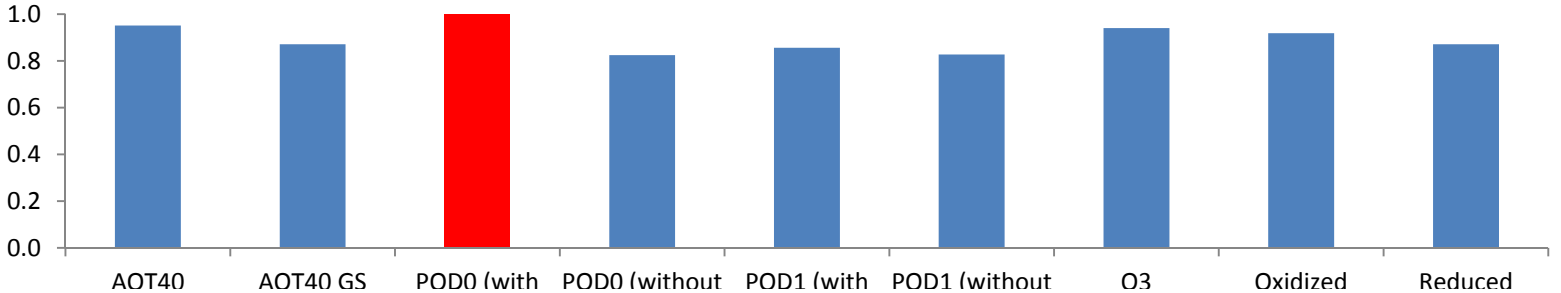
Dependent Variable: Defoliation 2000



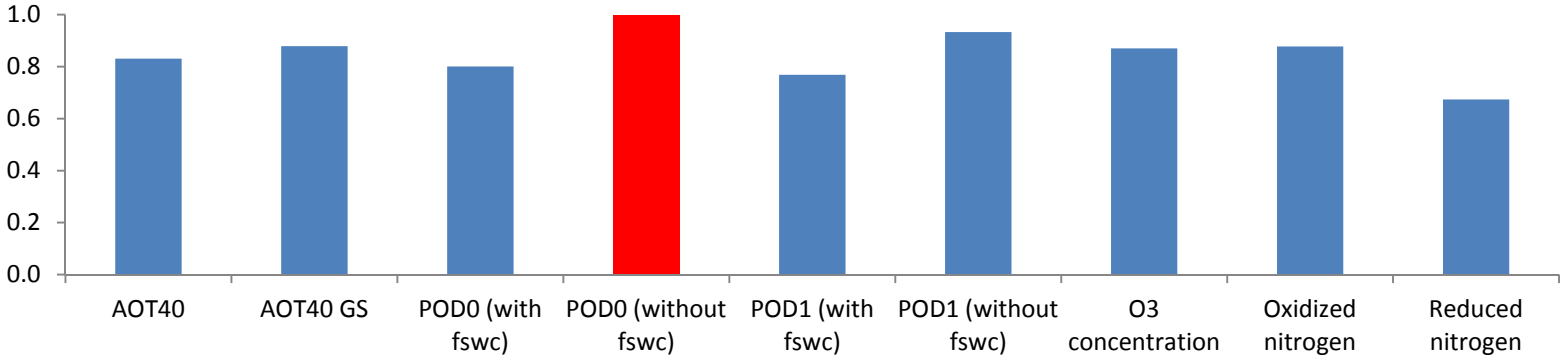
Abies alba



Fagus sylvatica



