Assessing the Global Impact of Air Pollution on Agriculture

Lisa Emberson

l.emberson@york.ac.uk

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Outline

How do air pollutants affect agricultural productivity?

How is the risk to agricultural systems assessed ?

What are the key limitations with these “risk assessments”?

What are the difficulties in making “risk assessments” at the global scale?

What are the implications for air pollution impacts to agriculture under climate change?

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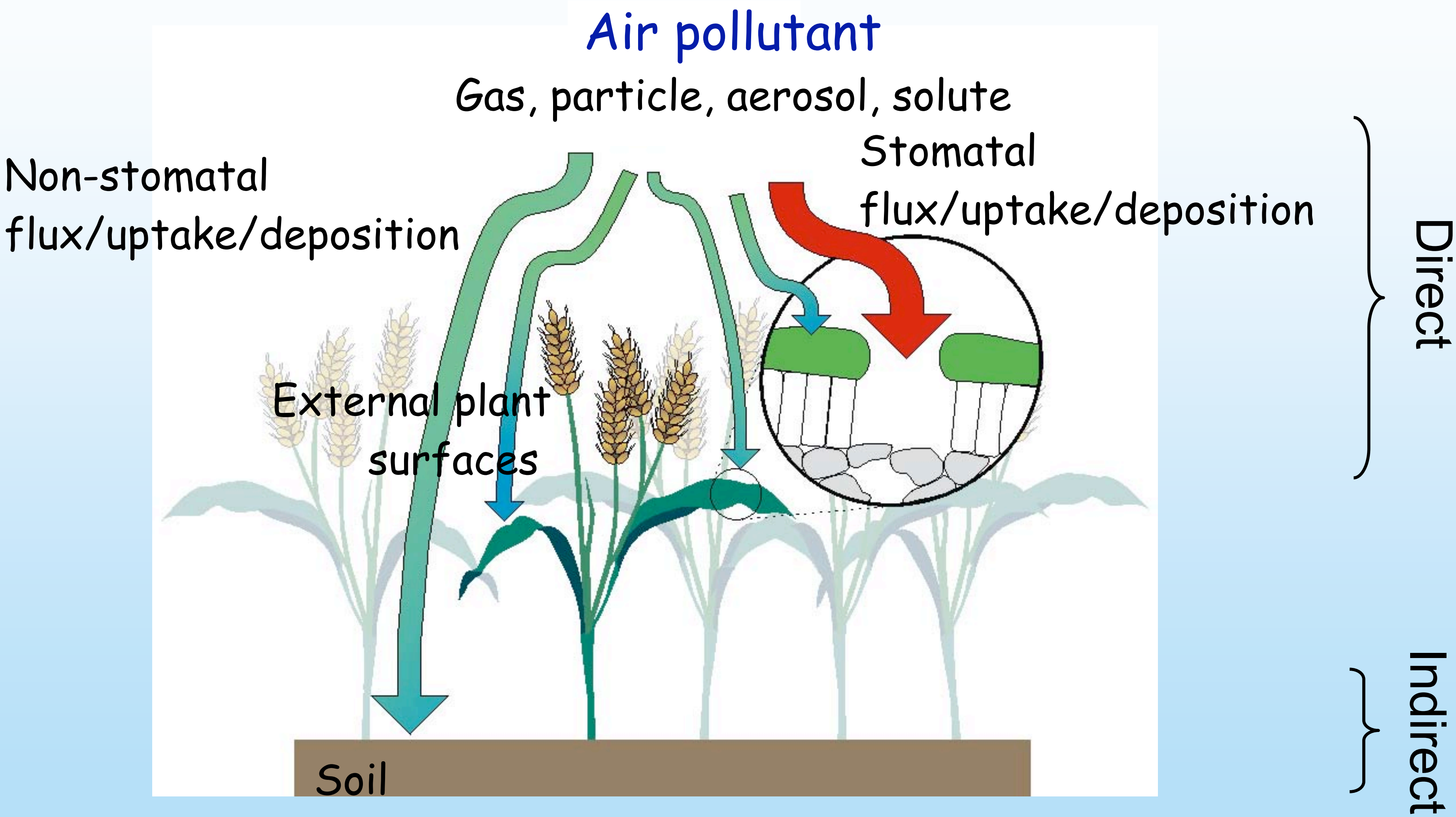
How do air pollutants affect agricultural productivity?



What damage do these pollutants cause?

Pollutant	Impact mode	Impact	Scale
Ozone (O_3)	Direct (stomates)	Visible injury, growth & yield reductions, chemical quality	Regional
Sulphur dioxide (SO_2)	Direct (stomates & cuticle) Indirect	* Visible injury, growth & yield reductions Soil acidification (growth & yield reductions)	Local Regional
Nitrogen oxides (NOx)	Direct (stomates) Indirect	* Growth & yield reductions Soil acidification (growth & yield reductions)	Local Regional
Hydrogen Fluorides (HF)	Direct (stomates & cuticle)	Visible injury, growth & yield reductions. Fluorosis in grazing animals	Local
Suspended Particulate Matter (SPM)	Direct	**Phytotoxicity, abrasive action, reduced light transmission, occlusion of stomates	Local / Regional

* At low concentrations can stimulate growth via fertilization effect
** Dependant upon chemical composition of particles

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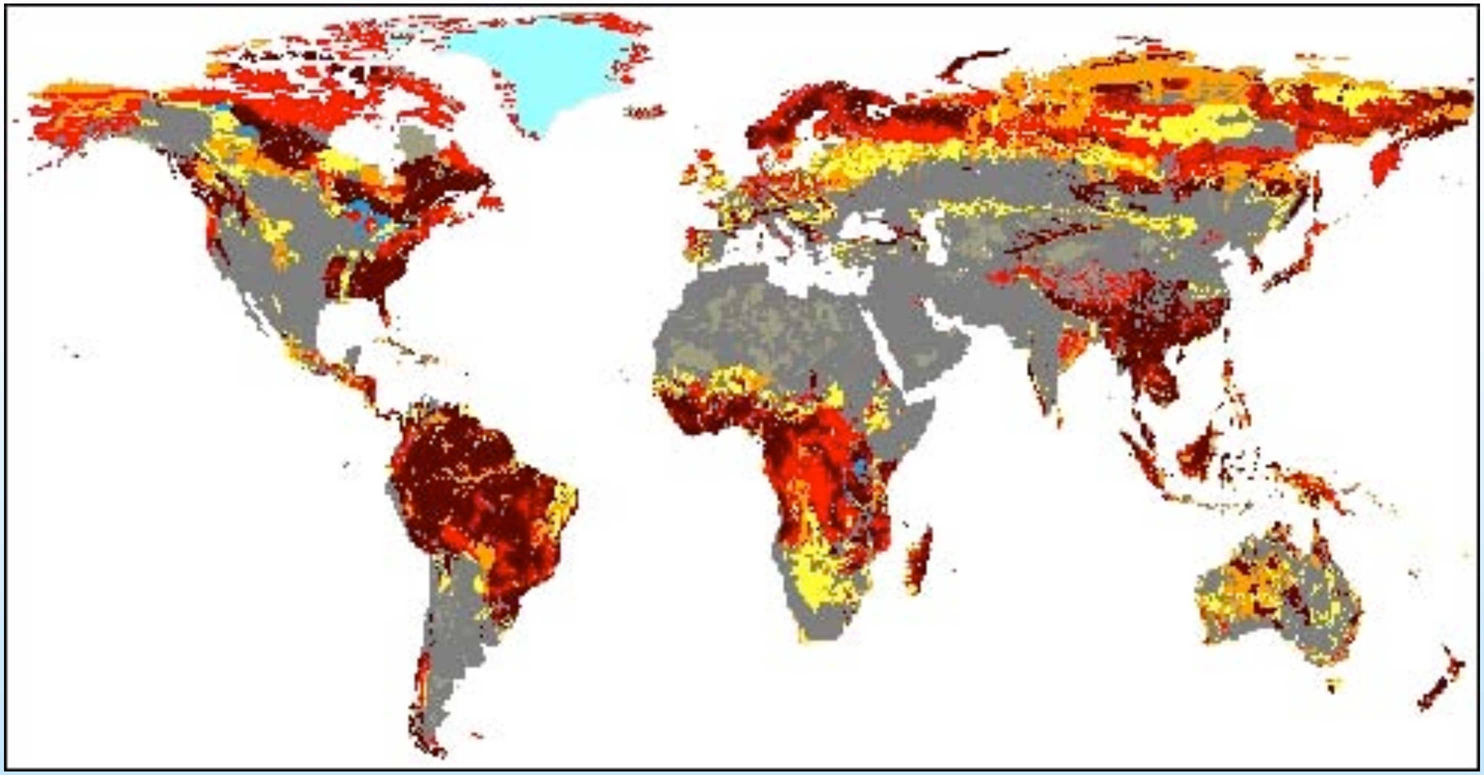
What damage do these pollutants cause?

