This presentation was given at the
GECC GBSC meeting in March 2009
by Professor David Fowler, CEH

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Ground-level ozone in the 21st century

David Fowler FRS et al (17 members and 3 secretariat)

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Outline

- **Ozone in the Atmosphere**
- **Ozone production, destruction and trends**
- **Effects on climate**
- **Effects on human and plant health**
- **Modelling global ozone**
- **future ozone, with and without climate change**

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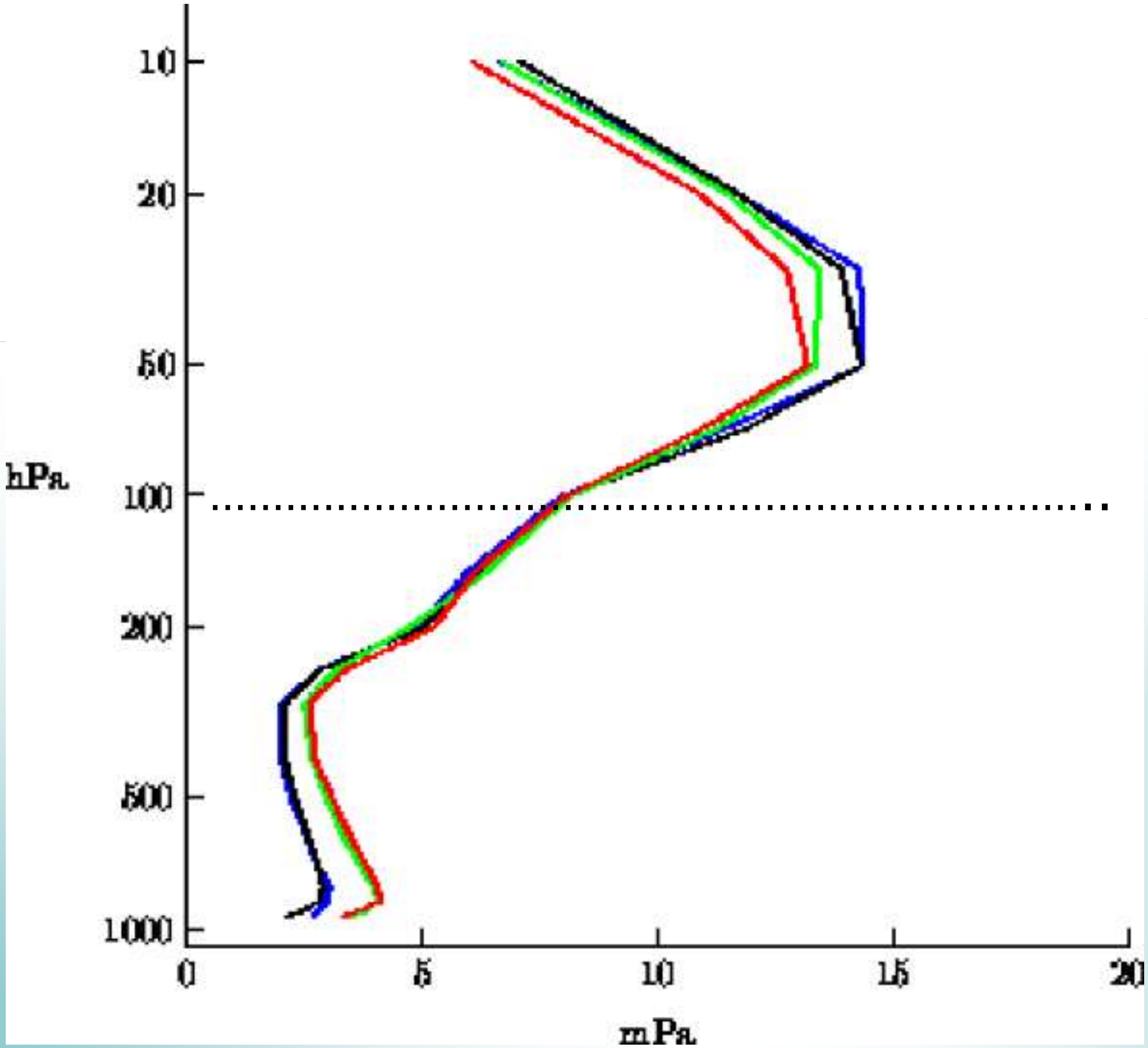
1990s -   1960s -



stratosphere

…..10 km……

tropopause

troposphere

- Some input from stratosphere (10-20% at mid latitudes)
- Photochemical production from natural and anthropogenic NO_x and VOC

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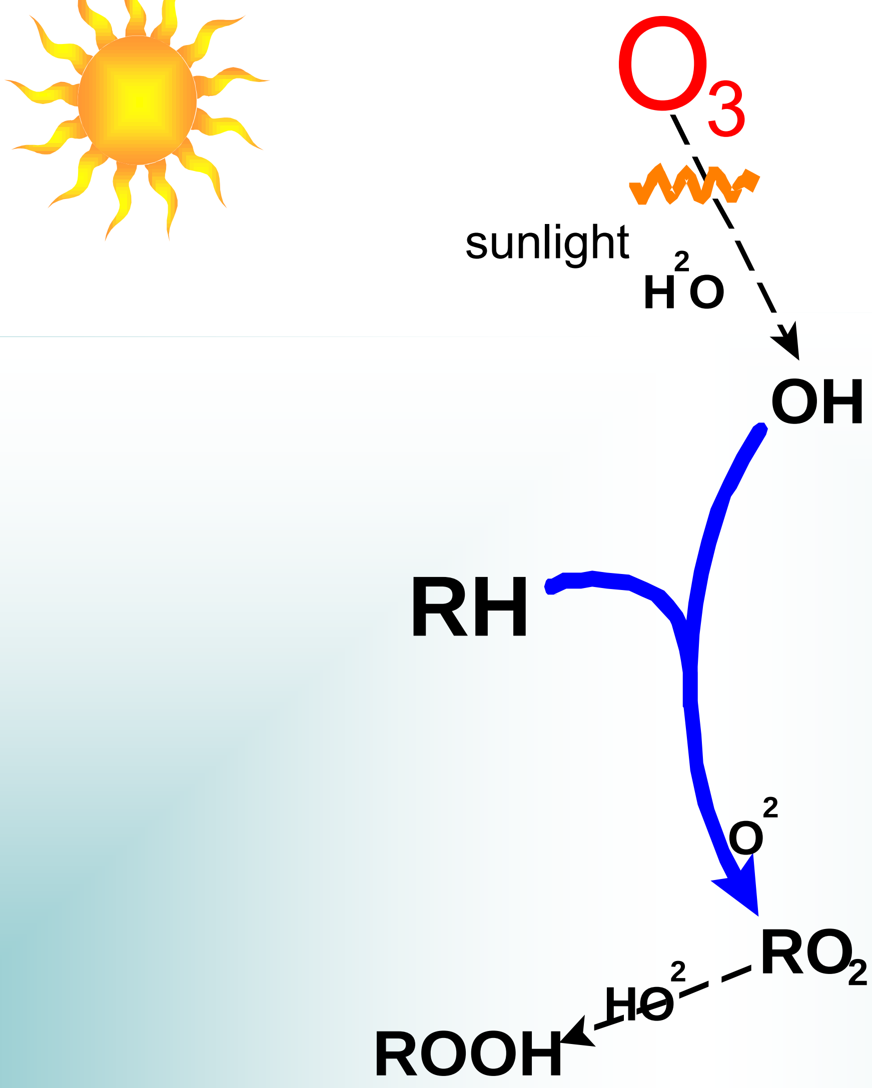
CLEAN ATMOSPHERE