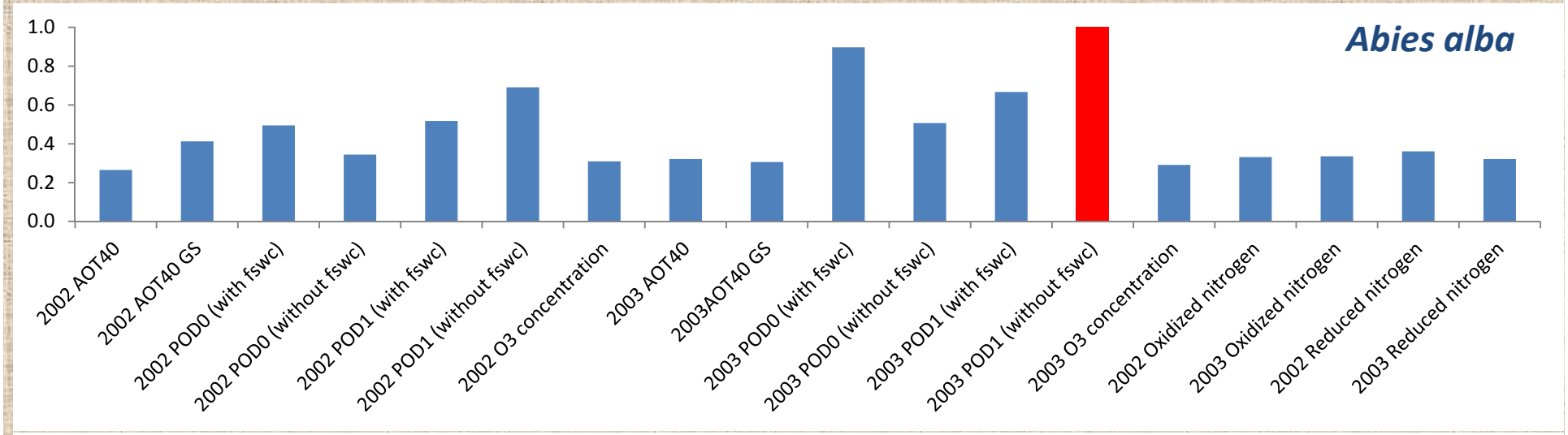
Pinus sylvestris

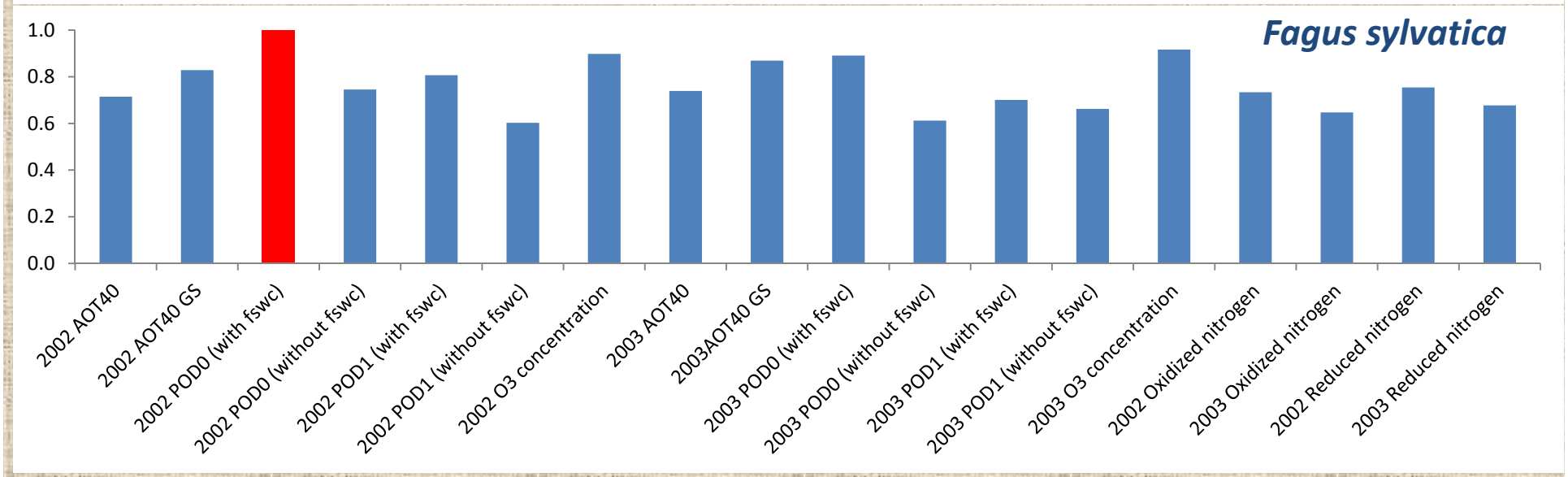


Quercus ilex

Random Forests Analysis (RFA)