Soil Sensitivity to Acidic Deposition



Soil sensitivity determined by weathering rate (T) and resulting buffering capacity

S & N emissions - aerosol formation - deposition fields (driven by P)

Growth and yield reduction impacts

Managed systems (i.e. agriculture) little evidence of sensitivity to acidification

Management can reduce impacts (e.g. addition of lime)

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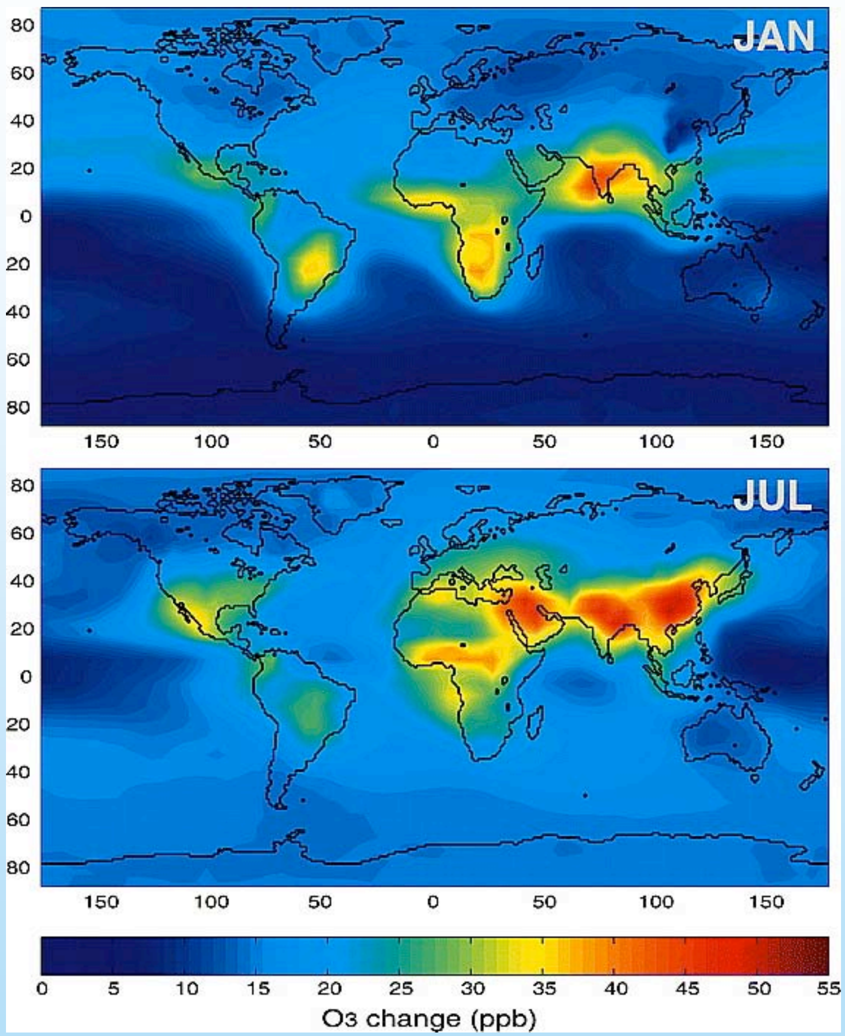
Increases in surface O_3 concentration from 2000 to 2100



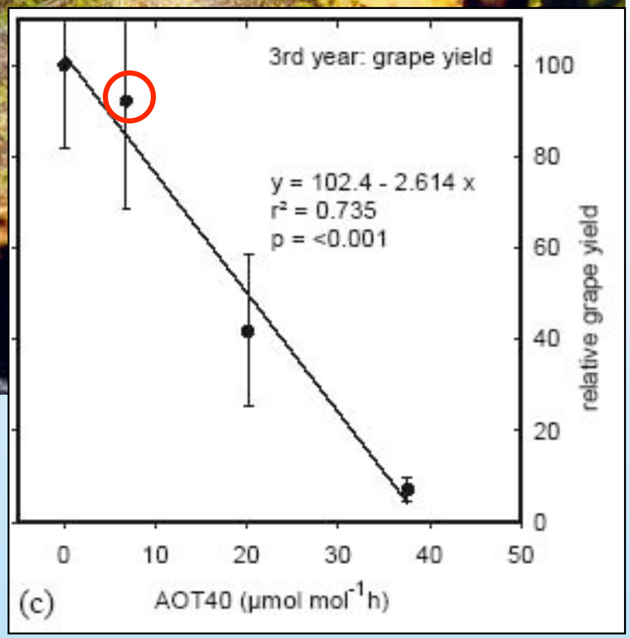
Prather et al. (2003)

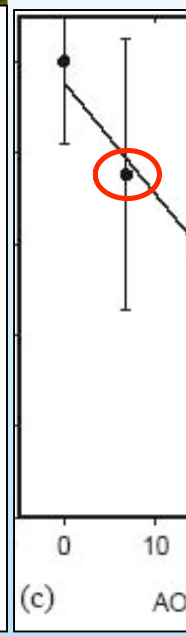
O_3 injury to wheat, **Pakistan** (courtesy of A. Wahid)

What damage do these pollutants cause?

Ozone impacts on grapevine (*Vitis vinifera*)

Soja et al. (2004)
OTC experiments
30 km Vienna, Austria
4 treatments, CF, NF, +25 ppb, +50 ppb
Exposed for 3 years





Non-filtered (NF) air i.e. ambient

Consistently failed wine tasting tests

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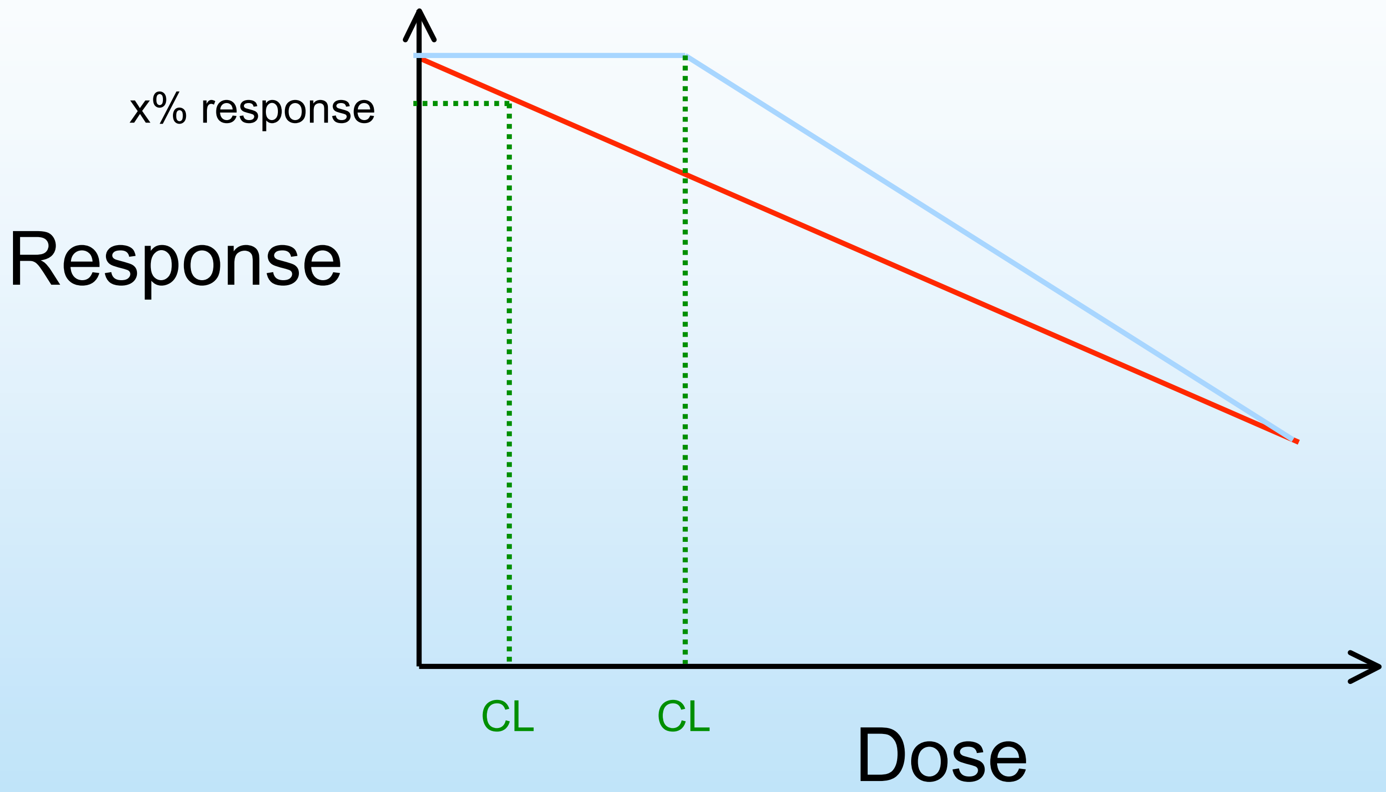
How is the risk to agricultural systems assessed?
Dose-Response Relationships