$NO_2 < 20$ ppt



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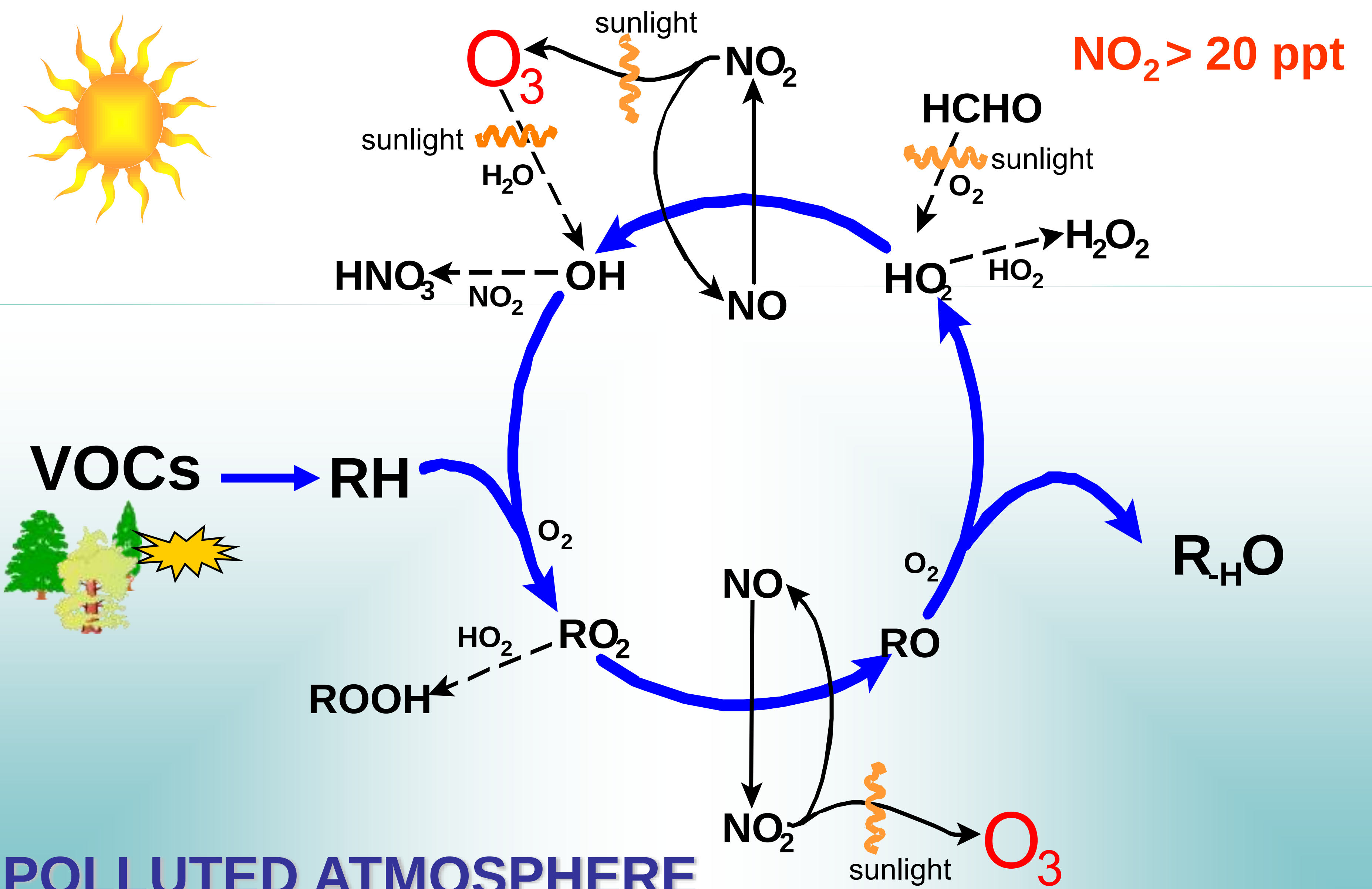
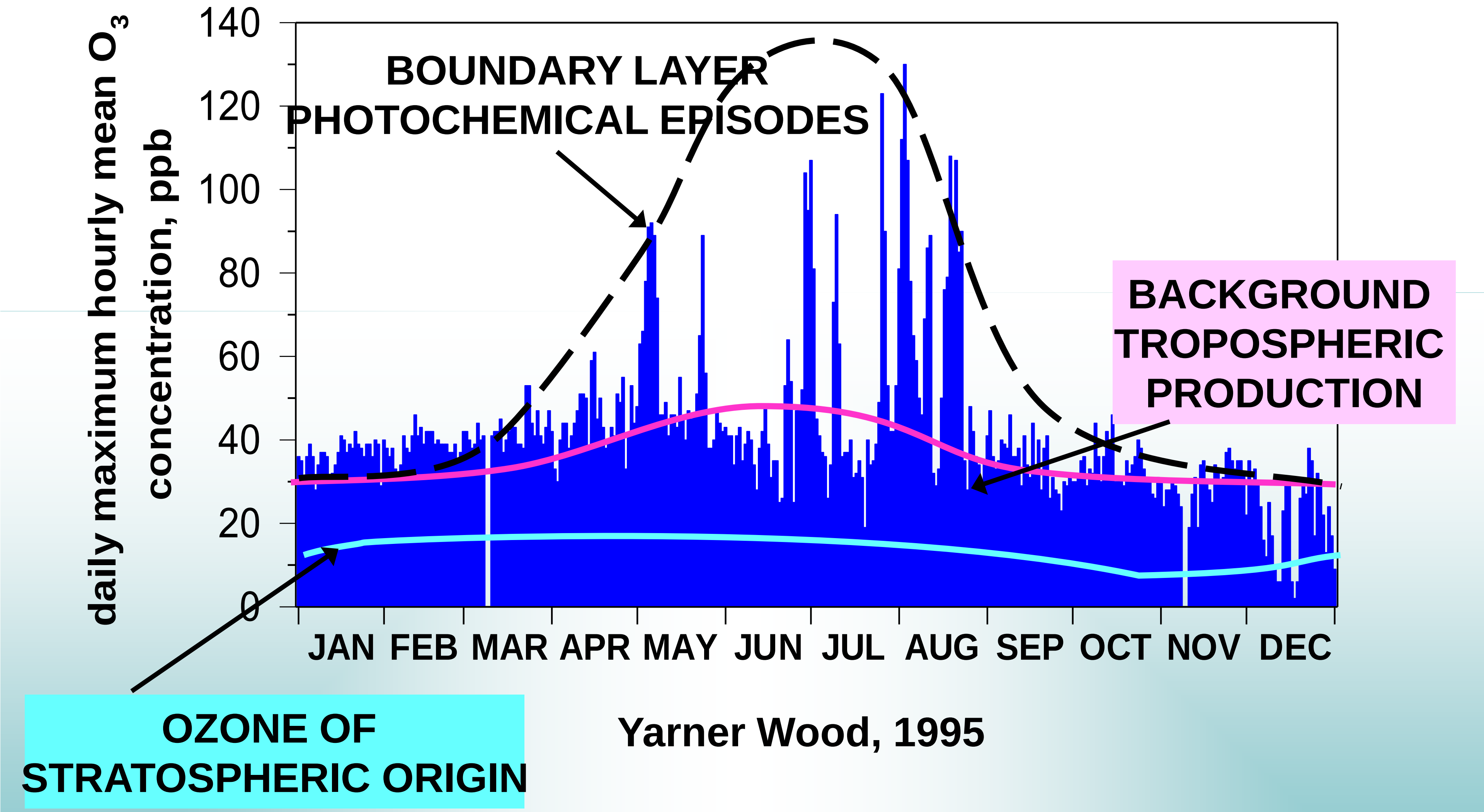
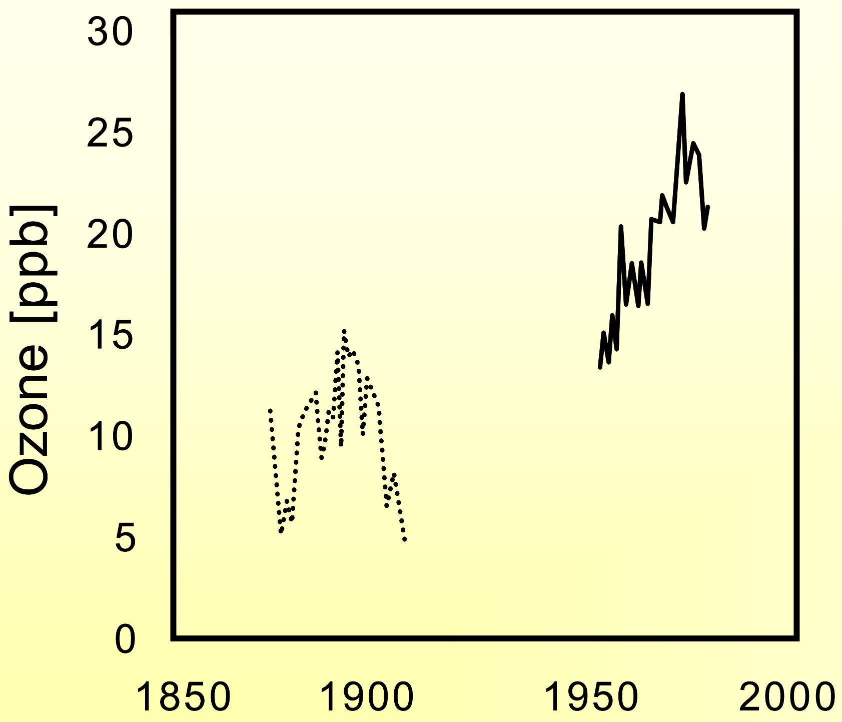


