Ozone effects on vegetation and ecosystems

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Ecotoxicology of Air Pollution - CIEMAT

Workshop on air quality policy implementation related to ozone

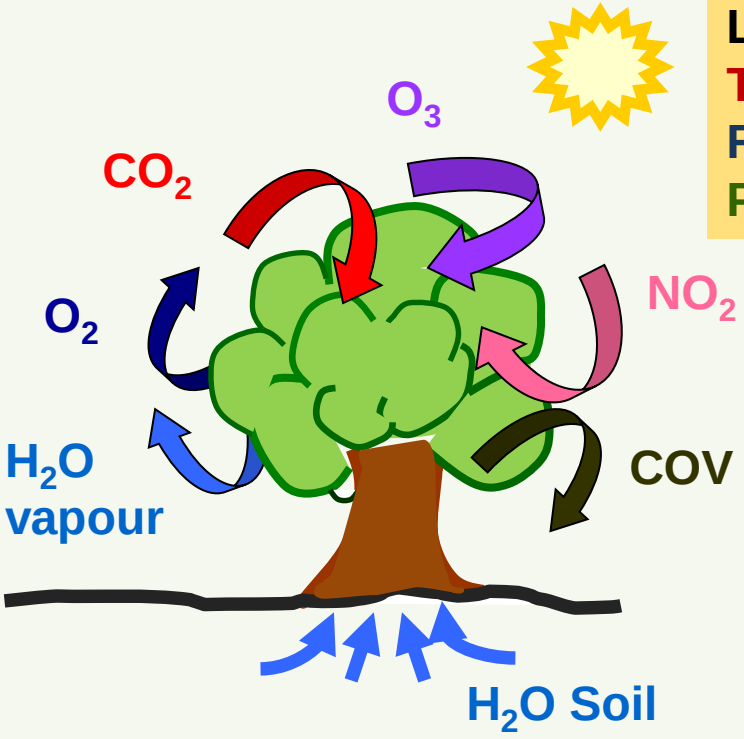
Madrid, 21-22 November 2018

Outline:

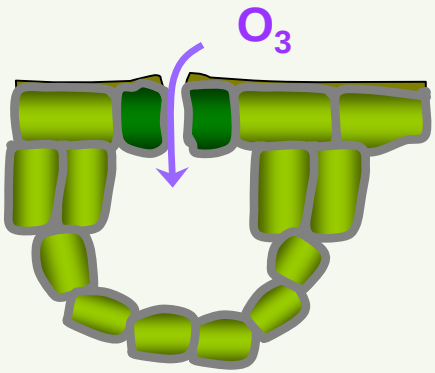
- Ozone effects on vegetation and ecosystems
- Ozone standards for the protection of vegetation
- Current challenges for improving O_3 risk assessments

Effects of ozone on vegetation

Stomata



Light
Temperature
RH
Plant condition



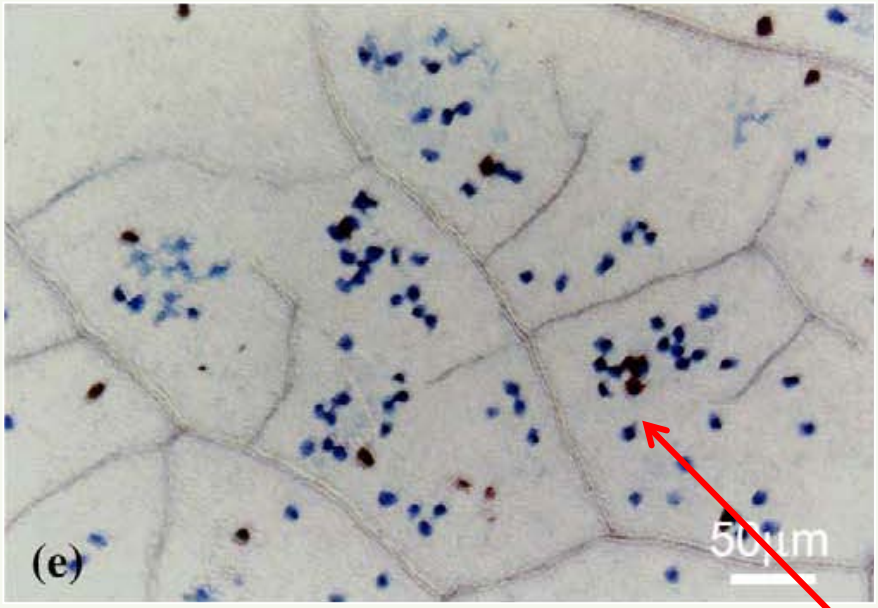
Formation of reactive oxygen species (ROS)

Effects on cellular metabolism:

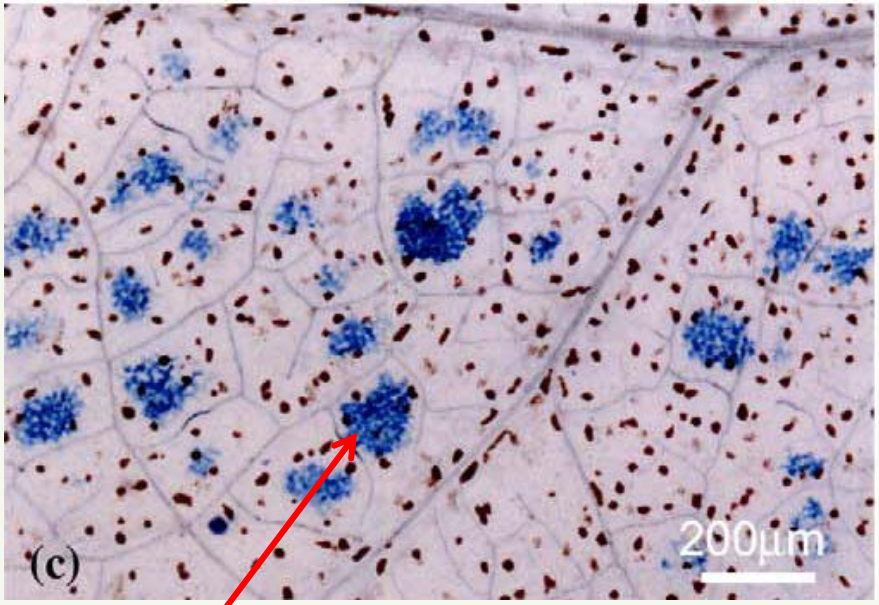
- Alteration of membrane functioning
- Cell oxidative stress
- Variation of stomata functioning
- Changes in C / N metabolism
- Tolerance / cell death