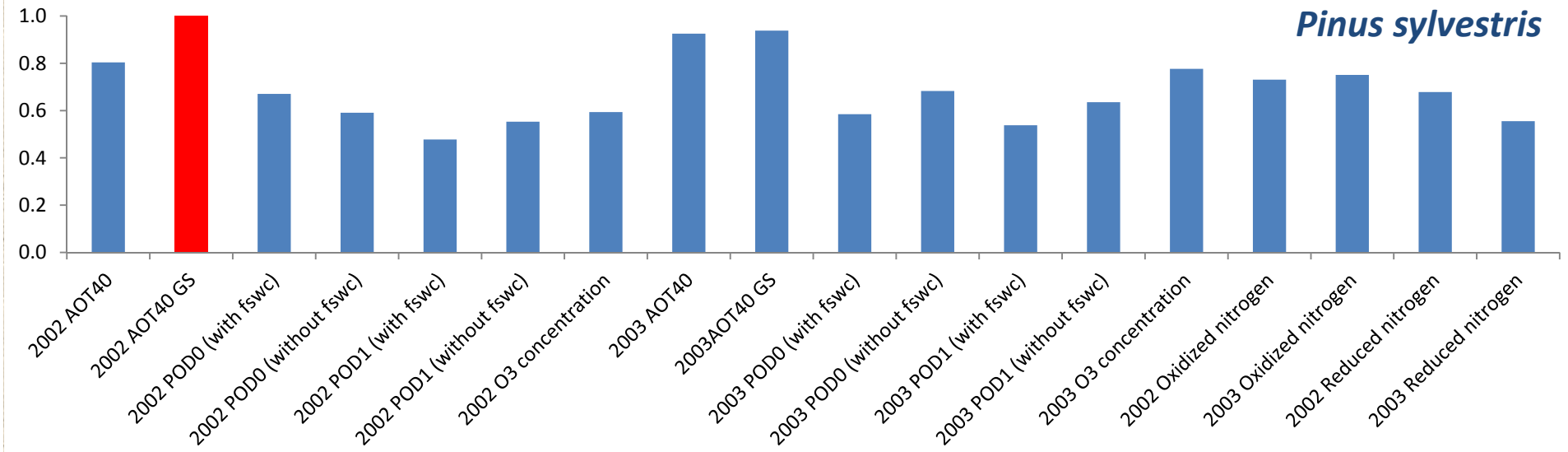
Dependent Variable: Defoliation 2003

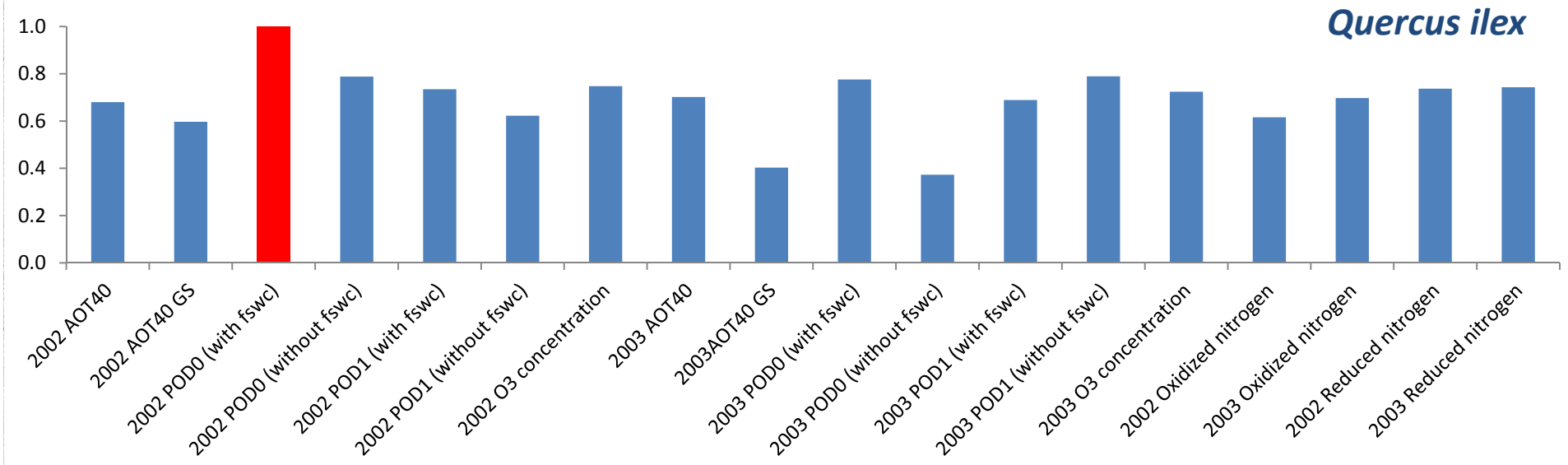




Random Forests Analysis (RFA)