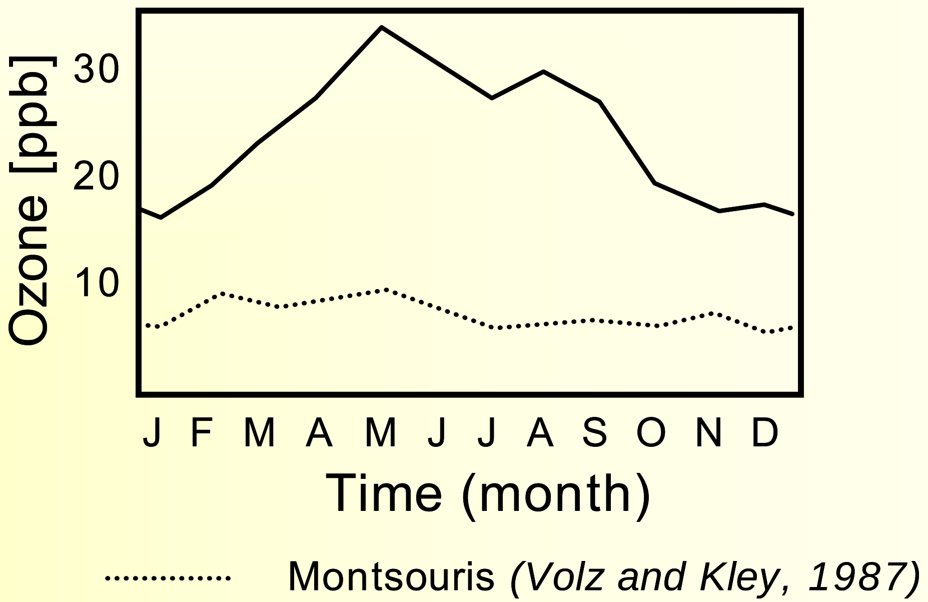
POLLUTED ATMOSPHERE


daily maximum hourly mean O_3 concentration, ppb
140
120
100
80
60
40
20
0
BOUNDARY LAYER PHOTOCHEMICAL EPISODES
BACKGROUND TROPOSPHERIC PRODUCTION
OZONE OF STRATOSPHERIC ORIGIN
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Yarner Wood, 1995

How has ozone changed since 1750?