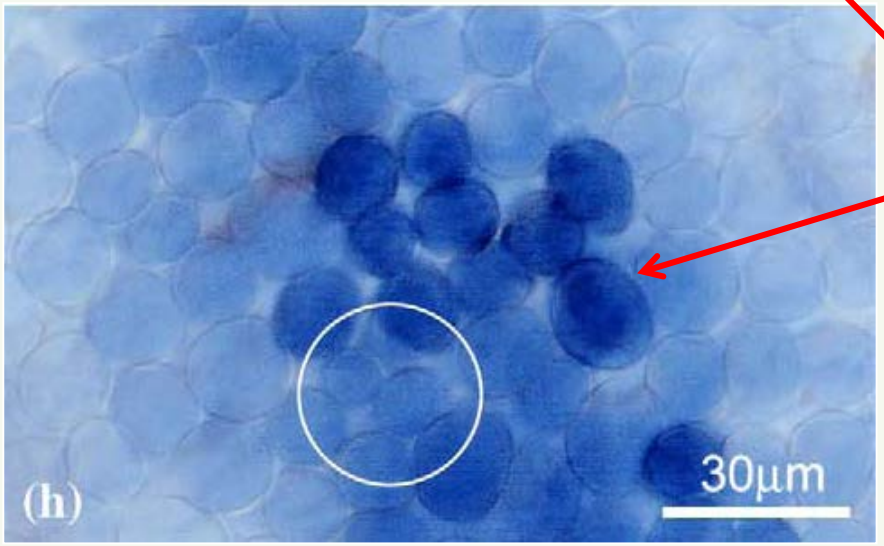
Effects of ozone on vegetation

50 ppb O_3



80 ppb O_3





Cell death

Lycopersicon pimpinellifolium

Iriti et al., 2006, *Env. Pol.*

Effects of ozone on vegetation

Visible symptoms

Tobacco var. Well W3

Lettuce var. Romana

Bean var. Lit

Spinach

Aleppo pine

Clover

Effects of ozone on vegetation

Early senescence

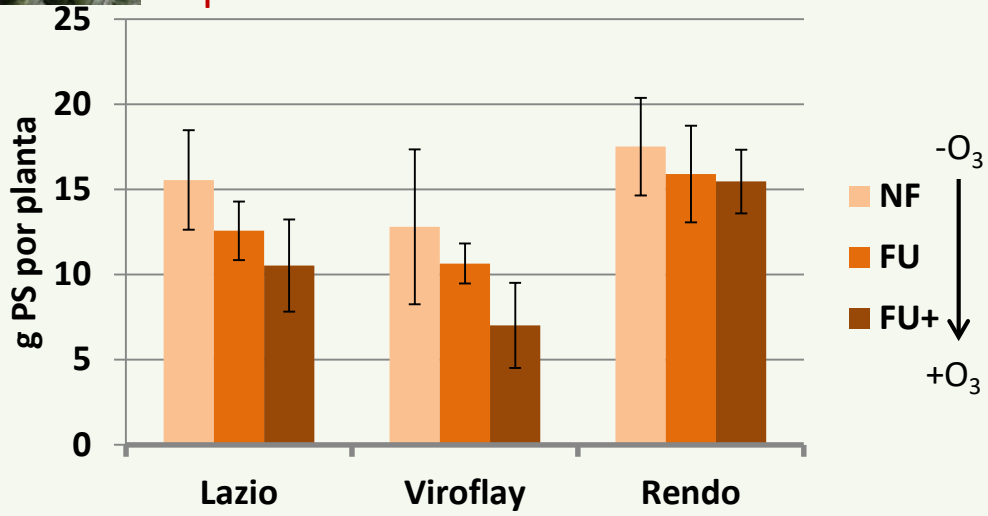
Ambient + 40 ppb O_3	Ambient + 20 ppb O_3	Ambient Air	Filtered Air

+ Ozone ← **- Ozone**

Effects of ozone on vegetation

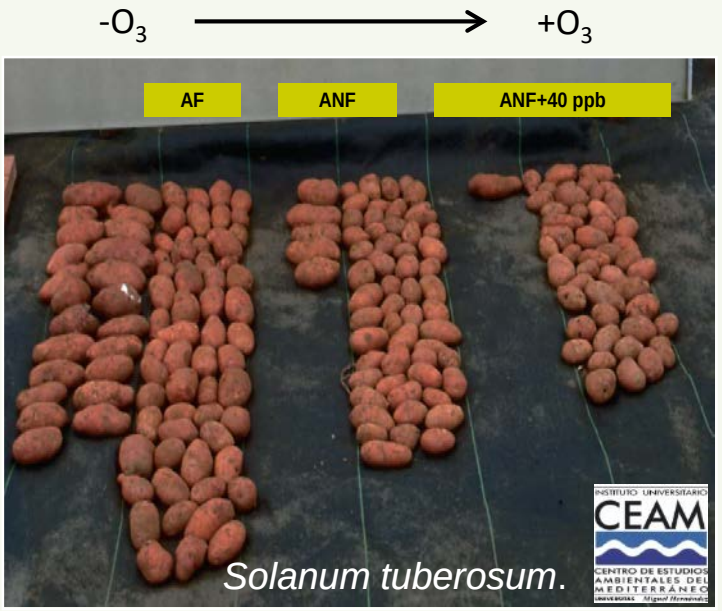
Decrease in growth / production / quality

Spinach – comercial biomass



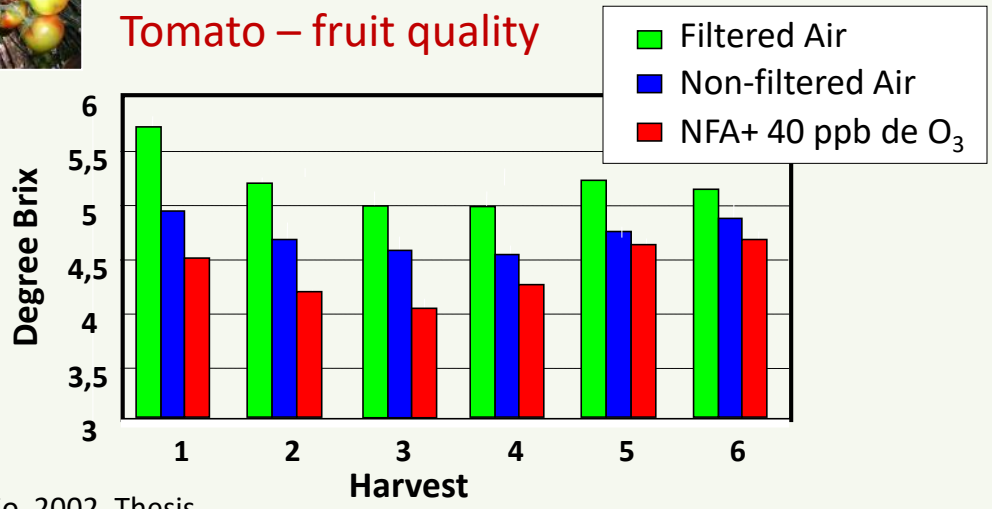
González-Fernández et al., 2016, *Agric. Eco. Env.*