CL = Critical Level

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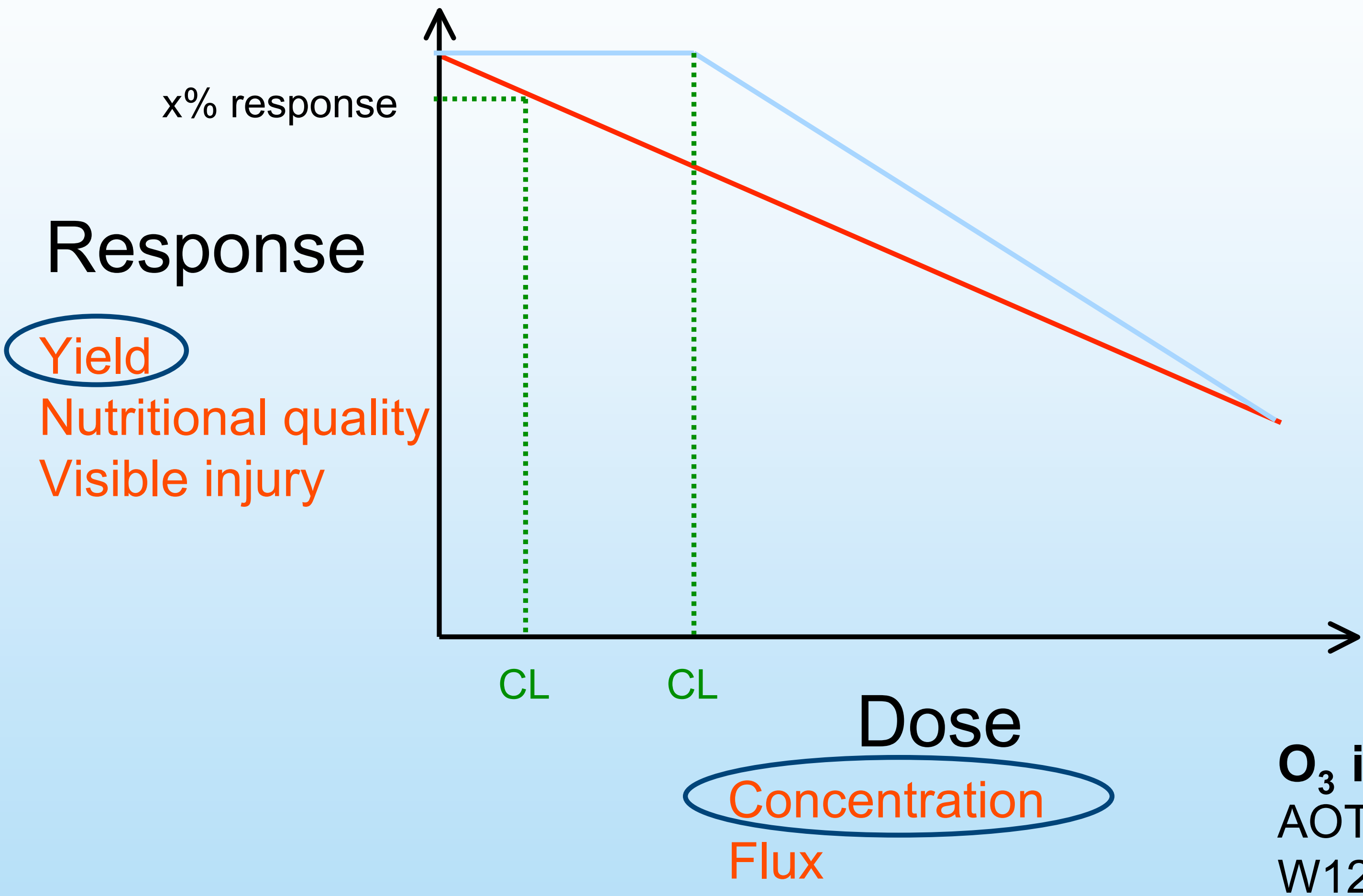
How is the risk to agricultural systems assessed?
Experimental fumigation studies

Open Top Chambers

Solardomes

How is the risk to agricultural systems assessed?
Dose-Response Relationships



O_3 indices:
AOT40, SUM06, W126

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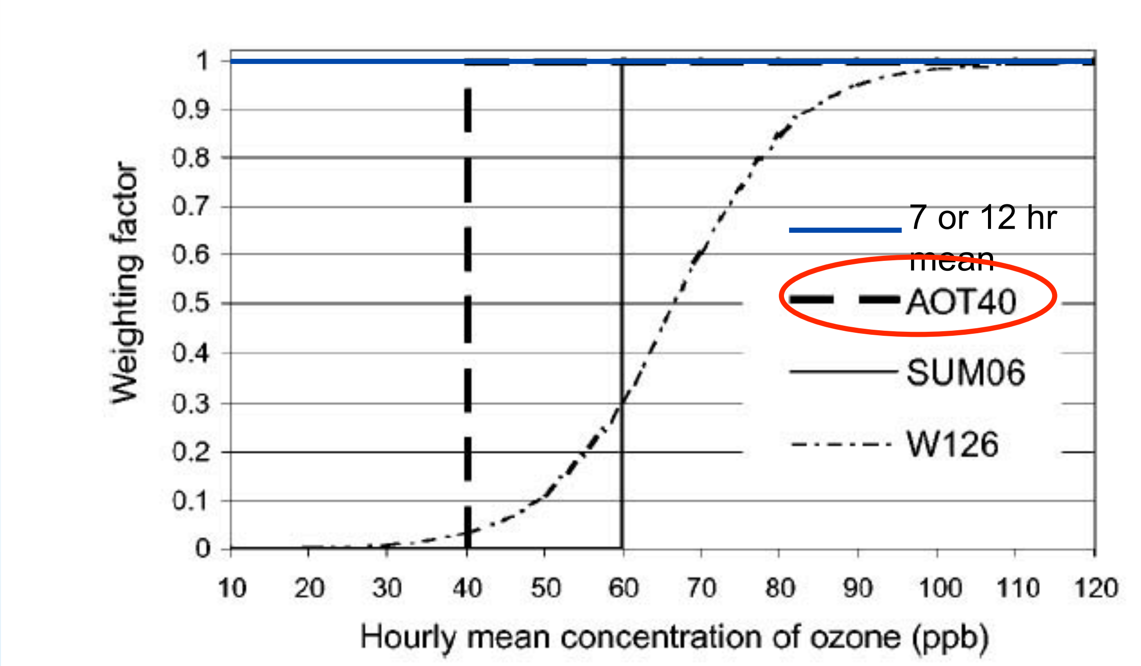
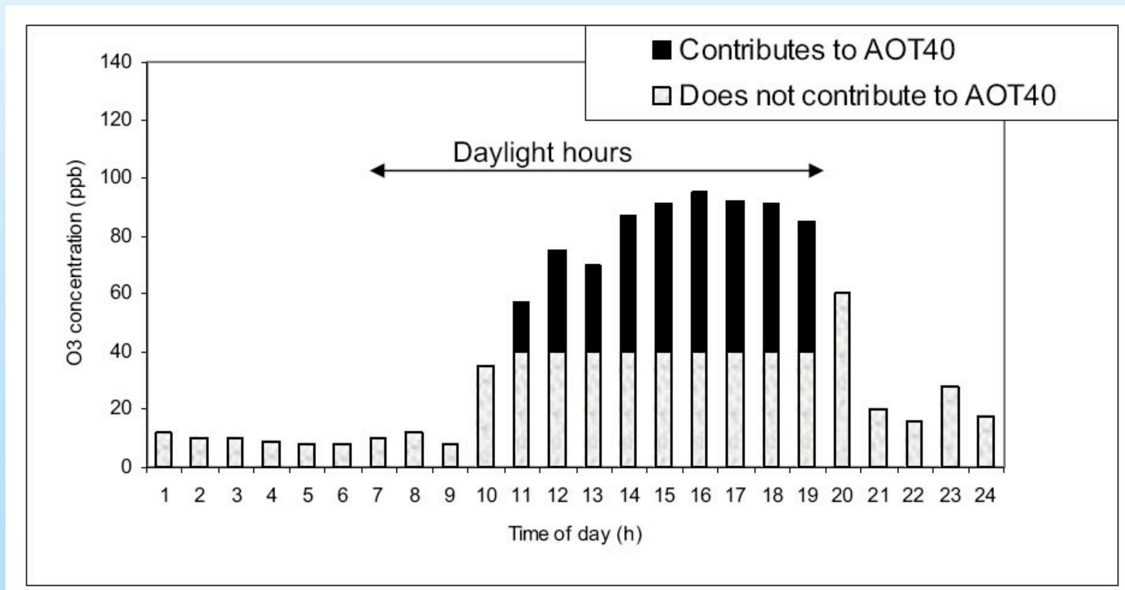