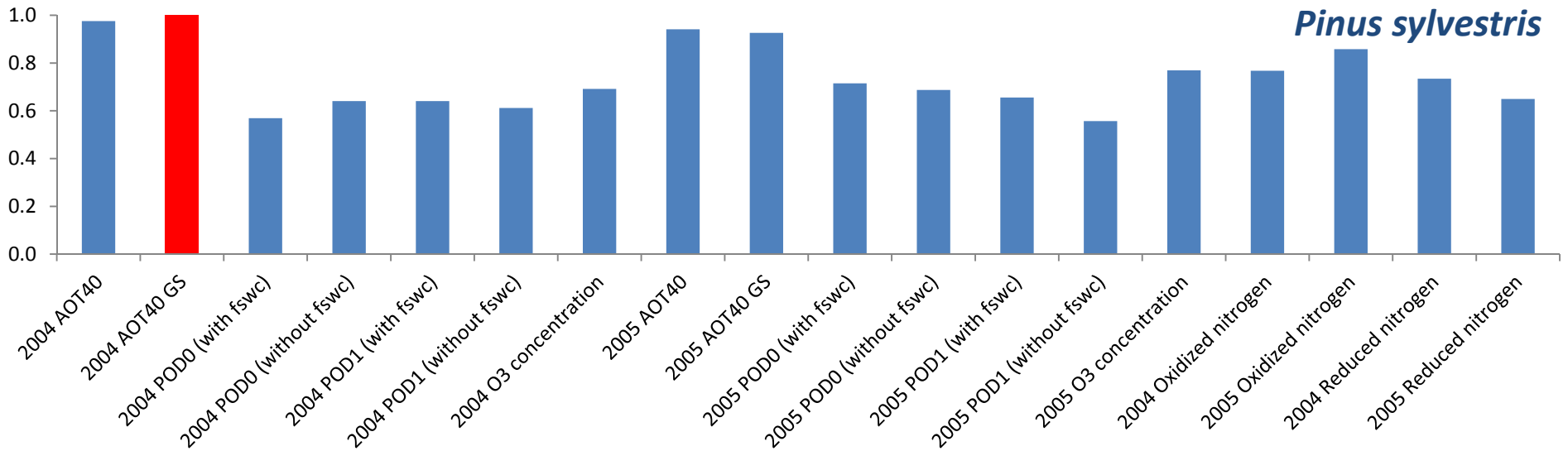
Dependent Variable: Defoliation 2003

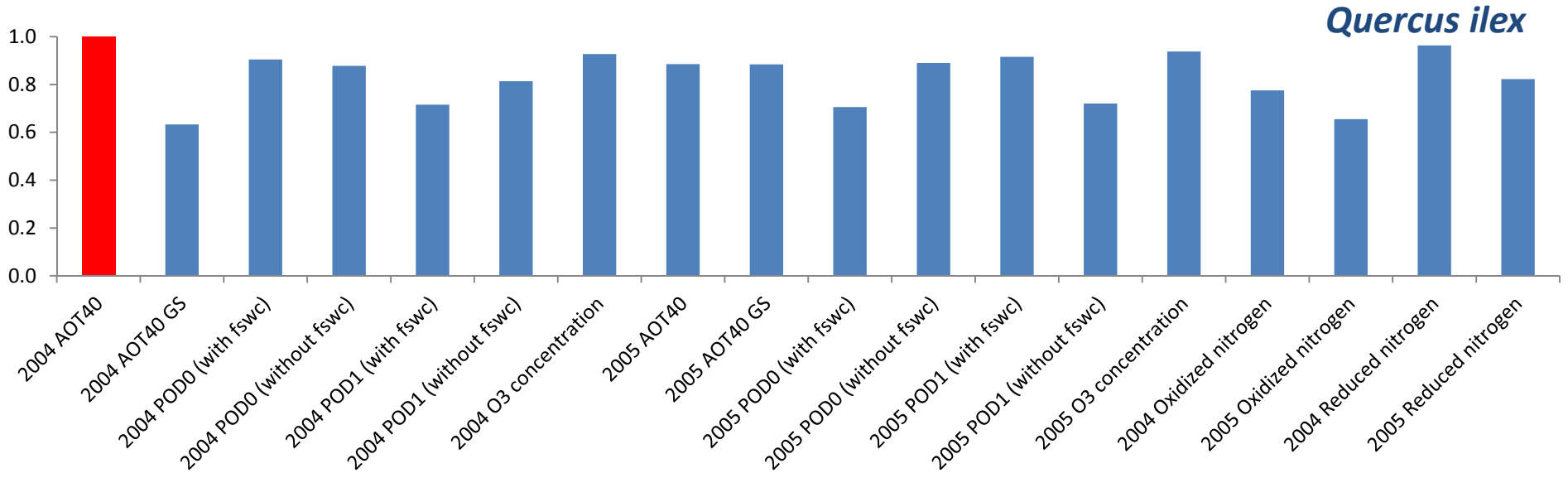




Random Forests Analysis (RFA)