Potato - production



Calvo et al., 2009, *Agric. Eco. Env.*

Tomato – fruit quality



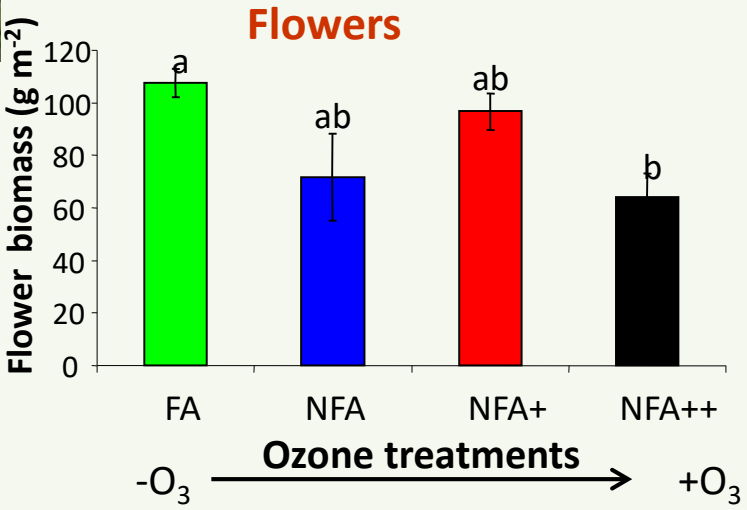
Bermejo, 2002, Thesis

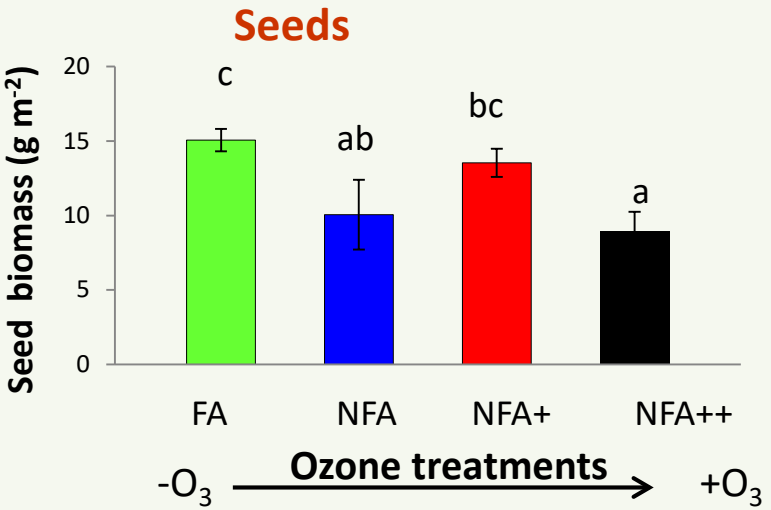
watermelon	wheat	vine
bean	corn	rape
tomato	rice	pea
lettuce	soja	cabbage
spinach	peanut	tobacco
artichoke	melon	

Effects of ozone on vegetation

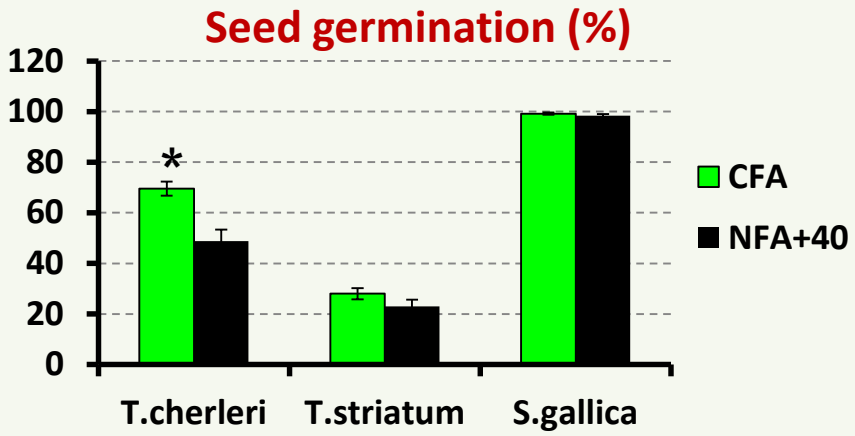
Reduction in flower and seed production

Trifolium striatum



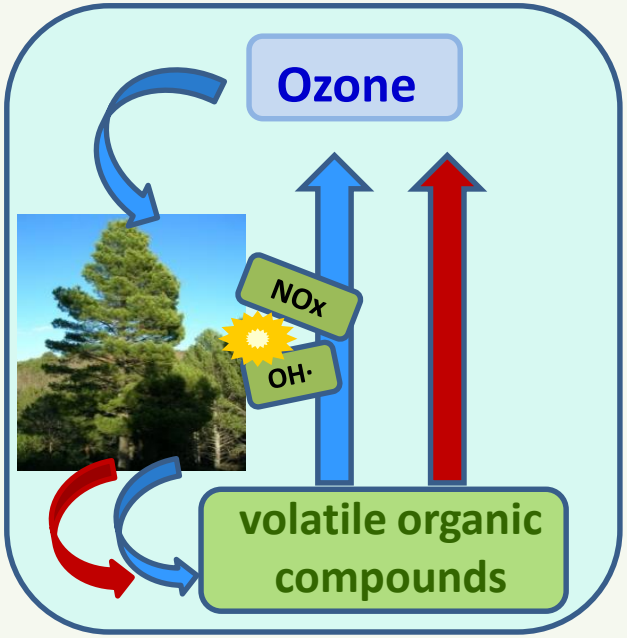


Calvete-Sogo, 2016, Thesis



Changes in communities

Effects of ozone on ecosystems



- Changes in emissions of biogenic volatile organic compounds
- Degradation of floral scent and reduction of pollinator attraction to flowers

Farré-Armengol et al. (2015)

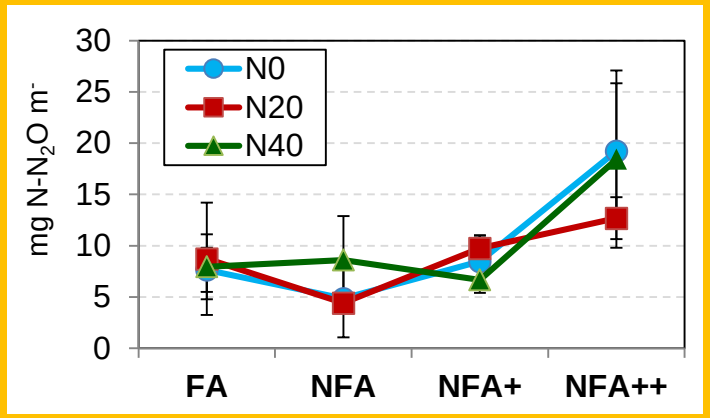

Bombus terrestris


Brassica nigra

Increase in soil N_2O emissions

annual pastures

Sánchez-Martín et al. (2017)