Modified from Mauzerall & Wang (2001)



Growing season

e.g. 3 months for wheat

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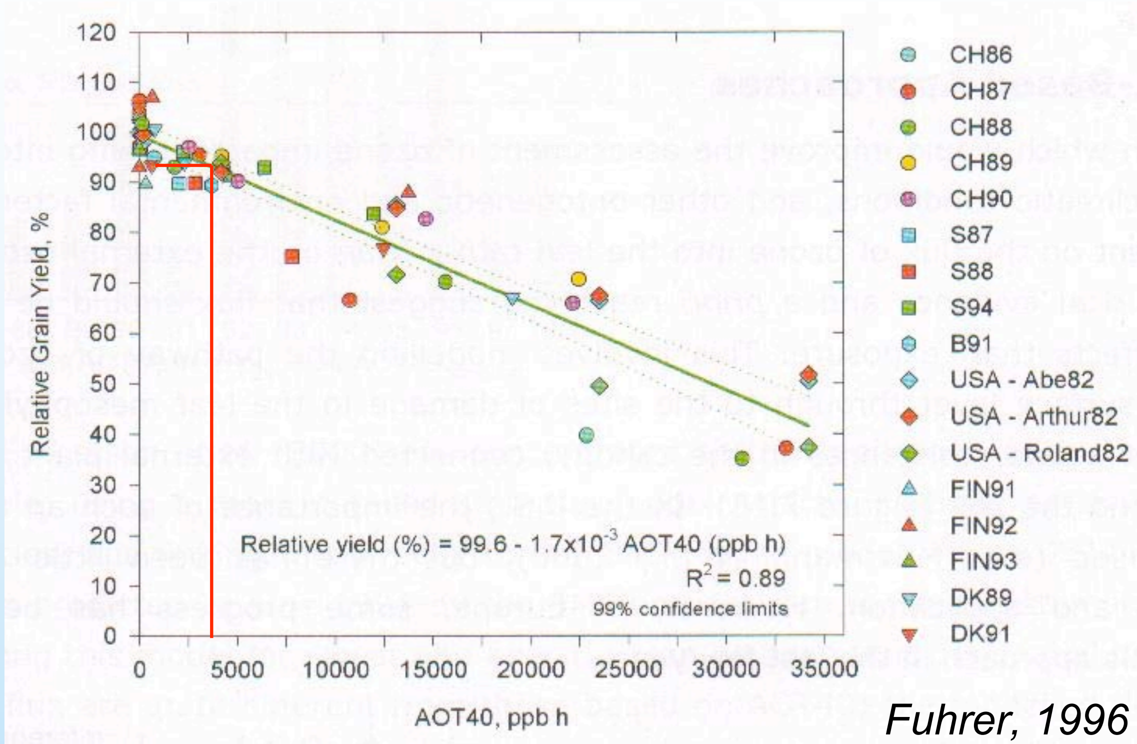
How is the risk to agricultural systems assessed?

AOT40 relationship with wheat (*Triticum aestivum*) grain yield



Fuhrer, 1996

- Most robust AOT40 relationship
- 17 experiments, 6 countries, 10 growing seasons, 10 cultivars
- **Critical Level** : AOT40 of 3, 000 ppb.h. corresponding to 5% yield loss (99% confidence) calculated over a 3 month growing period

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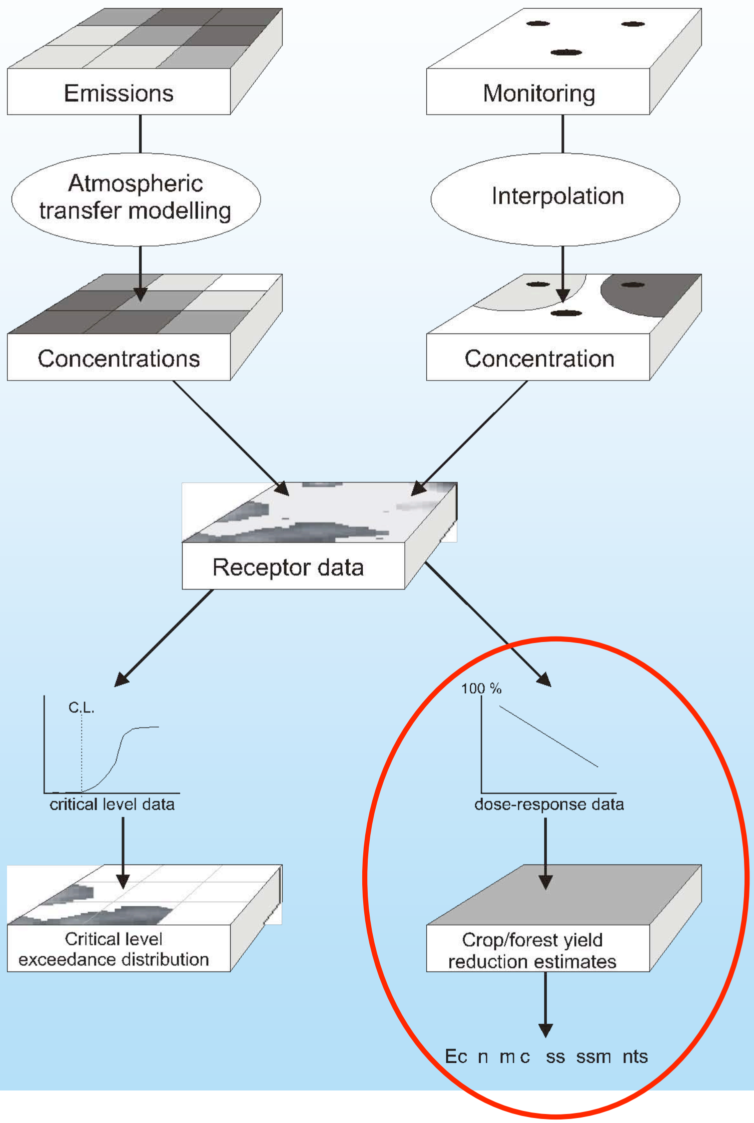
How is the risk to agricultural systems assessed?

Application of dose-response relationships



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How is the risk to agricultural systems assessed?