- No ice-core data (O_3 is too reactive)





I.e. some evidence that P-I surface O_3 in Europe was <10 ppb

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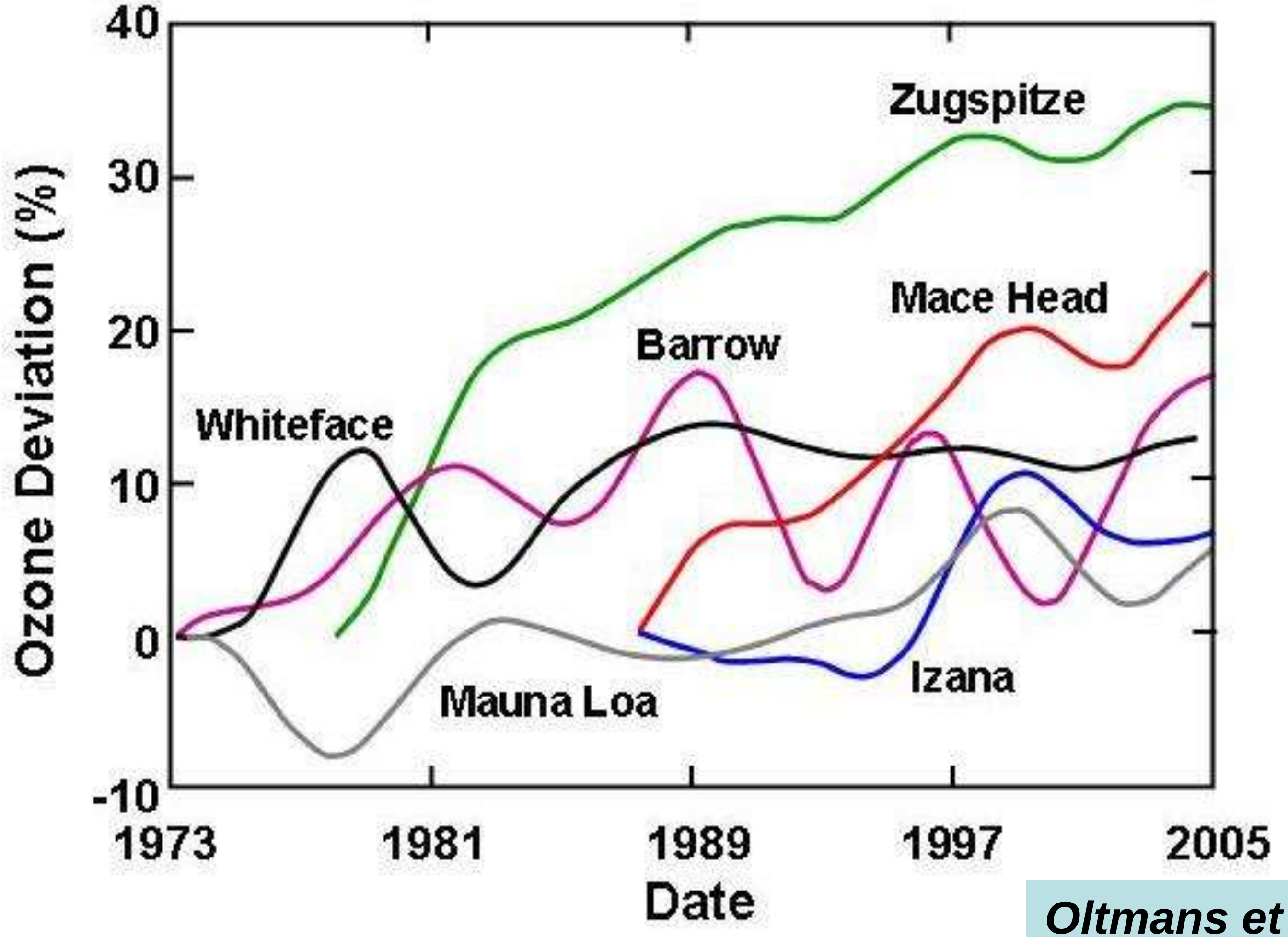
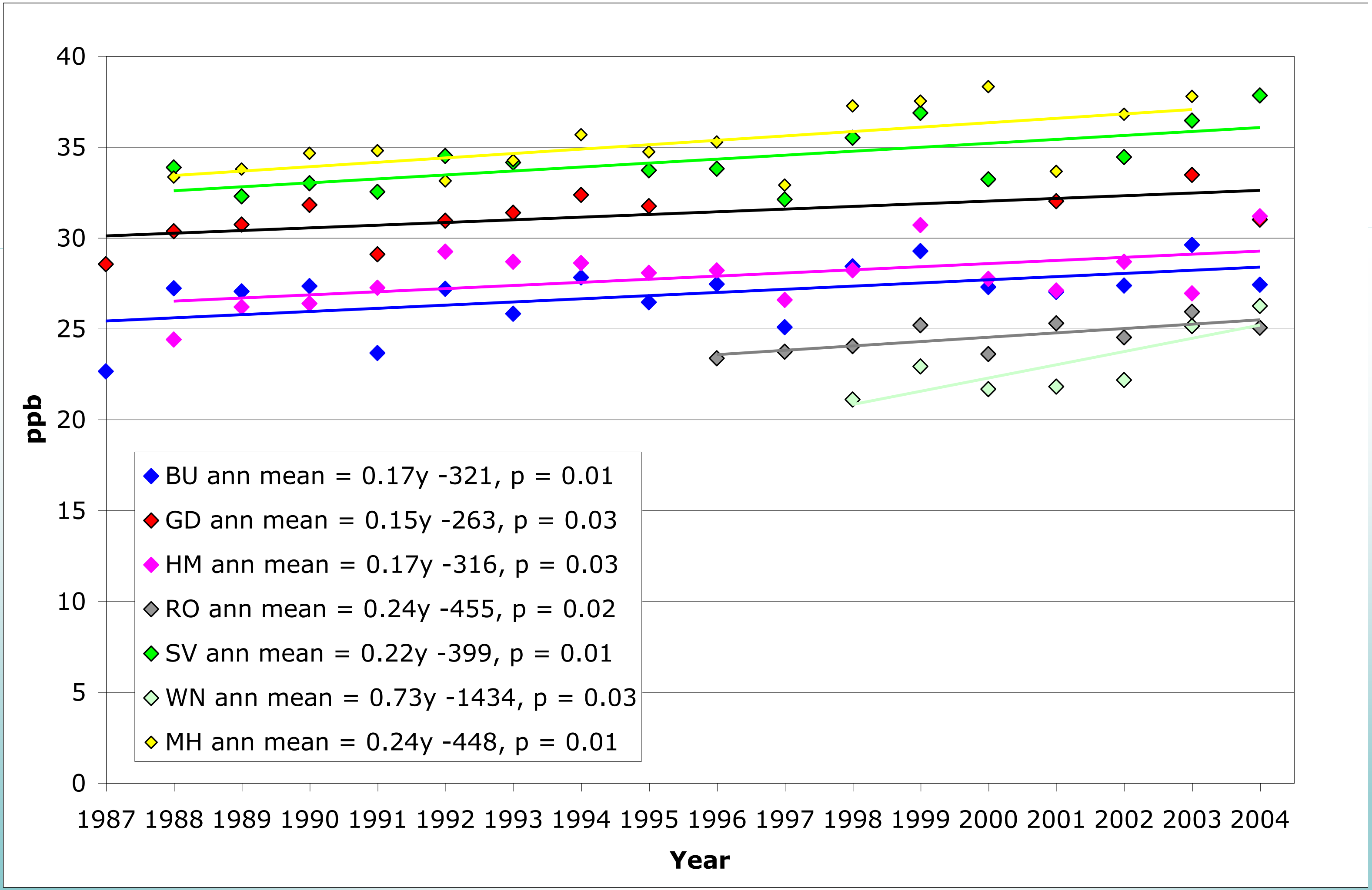
O_3 concentrations have roughly doubled since the early 1900's.