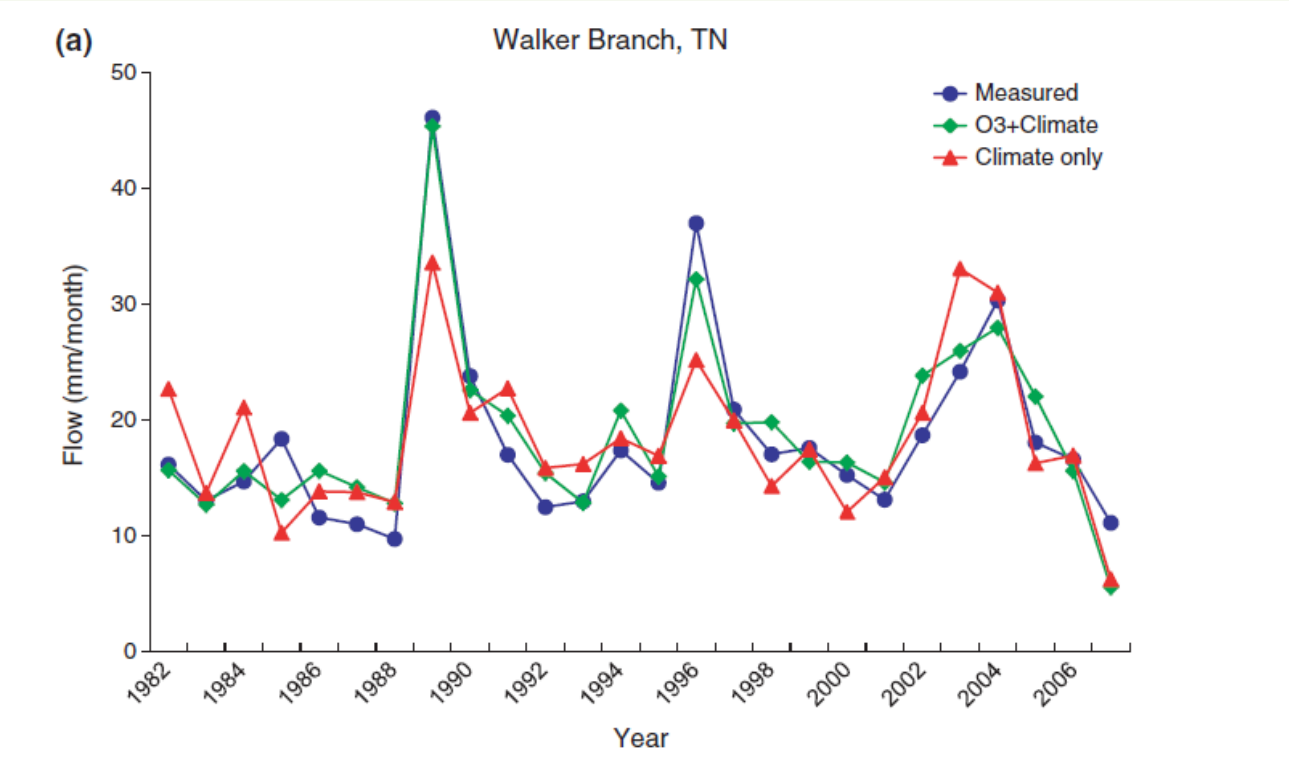
GHG → Climate change

→ Changes in soil communities and biogeochemistry

Effects of ozone on ecosystems

Predispose to drought stress / changes in ecosystem hydrological relationships

Ozone → ↑ Whole-tree canopy conductance → ↓ Soil mosture in rooting zone; ↓ Streamflow



Apalachian mixed forests (USA)

Sun et al., 2012, *GCB*

Effects of ozone on vegetation and ecosystems

- Visible symptoms
- Early senescence
- Decrease in growth
- Decrease in production/quality
- Decrease in flowers/seeds
- Changes in communities
- Predispose plant to other stress: pests, drought
- Changes in atmospheric chemistry
- Changes in ecosystem hydrology
- Contributing to the smog

Effects on ecosystem services

- ✓ Reducing **provisioning services**: crops, timber, genetic resources, water
- ✓ Affectting **regulating services**: reducing C sequestration, climate regulation, water regulation, erosion, pollination, pest control
- ✓ Changes in biodiversity: **supporting services**

Control of tropospheric ozone

European Air Quality Directive (2008/50/EC)

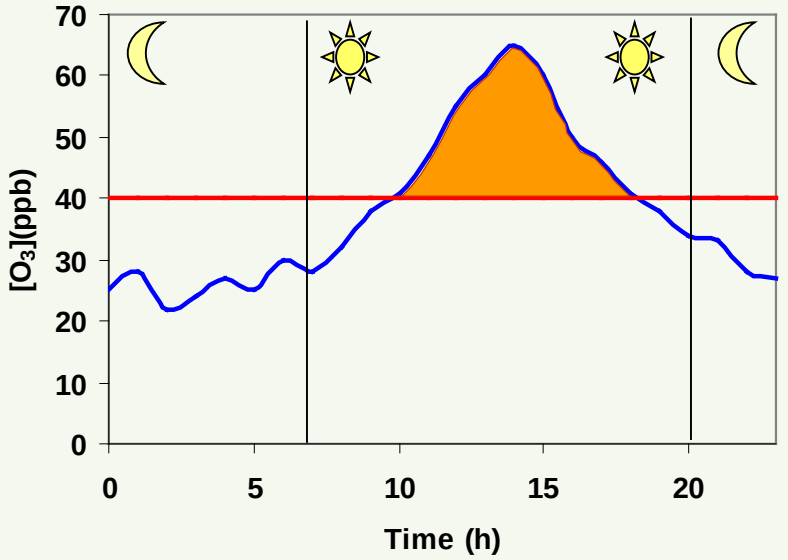
Target value for the protection of vegetation (2010)

AOT40 **9000 ppb.h** accumulated over 3 months (May-July) averaged over 5 years

Long-term objective for the protection of vegetation

AOT40 **3000 ppb.h** accumulated over 3 months (May-July)

Accumulated exposure index AOT40: the sum of the difference between hourly concentrations greater than 40 ppb (80 μg/m^3) and 40 ppb between 8:00h and 20:00h (CET) over a given period May-July



Control of tropospheric ozone

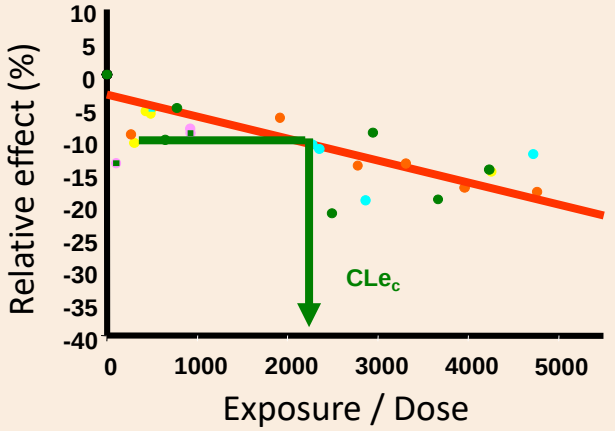
Convention on Long-range Transboundary Air Pollution (CLRTAP, UNECE)

- Since 1979. Including 51 member States.
- Objective: gradually reduce and prevent air pollution in the region to improve air quality on the local, national and regional levels
- Effects oriented approach

- International research programme investigating the impacts of air pollutants
- Establishing ozone critical levels

Critical level:
concentration, cumulative exposure or cumulative stomatal flux of atmospheric pollutants above which direct adverse effects on sensitive vegetation may occur according to present knowledge

(1st definition CLRTAP 1996)



Ozone critical levels

3 types of vegetation:

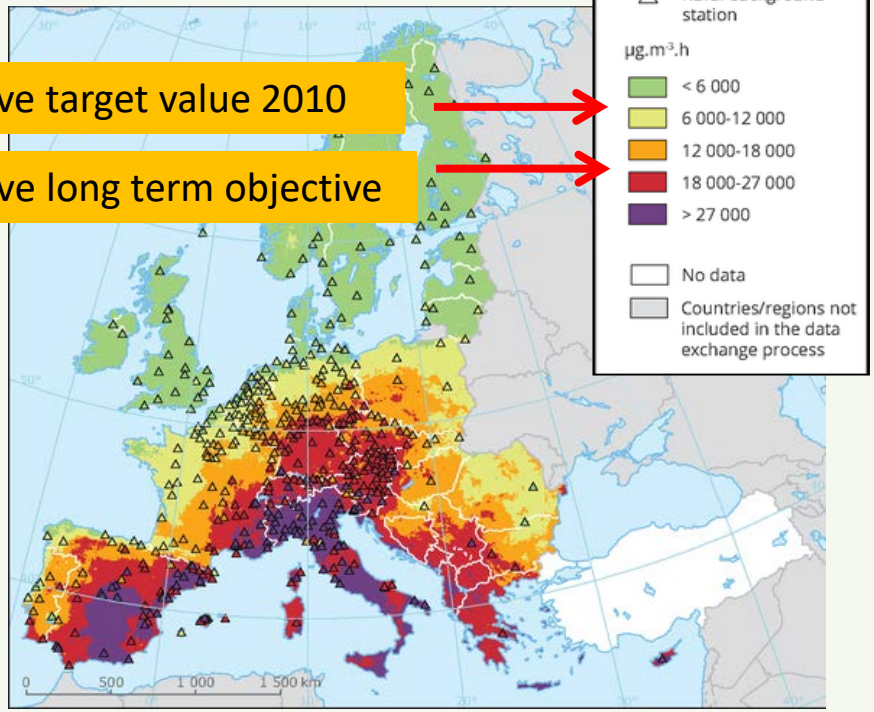
- Crops
- Semi-natural vegetation
- Forests

Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends

Vegetation	Critical Level	Time period	Effect
Crops	*Agricultural crops* AOT40 3000 ppb.h *Horticultural crops* AOT40 6000 ppb.h	3 months 3.5 months	Yield reduction (5%)
Semi-natural vegetation	*Perennial* AOT40 5000 ppb.h *Annual* AOT40 3000 ppb.h	6 months 3 months	Perennial: biomass reduction (10%) Annual: biomass or seed reduction (10%)
Forests	AOT40 5000 ppb.h	Growing season	Biomass reduction (5%)

Control of tropospheric ozone

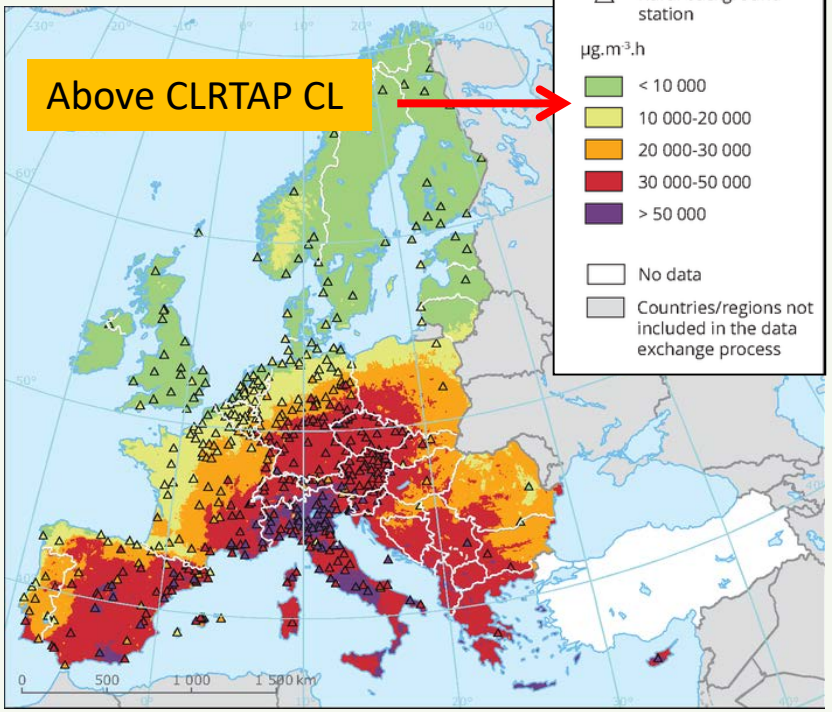
Rural [O_3] AOT40 for crops



Above target value 2010

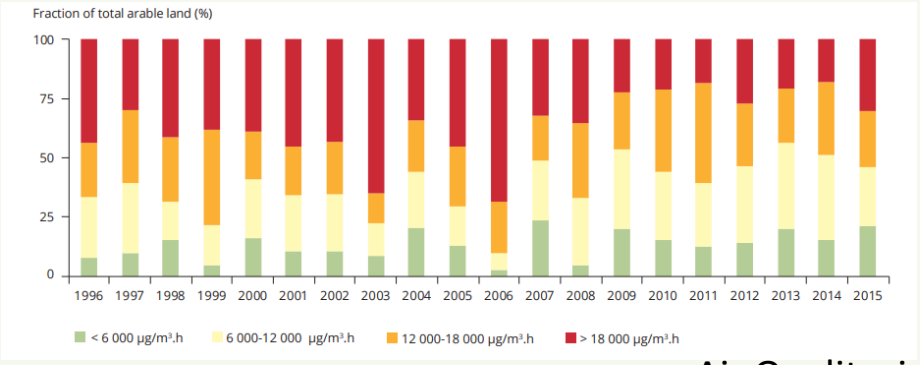
Above long term objective

Rural [O_3] AOT40 for forests

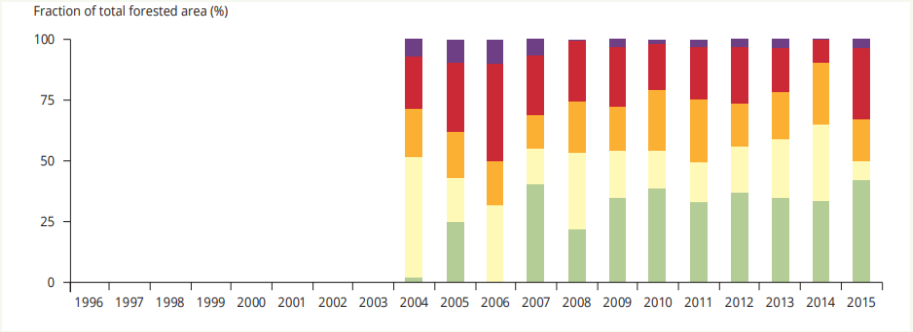


Above CLRTAP CL

Exposure of agricultural area to ozone in EEA member countries



Exposure of forest area to ozone in EEA member countries



Air Quality in Europe Report 2018, EEA

Ozone critical levels

Ozone effects more related to the **dose absorbed** through stomata than to exposure

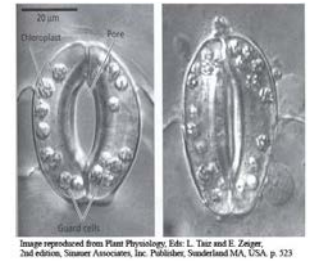


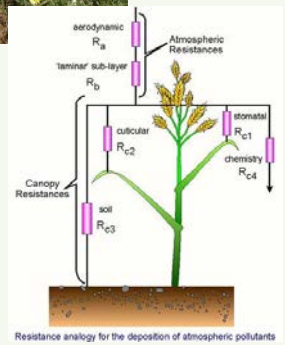
Image reproduced from Plant Physiology, Eds: L. Taiz and E. Zeiger, 2nd edition, Sinauer Associates, Inc. Publisher, Sunderland MA, USA. p. 323