Key economic assessments

~ Current day

Reference	O_3 index	Geographical Region	Crops	Yield / economic crop losses
Adams et al. (1988)	7- & 12- hr seasonal means	US	9 crops arable	**US \$ 3 x 10^9**
Holland et al. (2002)	AOT40	Europe	> 20 arable crops	**US \$ 8 x 10^9**
Aunan et al. (2000)	7- & 12- hr seasonal means	China	wheat, rice, corn	1 to 4 %
Wang & Mauzerall (2004)	7- & 12- hr seasonal means	East Asia (China, Japan, S. Korea)	wheat, rice, corn soybean	1 to 9 % 23 to 27 % **US \$ 5 x 10^9**

How is the risk to agricultural systems assessed?
Key economic assessments

~ 2020

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	7- & 12- hr seasonal means	China	wheat, rice, corn	3 to 8 %
Wang & Mauzerall (2004)	7- & 12- hr seasonal means	East Asia (China, Japan, S. Korea)	wheat, rice, corn soybean	1 to 9 % 23 to 27 % US $ 5 x 10^9
	7- & 12- hr seasonal means	East Asia	wheat, rice, corn soybean	2 to 16 % 28 to 35 %

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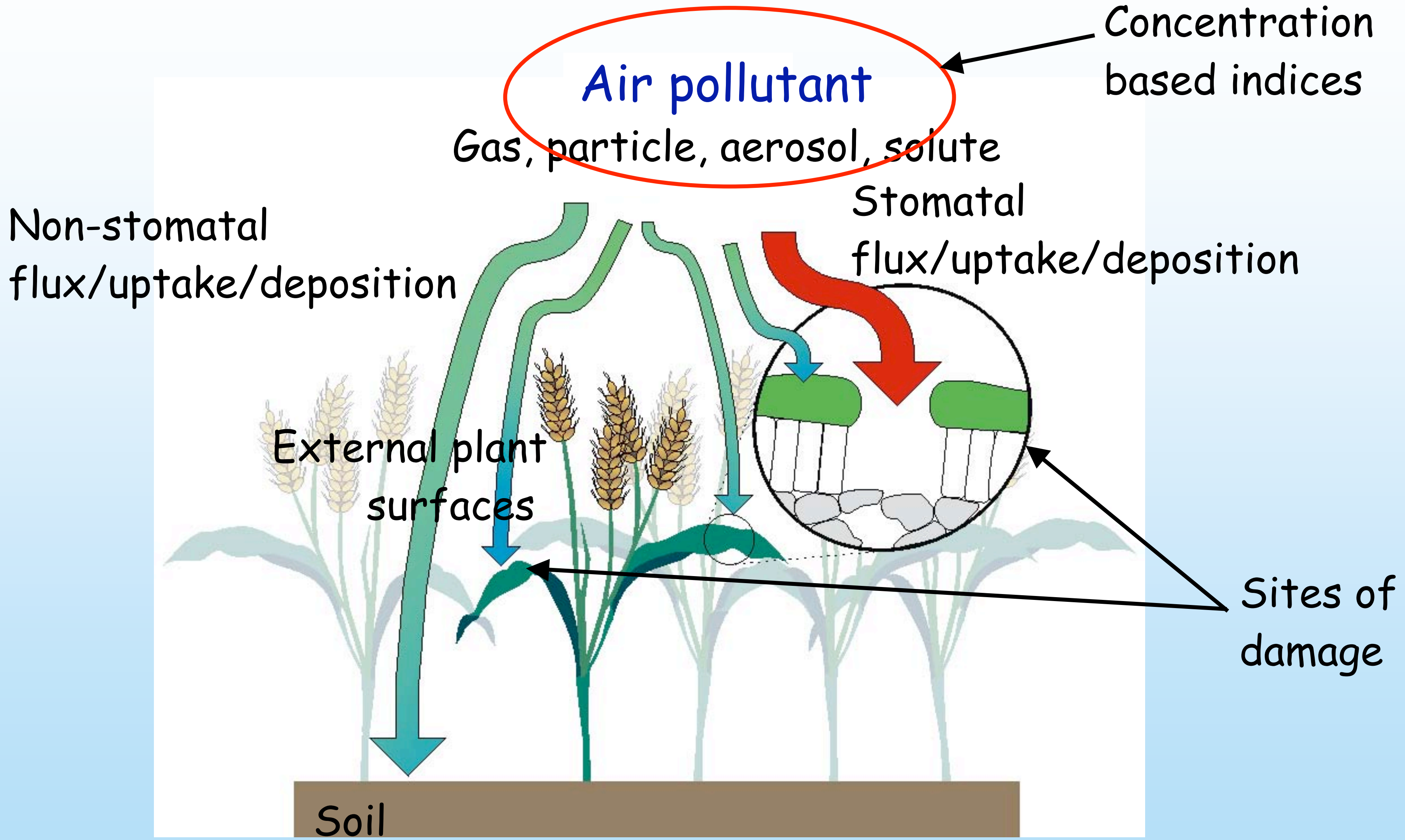
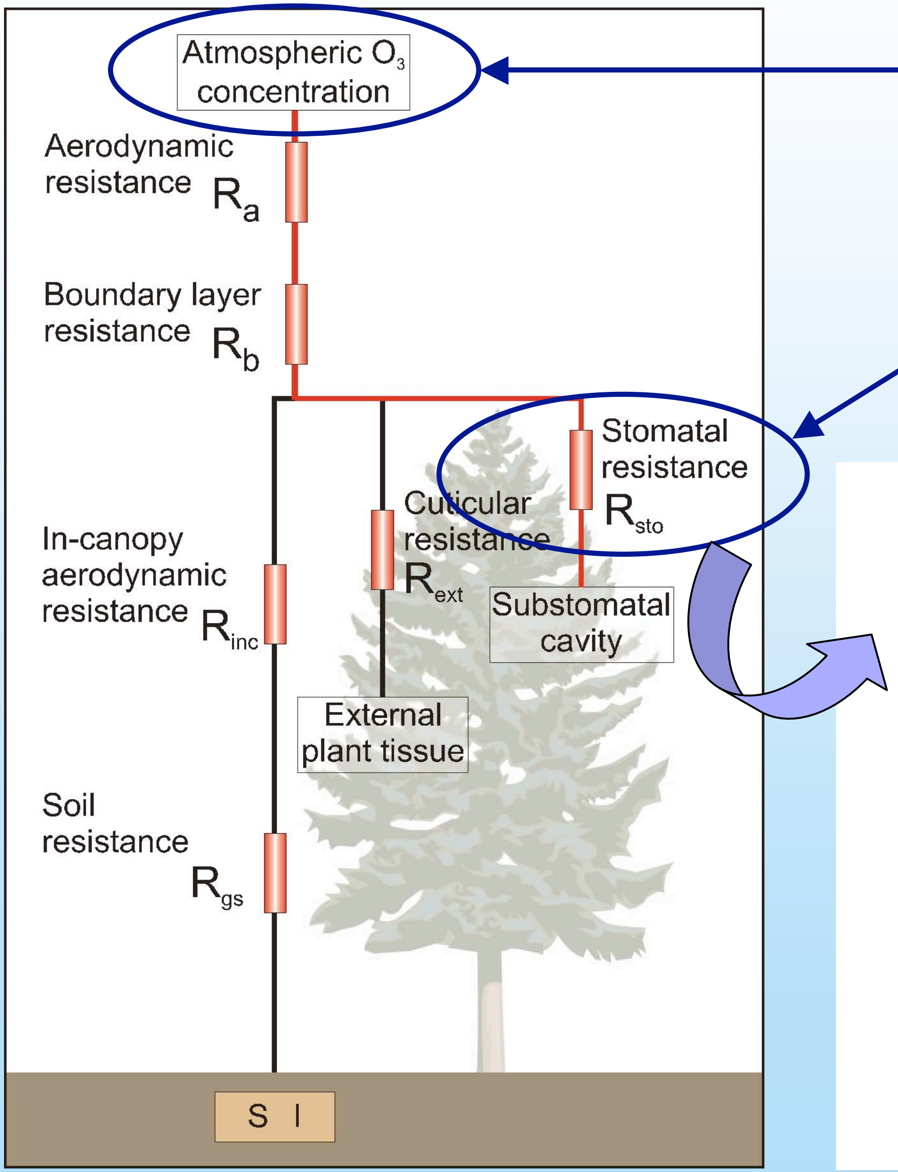
What are the key limitations with these “risk assessments”?