Observed trends in surface O_3 since the 1970s at various relatively remote sites



Oltmans et al., 2006

Statistically significant trends



Data from http://www.airquality.co.uk and Mace Head from Peter Simmonds, Bristol University

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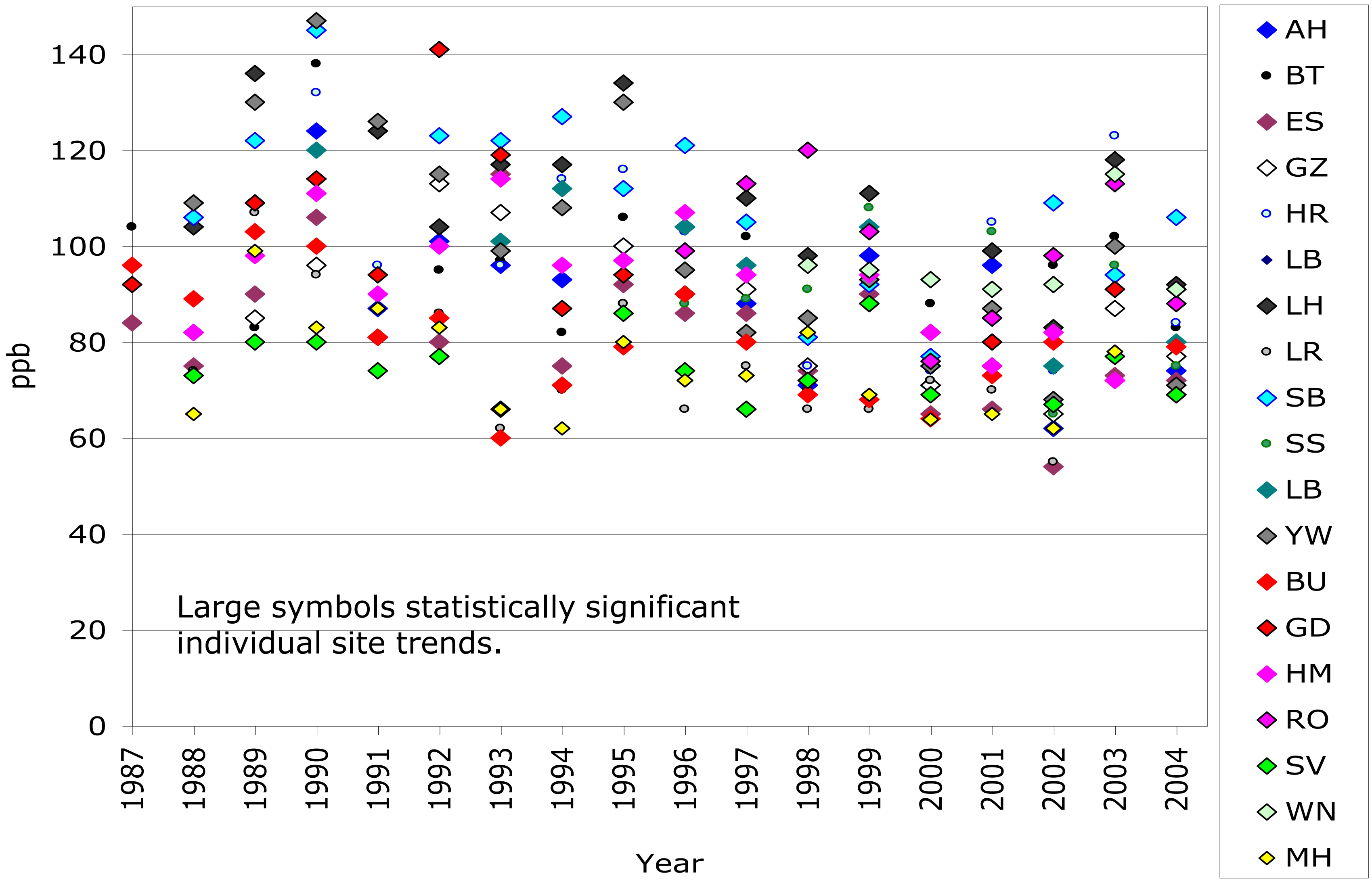
Annual Max at all Network Sites



Data from http://www.airquality.co.uk and Mace Head from Peter Simmonds, Bristol University