Dependent Variable: Defoliation 2005





Conclusions

Climatic parameters seem to be generally more important than ozone parameters in affecting GPP;

GPP is negatively related with O_3 concentration but positively related with ozone fluxes;

Strong inconsistency between WRF-Chimere model and EMEP model in the ICP Forests plots;

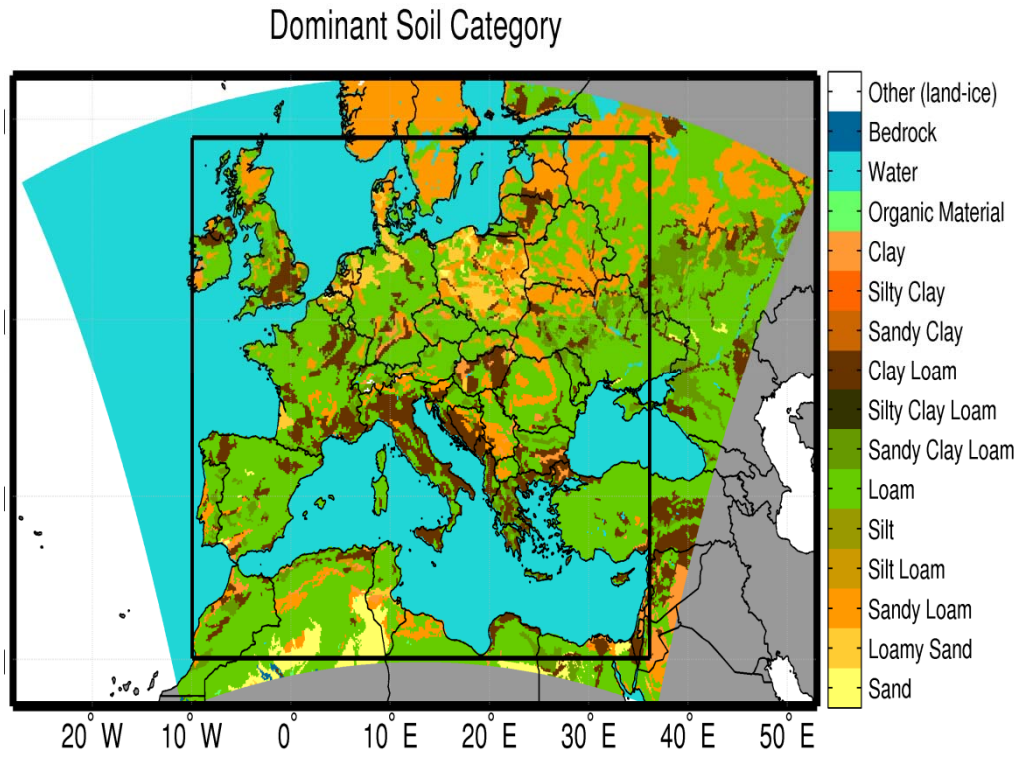
Large difference in POD1 magnitude when including soil water content function (especially in Mediterranean area);

Correlation analysis between crown defoliation and ozone (and related metrics) are extremely low and often not significant;

RFA is able to discern the most important factor affecting crown defoliation, although climatic parameters were not included in the RFA and, consequently, further investigations are needed.