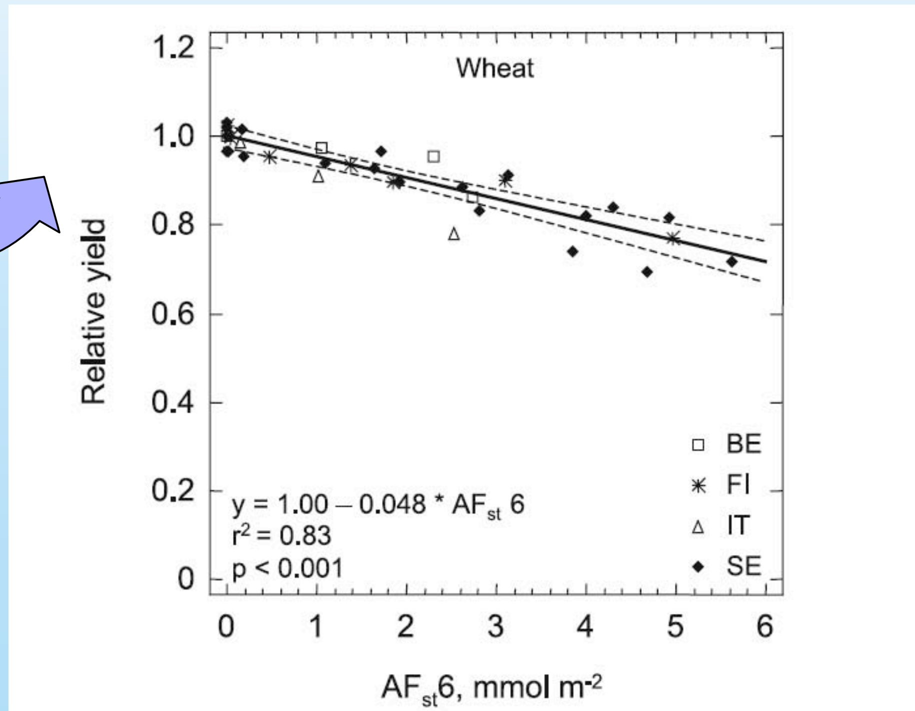
What are the key limitations with these "risk assessments"?

Flux based approach for O_3 risk assessment



Concentration based indices

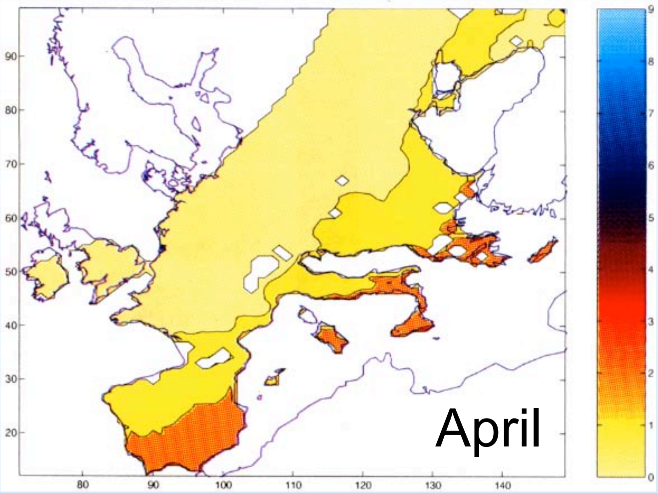
(stomatal) Flux based indices

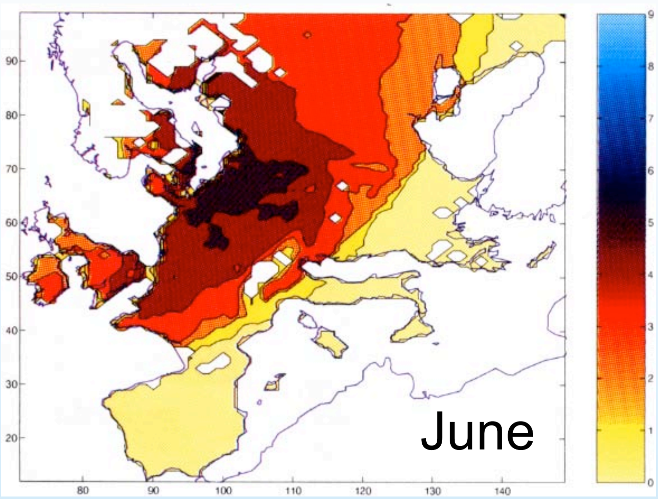


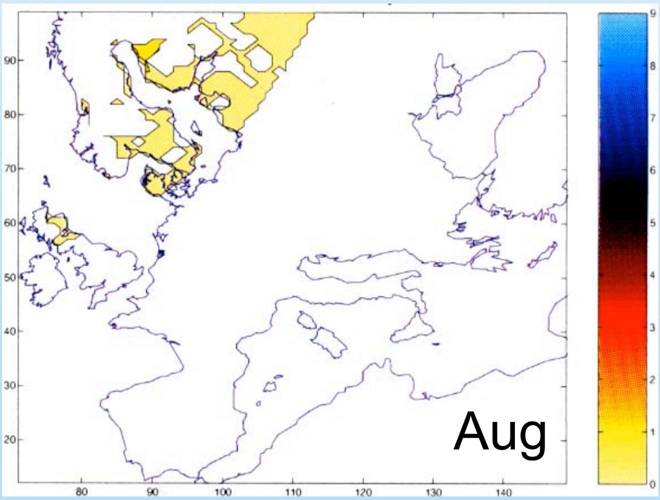
What are the key limitations with these "risk assessments"?

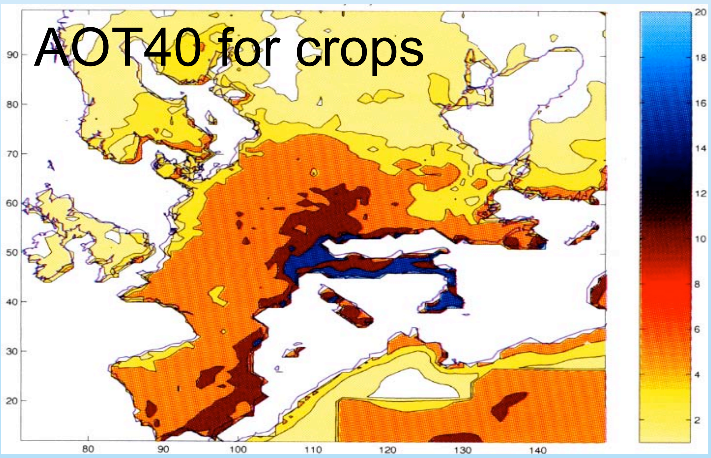
Flux based approach for O_3 risk assessment

Estimated stomatal fluxes to **wheat** (nmol O_3 m^{-2} s^{-1})



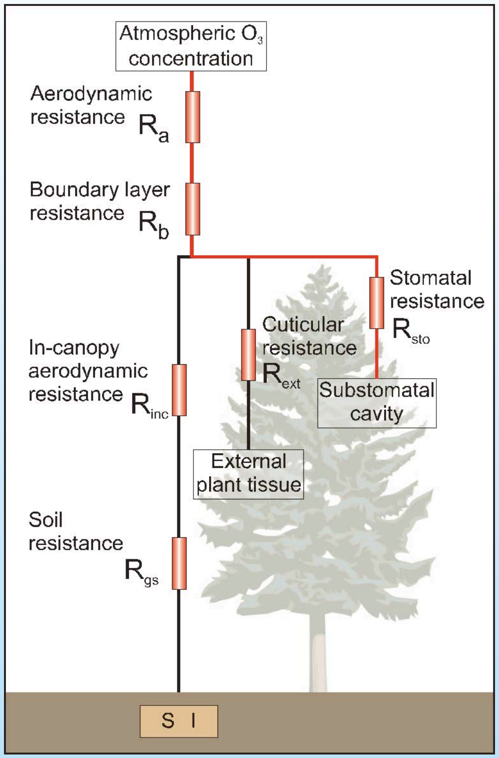






What are the key limitations with these "risk assessments"?