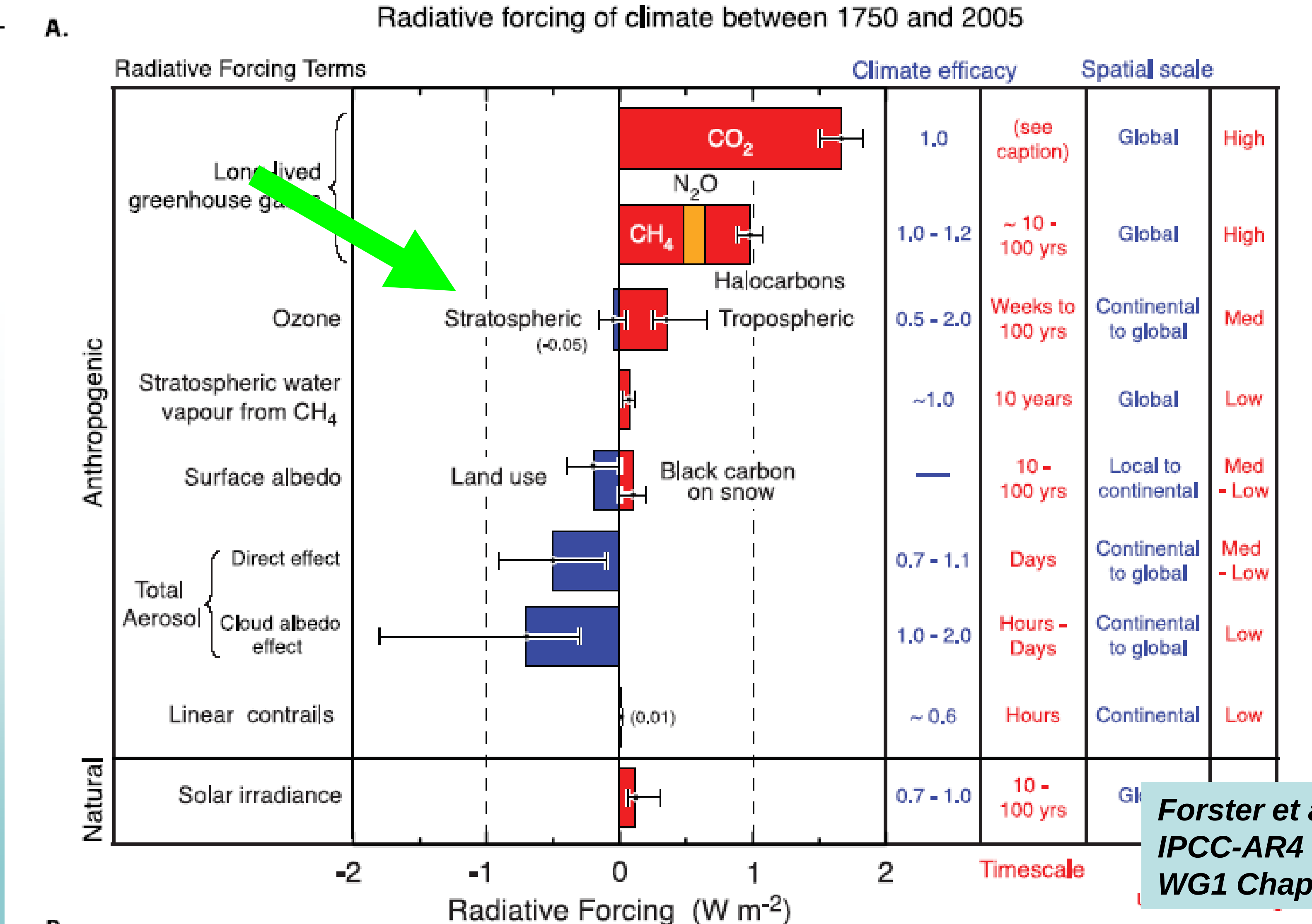
Summary of observed ozone

- A very few measurements before 1900 suggest surface O_3 in Europe was <10 ppb before industrialisation
- Before 1970s, a few observations show increases in surface O_3
- Since ~1970, surface/sonde monitoring networks have expanded
  - Most sites show increases in ozone, some show strong increases, but significant levels of variability (time and space)
- Models needed to produce a global picture

Ozone effects

- IPCC (2007): Tropospheric O_3 is the third largest greenhouse gas contributor to radiative forcing of climate change:
  0.35 Wm^{-2} *(CO_2: 1.66 Wm^{-2}; CH_4: 0.48 Wm^{-2})*

Radiative forcing from tropospheric O_3



Forster et al. (2007)
IPCC-AR4
WG1 Chapter 2

Ozone effects

- IPCC (2007): Tropospheric O_3 is the third largest greenhouse gas contributor to radiative forcing of climate change:

  0.35 Wm^{-2} *(CO_2: 1.66 Wm^{-2}; CH_4: 0.48 Wm^{-2})*

- Ground level O_3 is also a serious air pollutant (it is a reactive oxidant), affecting human health, & damaging crops & natural vegetation.

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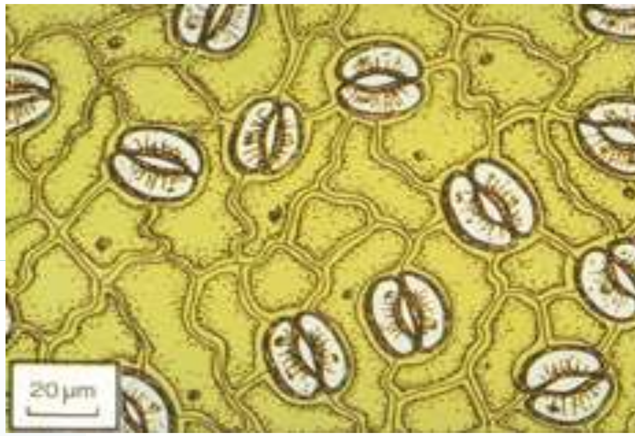
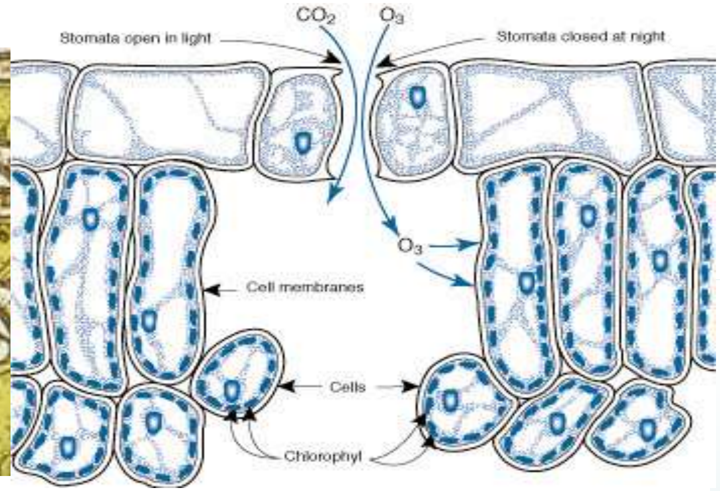
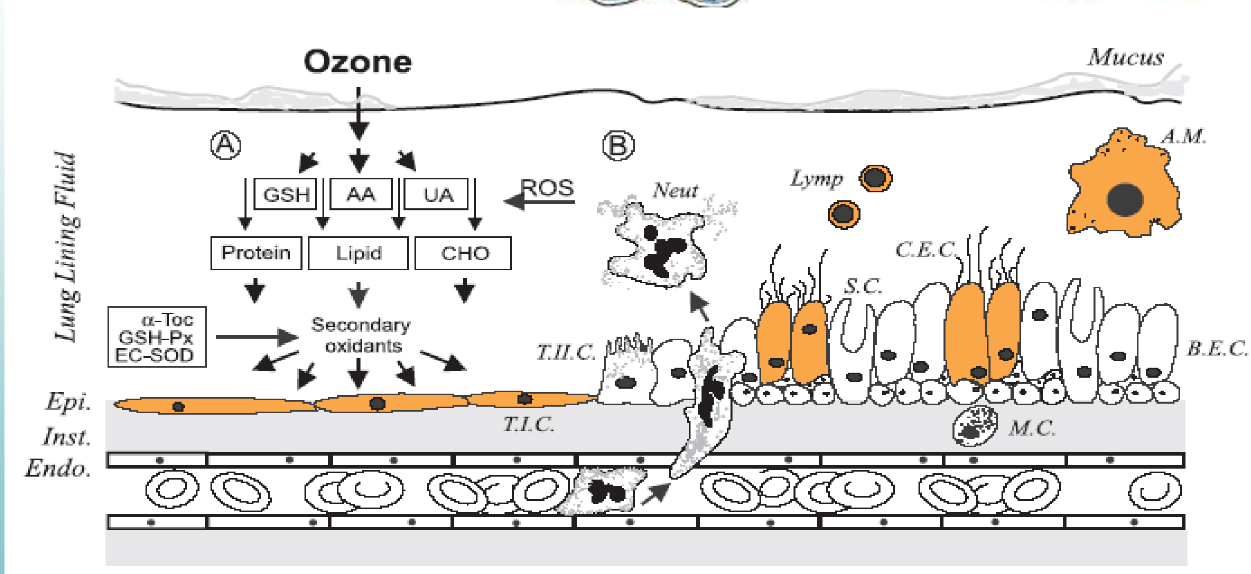
The biosphere-atmosphere boundary