Climate change

Consider the influence of meteorology

Combine measurements and modelling

Estimate ozone absorbed fluxes
(POD) Phytotoxic Ozone Dose

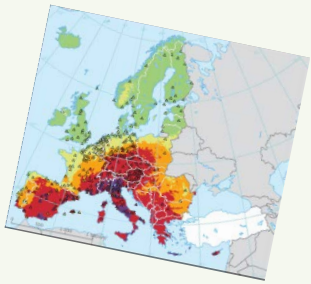


Resistance analogy for the deposition of atmospheric pollutants

Experiments

Dose - response functions

Flux-based O_3 critical levels and risk assessment



Estimating Phytotoxic Ozone Dose (POD)

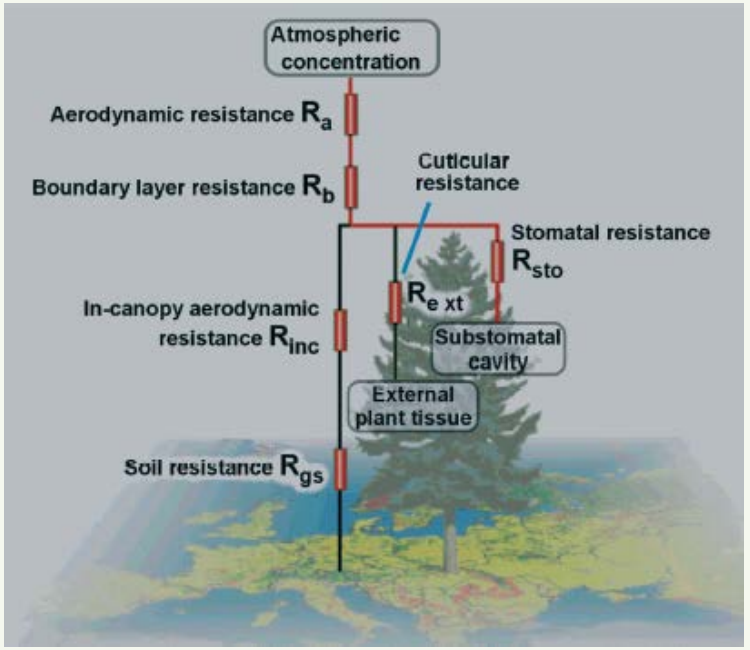
Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends (CLRTAP)

POD ⟹ $F_{st} = [O_3] \times gs_{to} \times \frac{r_c}{r_b + rc}$

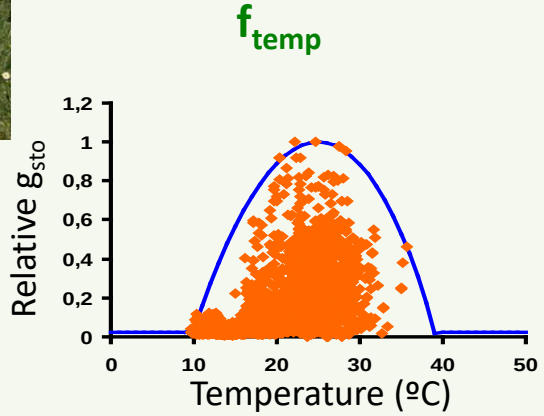
$$g_{sto} = g_{max} \times f_{light} \times f_{phen} \max\{ f_{min}, (f_{temp} \times f_{VPD} \times f_{SWP}) \}$$

Stomatal conductance model

(Jarvis, 1976; Emberson et al., 2000; Model DO_3SE -*Deposition of Ozone and Stomatal Exchange in EMEP model)*



EMEP - European Monitoring and Evaluation Programme, CLRTAP



Pameterizations of g_{sto} model :

- Published in Mapping Manual (CLRTAP) or scientific papers
- Experimentally

(https://icpvegetation.ceh.ac.uk/sites/default/files/FinalnewChapter3v4Oct2017_000.pdf)

O_3

Manual on
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April 201

Table III.6: List of effects for which O_3 critical levels are available for vegetation.

Species or vegetation type	Effect parameter	Biogeographical region*	Ozone metric	Section	Flux model parameters, critical levels (Table - T), response functions (Figure - F)
Species-specific critical levels, using $POD_Y SPEC$ (mmol m^{-2} PLA)					
Crops					
Wheat	Grain yield, 1000-grain weight, protein yield	A,B,C,M (S,P)**	POD_6SPEC	III.3.5.2	T III.9-10, F III.10
Potato	Tuber yield	A,B,C (M,S,P)	POD_6SPEC	III.3.5.2	T III.9-10, F III.11
Tomato	Fruit yield, fruit quality	M (A,B, C,S,P)	POD_6SPEC	III.3.5.2	T III.9-10, F III.11
Trees					
perennials					

Critical levels for forest tree species

Table III.12: $POD_Y SPEC$ critical levels (CL) for forest tre

Species	Effect parameter	Biogeo-graphi-cal	Potential effect	Criti		m
Beech and birch	Whole tre biomass					
Norway spruce	Whole tree biomass					
Med. deciduous oaks	Whole tree biomass					0.32
Med. deciduous oaks	Root biomass			10.3	1.4	0.45
Med. evergreen	Above-ground biomass	M	4%	47.3	3.5	0.09

Critical levels available for different vegetation types and for different biogeographical zones

ased
levels
D)

-based
evels
40)