Key advantages of a flux based approach



Risk assessments based on ***meteorological variables***:-

- Apply methods developed in one region globally e.g. in Europe / N America to Asia
- Apply methods under climate change conditions

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Risk assessments at the global scale?
Issues relating to transferability and application

- Species type / cultivar

- Climate
  - Precipitation patterns
  - Sunshine hours
  - Temperature differences
  - Atmospheric and soil water deficitis
  - ▼
  - Cropping patterns (growing season)
  - Pollutant dispersion (& formation)

- Agronomic practices
  - Irrigation

"Dose modifiers"

⇩

Flux

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Risk assessments at the global scale?
Issues relating to transferability and application

- Agronomic practices
  - Agrochemical useage
  - Breeding programmes (selecting increased / reduced crop sensitivity)
- Others
  - Soil nutrient status
  - Susceptibility to pests and pathogens
  - Co-occurrence of other pollutants
  - CO_2 concentration

- Translation of biological effects into **socio-economic** impacts
  - Traditional market-based methods
  - Non-marketable goods (e.g. subsistence crops, bartering of farm produce)

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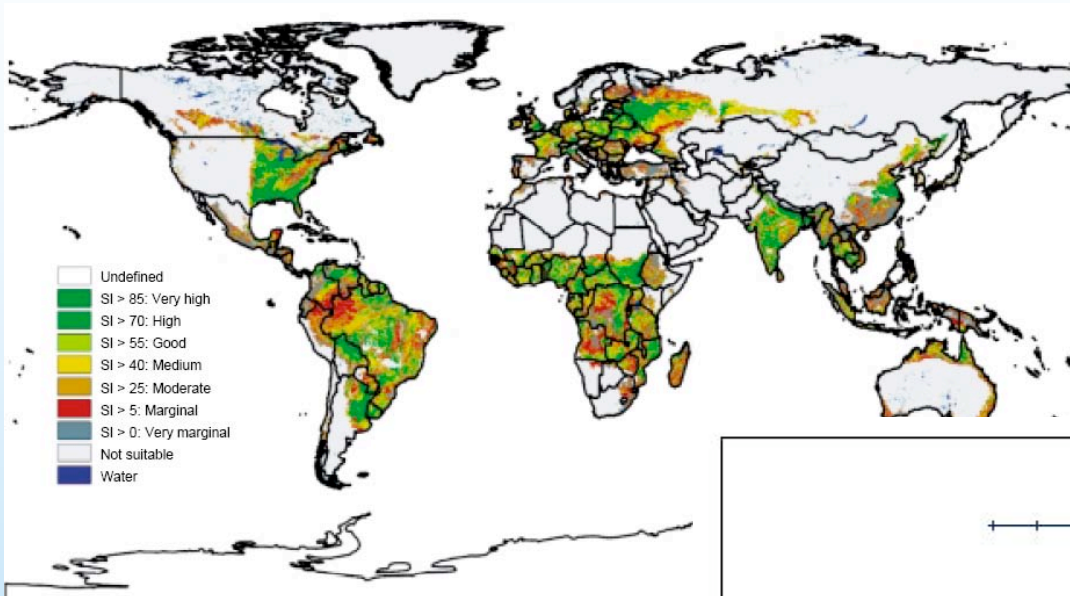
Risk assessments at the global scale?

Issues relating to transferability and application

Receptor (agricultural) distribution

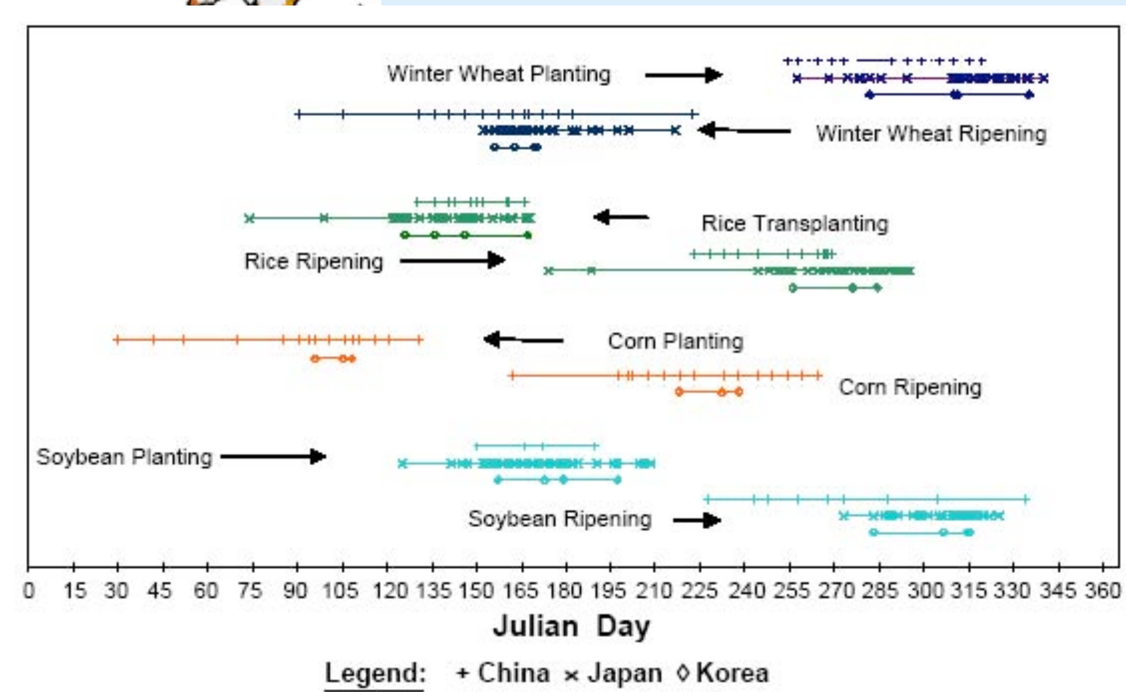


IIASA, 2002

Spatial

Identifying agricultural regions
(e.g. crop type, management regime, irrigated / rain fed, yield statistics)

Wang & Mauzerall, 2004



Temporal

Identifying crop growing seasons
(e.g. timing and length, rotation)

Risk assessments at the global scale?

Issues relating to transferability

Air **P**ollution **C**rop **E**ffect **N**etwork (APCEN)

RAPIDC Network (APCEN) Workshop, Bangkok, Thailand Dec 2003

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Risk assessments at the global scale?
Issues relating to transferability

Air **P**ollution **C**rop **E**ffect **N**etwork (APCEN)

Region	Network Members	Countries / regions represented
Asia undeveloped	33	India, South Korea, Philippines, Pakistan, P.R. China, Thailand, Taiwan, Nepal, Sri Lanka
Asia developed	10	Japan
Non-Asia undeveloped	5	Chile, South Africa, Egypt
Non-Asia developed	15	Europe, North America, Australia

Risk assessments at the global scale?
Issues relating to transferability

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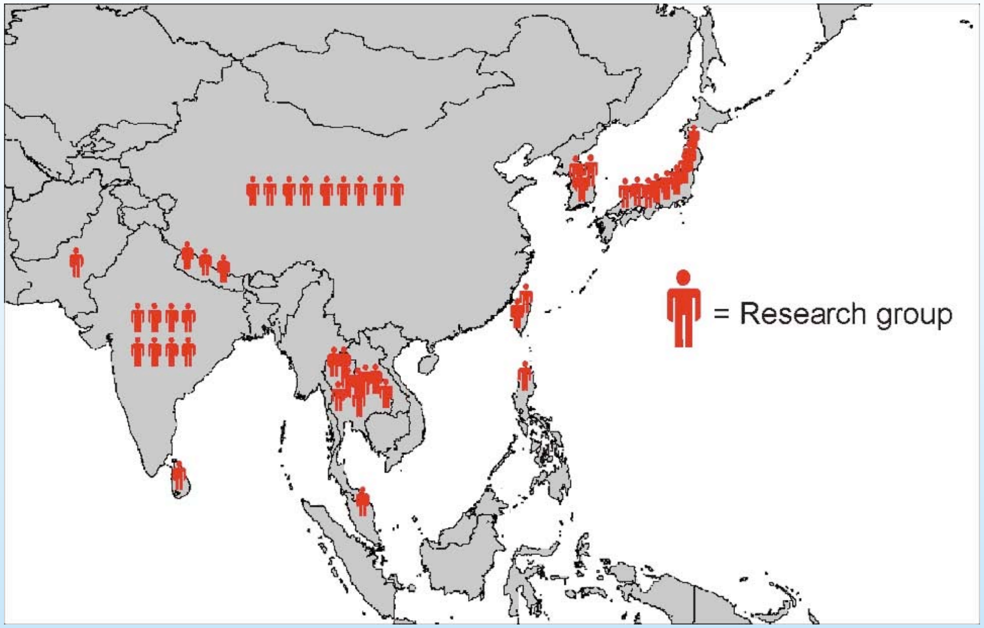

Air pollution effects scientists
Air pollution modellers
Socio/economic experts
Policy makers

Links with other programmes / organisations :-

ABC (Atmospheric Brown Cloud)
IRRI (International Rice Research Institute)
CIMMYT (International Centre for Wheat and Maize Improvement)
IFPRI (International Food Policy Institute)

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Risk assessments at the global scale?
Issues relating to transferability

Observational / Experimental methods :-

Bio-monitoring
Transect studies
Chemical protectant studies e.g. EDU
Filtration / fumigation studies

Increasing complexity

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Implications for agriculture of air pollution and climate change?