Ozone enters a plant via stomata; attacks plant cells



Ozone crosses the fluid lining of the lungs, and stimulates a variety of responses at the cell level

Mudway and Kelly (2000)

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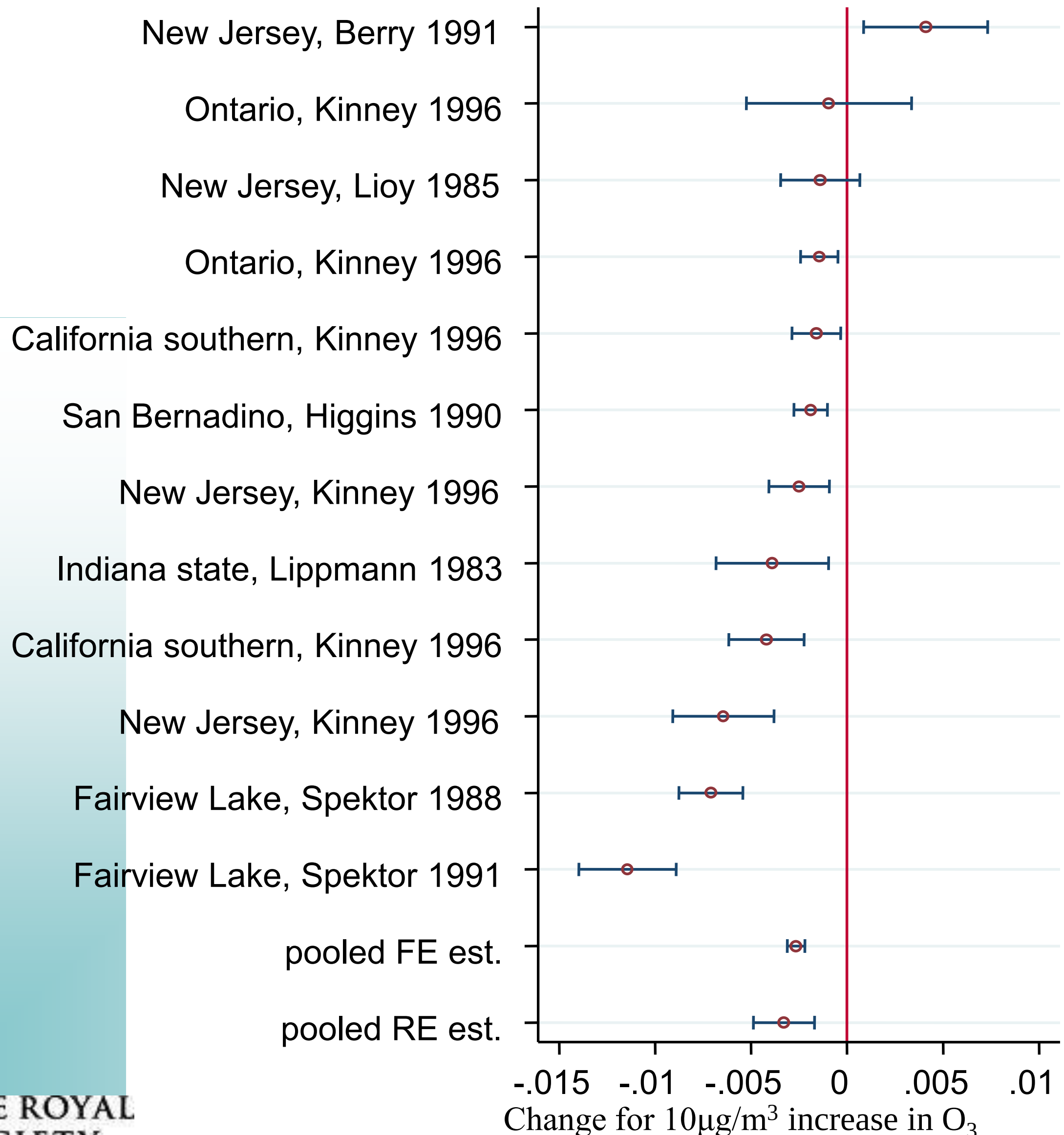
Lung function reduces at higher O_3 → **Lung function improves at higher O_3**