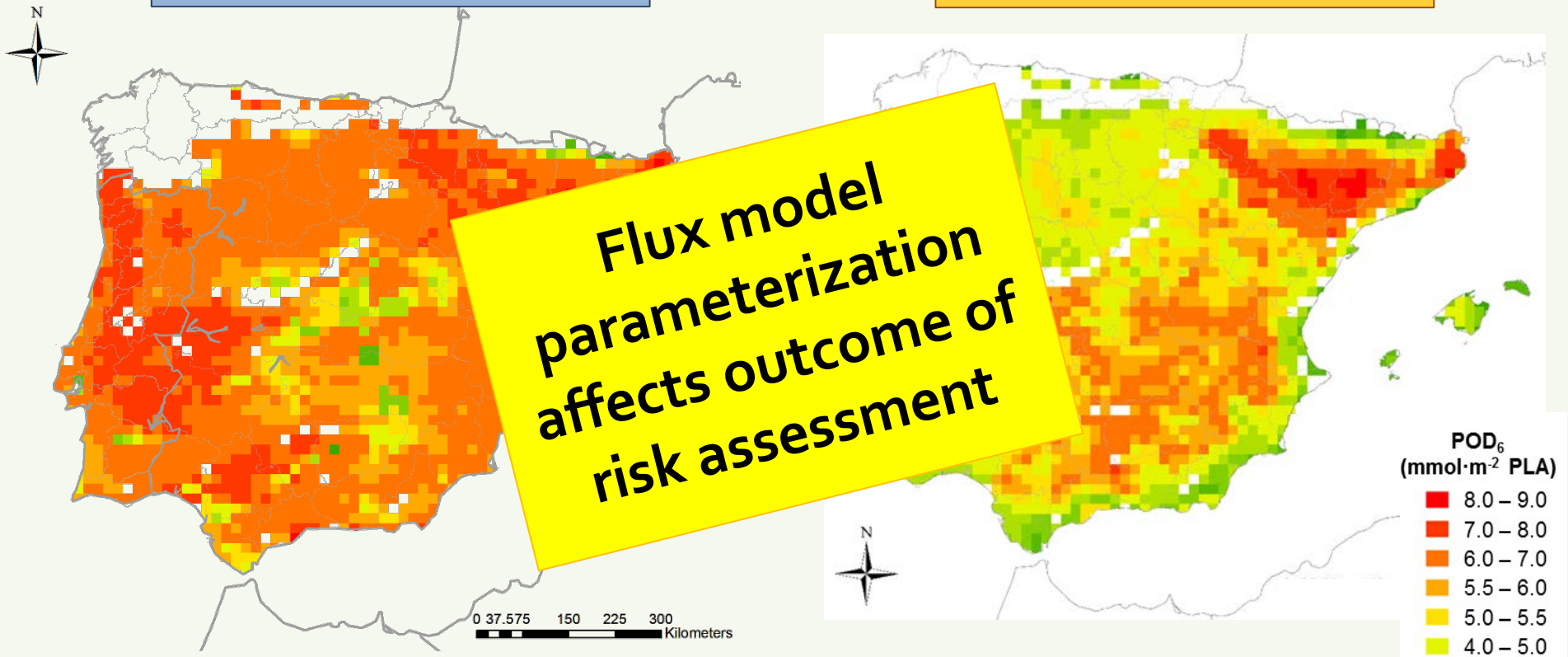
ICP Vegetation

Adequate ozone dose estimation

Bread wheat (*Triticum aestivum*)

Central European parameterization

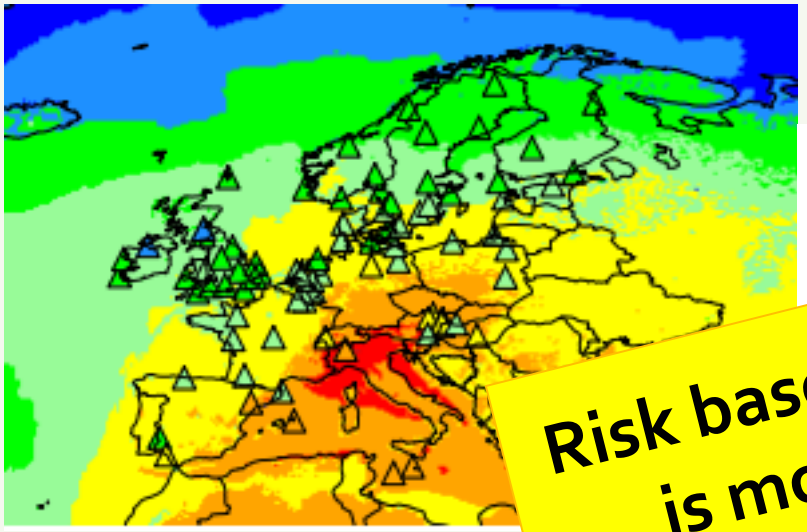
Mediterranean parameterization



Flux model parameterization affects outcome of risk assessment

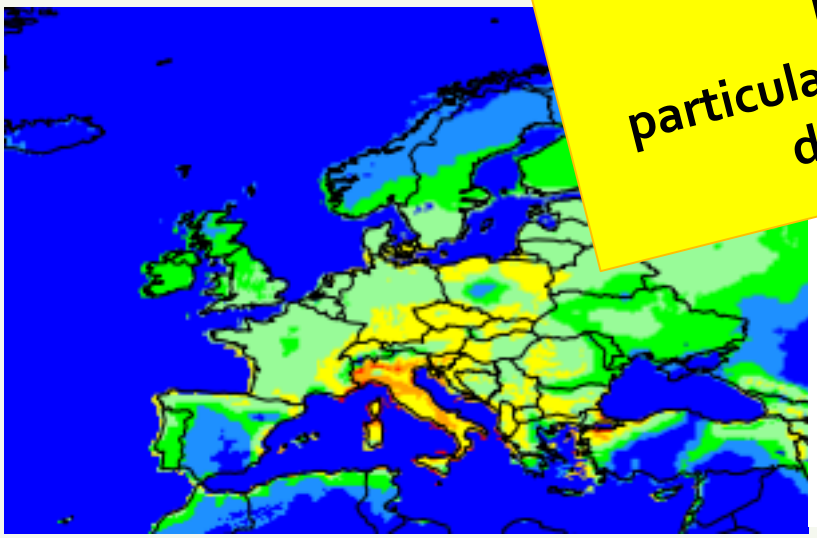
CMAQ v 4.6 model + gs (DO3SE model) + Soil Moisture content, data 2007)

Ozone risk assessment for forest in 2016



Risk based on exposure (AOT40 ppb.h)

50000
30000



30
25
20
15
10
5

CL

$_1$ nmol m^{-2}))

Risk based on flux uptake is more biologically meaningful

particularly in areas with frequent drought, high T, etc,

EMEP Report 2018

Ozone risk assessment

Pros for ozone risk assesmment based on flux uptake (POD):

- Risk based on flux uptake (POD) is better related to effects than exposure (AOT40) and includes climate change
- Ozone risk assessment based on POD is available for different biogeographical zones and vegetation types: considering specific sensitivity and dose parameterizations
- POD already included in:
  - Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone revised in 2012 - CLRTAP
  - National Emissions Ceilings (NEC) Directive (2016/2284/EU): Annex V - Optional indicators for monitoring air pollution impacts referred to in Article 9
  - Future revision of Air Quality Directive?

Future challenges?

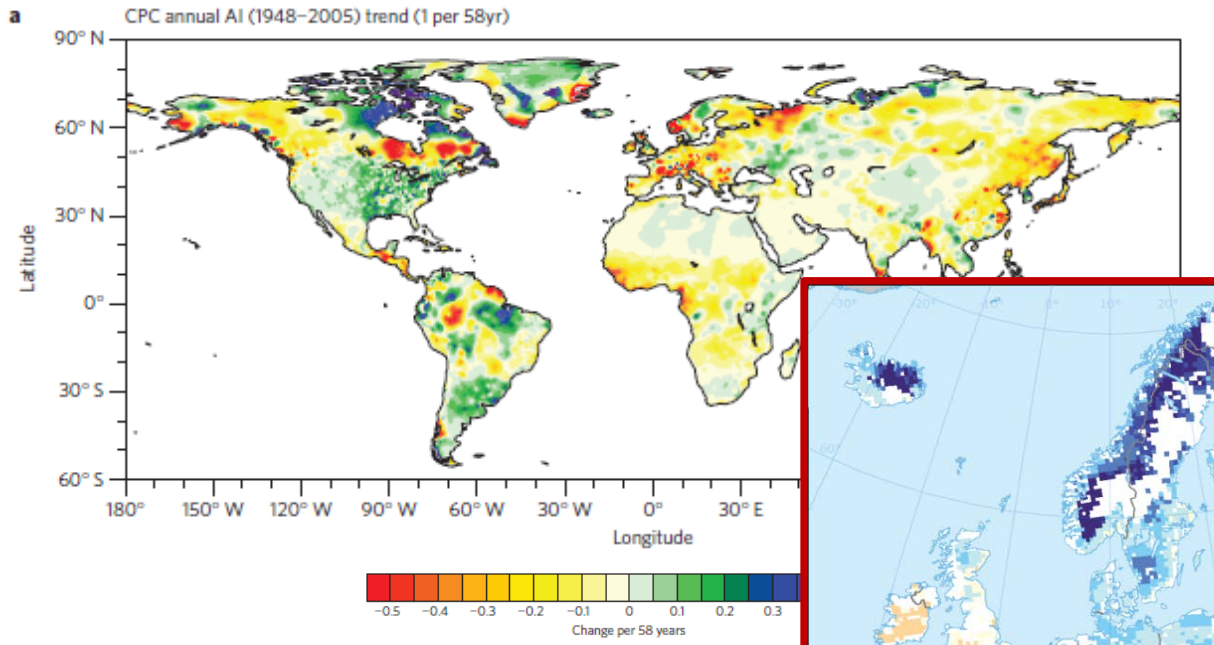
Future challenges for ozone risk assessment