Thank you

FRAMEWORK AND MODEL'S DOMAINS



WRF:

RESOLUTION: 12 Km, 400x300 points (lon/lat)

BOUNDARY CONDITIONS: ERA-INTERIM (~75km)

LSM: NOAH

3D Meteo Forcing

CHIMERE:

RESOLUTION: 12 Km, 295x270 points (lon/lat)

METEO FORCING: WRF (Offline)

EMISSIONS: EMEP

T2m, Rh2, PAR, Smois, O_3

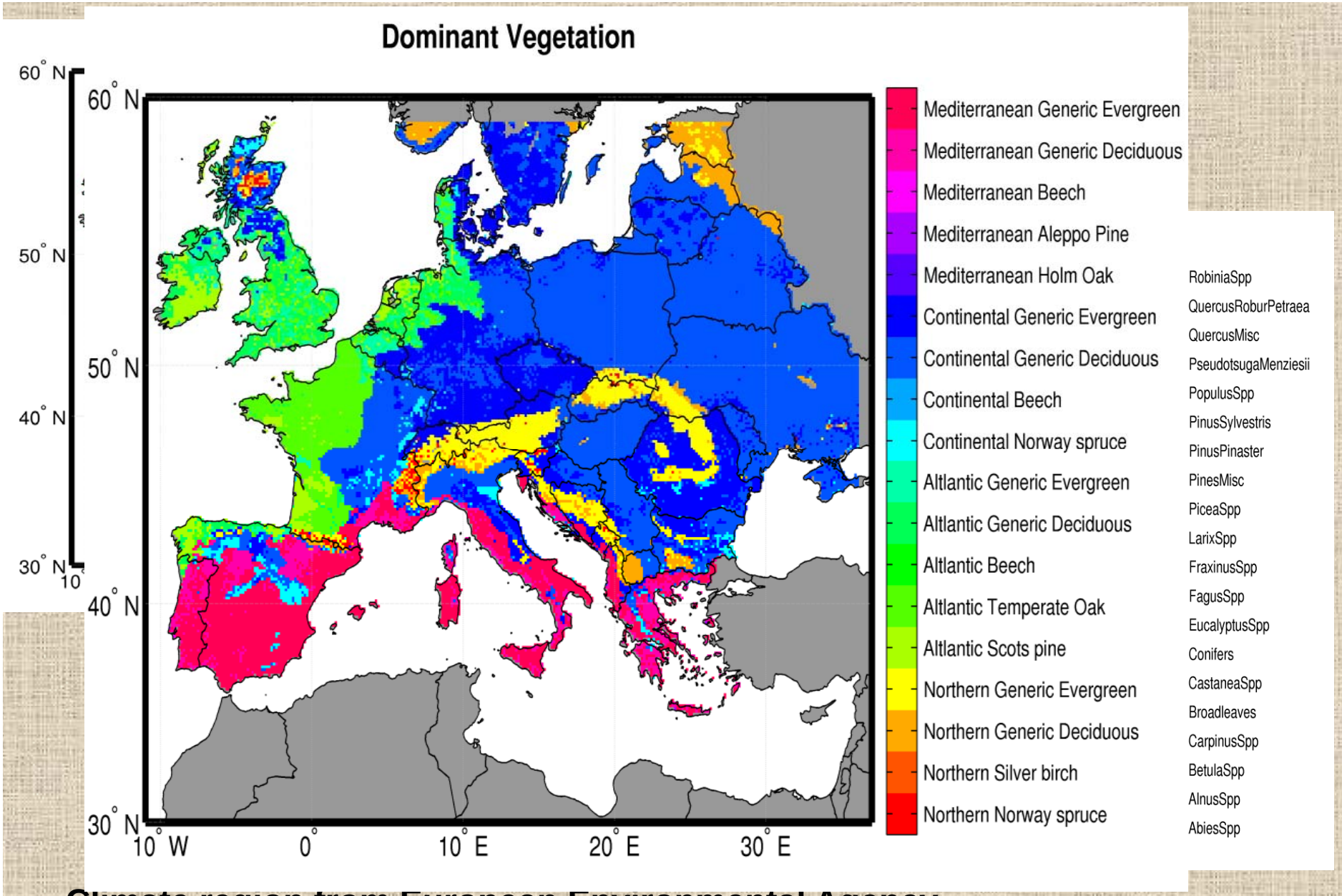
DO_3SE:

$$g_{sw} = g_{max} \cdot f_{phen} \cdot f_{light} \cdot \max\{f_{min}, (f_{temp} \cdot f_{VPD} \cdot f_{SWC})\}$$

POD0 = $\Sigma [(g_{sw} * [O_3] * 0.663]$

PODY = Σ max ((POD0 - Y), 0)

AOT40 = Σ max ((C-40), 0).dt



Climate region from European Environmental Agency

Vegetation data at 1 km resolution from EFI

"Tree species maps for European forests" *G. J. Nabuurs, D. J. Brus, G. M. Hengeveld, D. J. J. Walvoort, P. W. Goedhart, A. H. Heidema, K. Gunia* (2011)