Key factors:

- Temperature
- Soil moisture
- Atmospheric CO_2
- Tropospheric O_3

▼

Direct effects at plant level

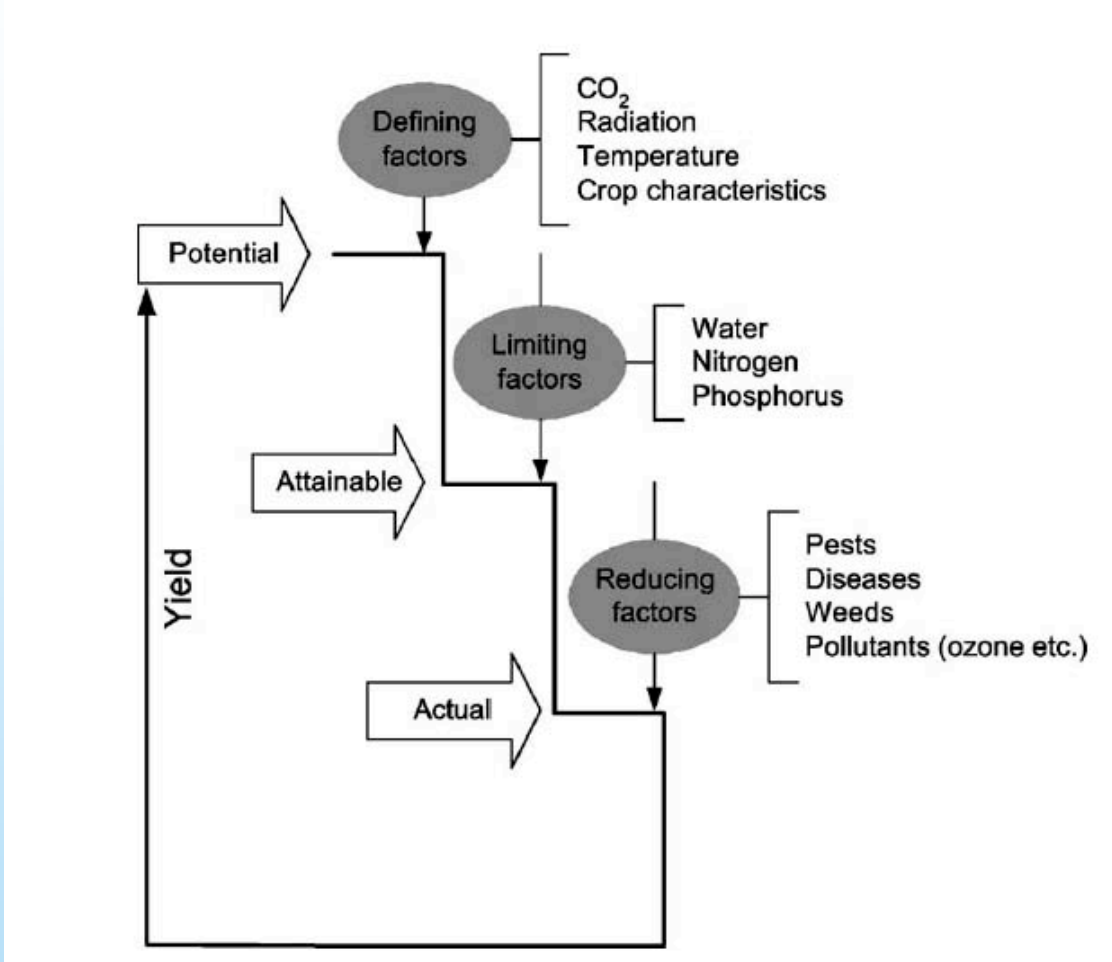
Indirect effects at system level

- Shifts in nutrient cycling
- Crop-weed interactions
- Insect pest occurrence
- Plant disease

Fuhrer, 2003

Implications for agriculture of air pollution and climate change?

Crop production levels depending on defining, limiting or reducing factors



Fuhrer, 2003

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Implications for agriculture of air pollution and climate change?

Agroecosystem responses to combinations of elevated CO_2, ozone and global climate change

Elevated CO_2 may have positive effects :

yield stimulation, improved resource use efficiency, more successful competition with C4 weeds, reduced O_3 toxicity, better pest & disease resistance

But many of these beneficial effects may be lost in a warmer climate:

Accelerates plant development, reduces grain fill, reduces nutrient use efficiency, increase crop water consumption, favours C4 weeds over C3 crops, increases rate of insect development, increases winter survival of insect pests, changes phenology

Agroecosystem effects dominated by ***shifts in climate*** rather than ***CO_2 elevation***.

Fuhrer, 2003

Implications for agriculture of air pollution and climate change?

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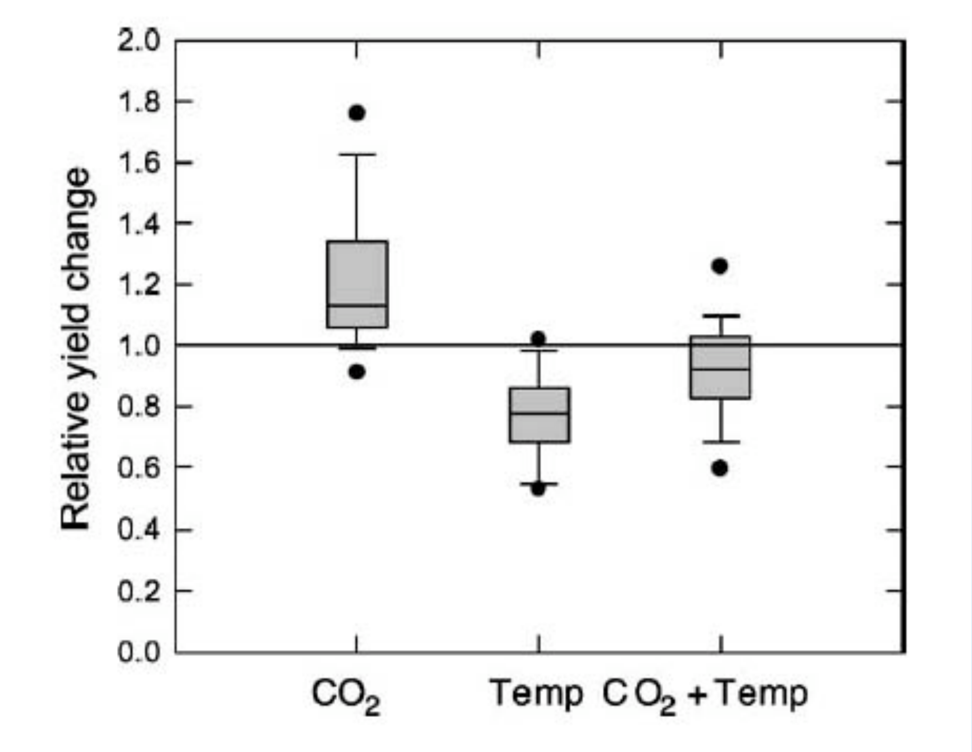

Effects of elevated CO_2 and increased temperature, singly and in combination, on yield of wheat.

Fuhrer, 2003

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Conclusions

A number of air pollutants are causing losses to agricultural productivity, with O_3 being one of the most important

Current day O_3 concentrations are causing damage to agricultural productivity and forest health

Projections of increases in O_3 concentration are extremely worrying for future food security, especially in Asia

Flux based assessment methods allow us to make more accurate assessments of damage and economic losses

Climate change (elevated CO_2 and **more importantly climate shifts**) will affect ozone impacts

Flux models provide a useful tool to investigate these combined stresses

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GLOBAL ATMOSPHERIC POLLUTION FORUM

Initiated at the 13th World Clean Air Congress, the Forum brings together all the main **regional policy networks and research initiatives** designed to promote **action on air pollution at the regional and hemispheric scales**. It will also contribute effectively to the debate about the now critical **interaction of climate change and pollution.**

It is jointly serviced by IUAPPA and **SEI**, and has the support of both UNEP and the Convention on Long Range Transboundary Air Pollution (CLRTAP).

The work programme for 2005 includes publication of the **Global Atlas** of Atmospheric Pollution, preparation of a **review of scientific and policy issues** associated with Northern Hemispheric pollution, and **major meetings** in Tokyo, Istanbul and Brazil.

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