Scientific ongoing work for:

- Reducing uncertainties in modelling the influence of soil moisture and drought on fluxes and effects

Towards a drier and warmer world

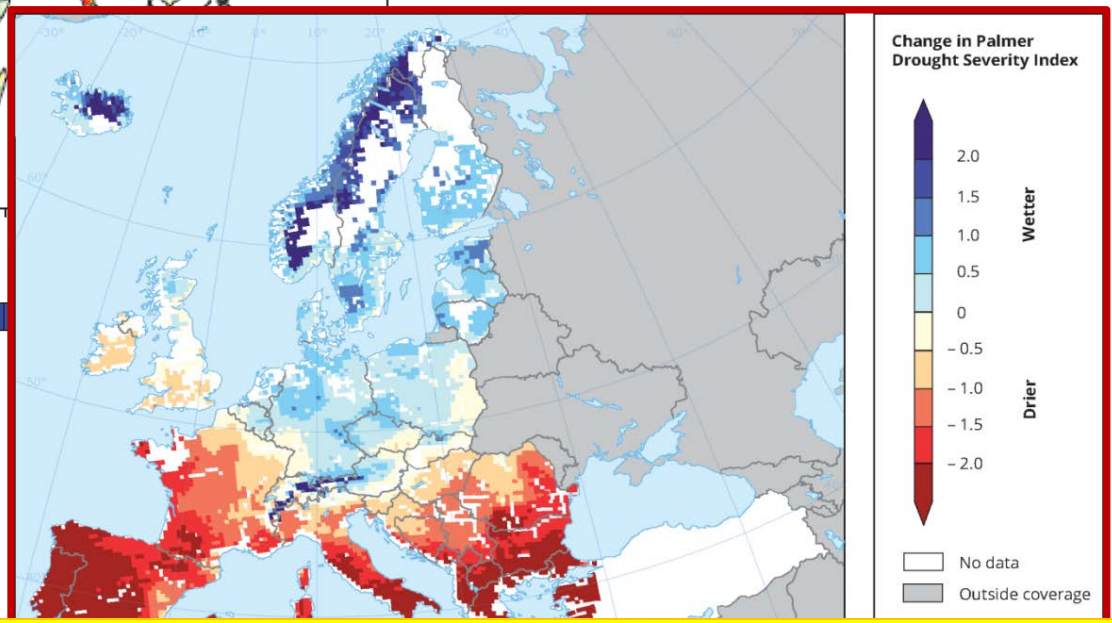
Increase in aridity 1948-2005



Huang et al., 2016, Nat. Clim. Change

Change summer drought severity

1961-1990 vs 2020-2050



Ongoing collaboration between EMEP, ICP-vegetation and ICP-Forest to improve risk assessment in soil moisture limited areas

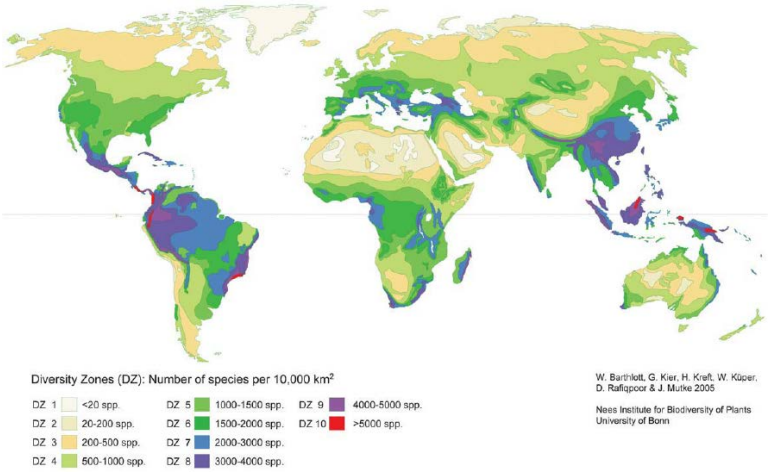
Future challenges for ozone risk assessment

Scientific ongoing work for:

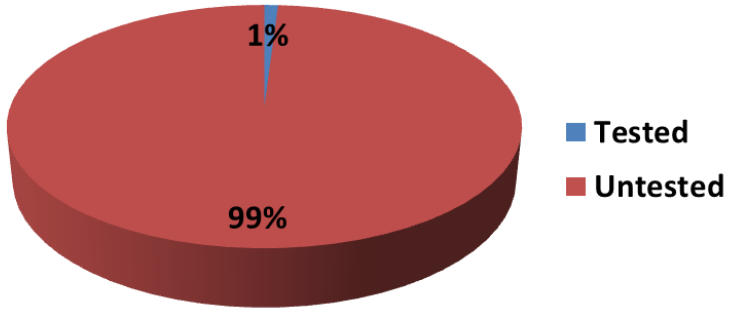
- Reducing uncertainties in modelling the influence of soil moisture and drought on fluxes and physiology
- Including interactions with other global change factors: drought, nitrogen, pathogens
- Considering other response variables related to ecosystem services for defining critical levels and risk assessments
- Improving knowledge about effects on different vegetation types (for example risk assessment in high mountain areas with valuable biodiversity)

Future challenges for ozone risk assessment

Plant biodiversity hotspots



Species tested for ozone sensitivity



Most species/ecosystems remain untested for O_3 sensitivity

Experimental data and long-term monitoring are crucial

but facilities are closing across Europe…

Key messages:

- ✓ Ozone is affecting vegetation and ecosystems endangering some of the services they provide
- ✓ Ozone effects are better related with the dose of ozone absorbed by plants (POD) than to exposure (AOT40)
- ✓ Methodology based on fluxes is available for ozone risk assessment for different vegetation types and biogeographical areas (already included in NEC Directive)
- ✓ Some improvements of risk analysis are in progress
- ✓ Long-term monitoring and experimental data are crucial for assessing the current effects and the achievements of implemented policies
- ✓ Essential interaction between policy makers and scientific working groups

Thank you!

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