Ozone reduces the lung function of healthy children

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Courtesy of Ross Anderson

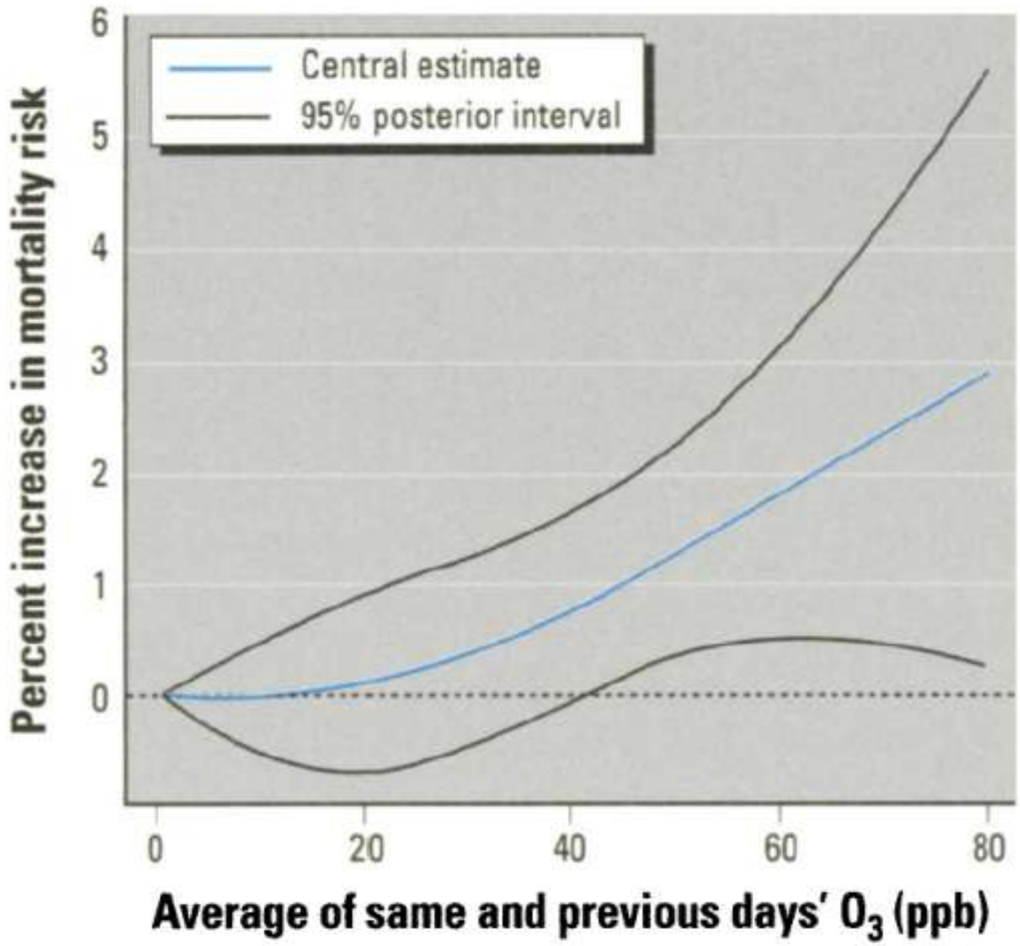


Figure 3. Exposure–response curve for O_3 and mortality using the spline approach: percentage increase in daily nonaccidental mortality at various O_3 concentrations.

High levels of ozone increase your chances of dying

Meta-analysis based on 98 US cities

Bell et al. (2006, Environmental Health Perspectives)

Ozone effects

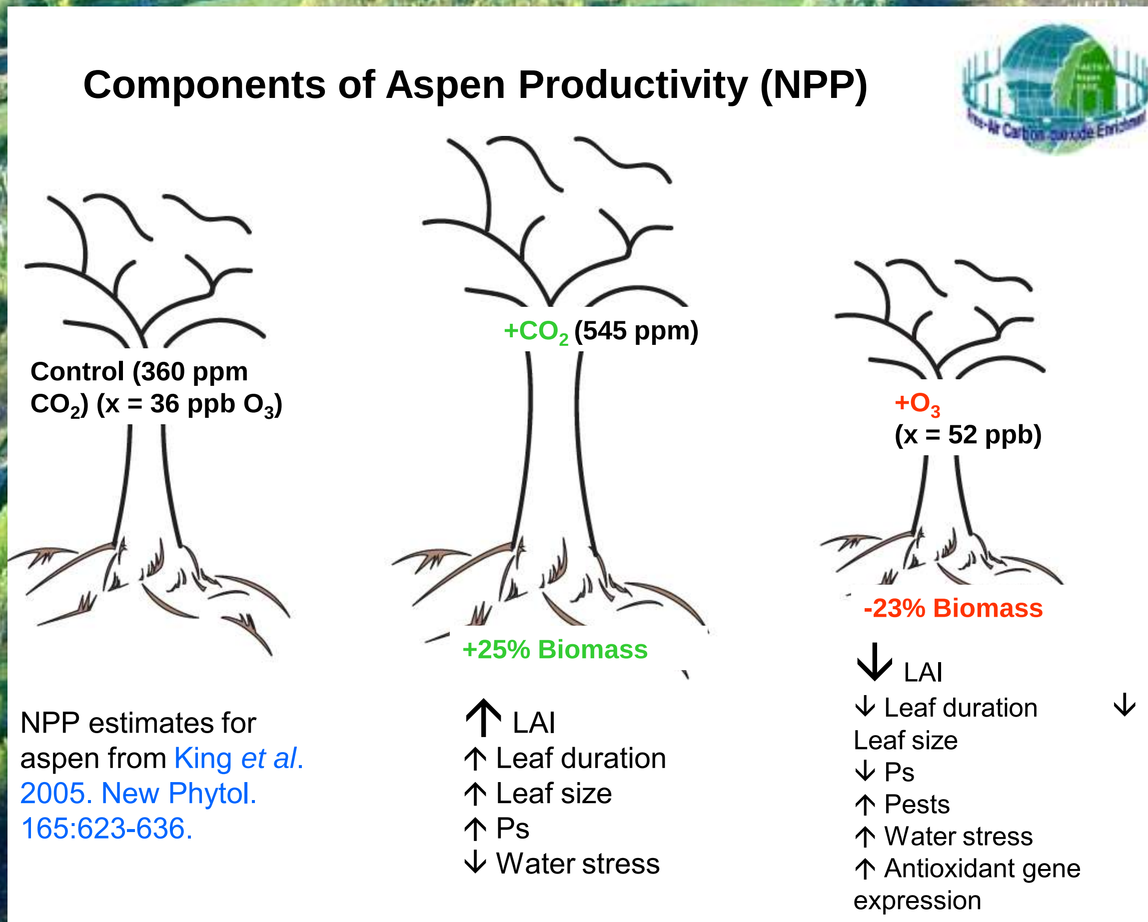
- IPCC (2007): Tropospheric O_3 is the third largest greenhouse gas contributor to radiative forcing of climate change:

  0.35 Wm^{-2} *(CO_2: 1.66 Wm^{-2}; CH_4: 0.48 Wm^{-2})*

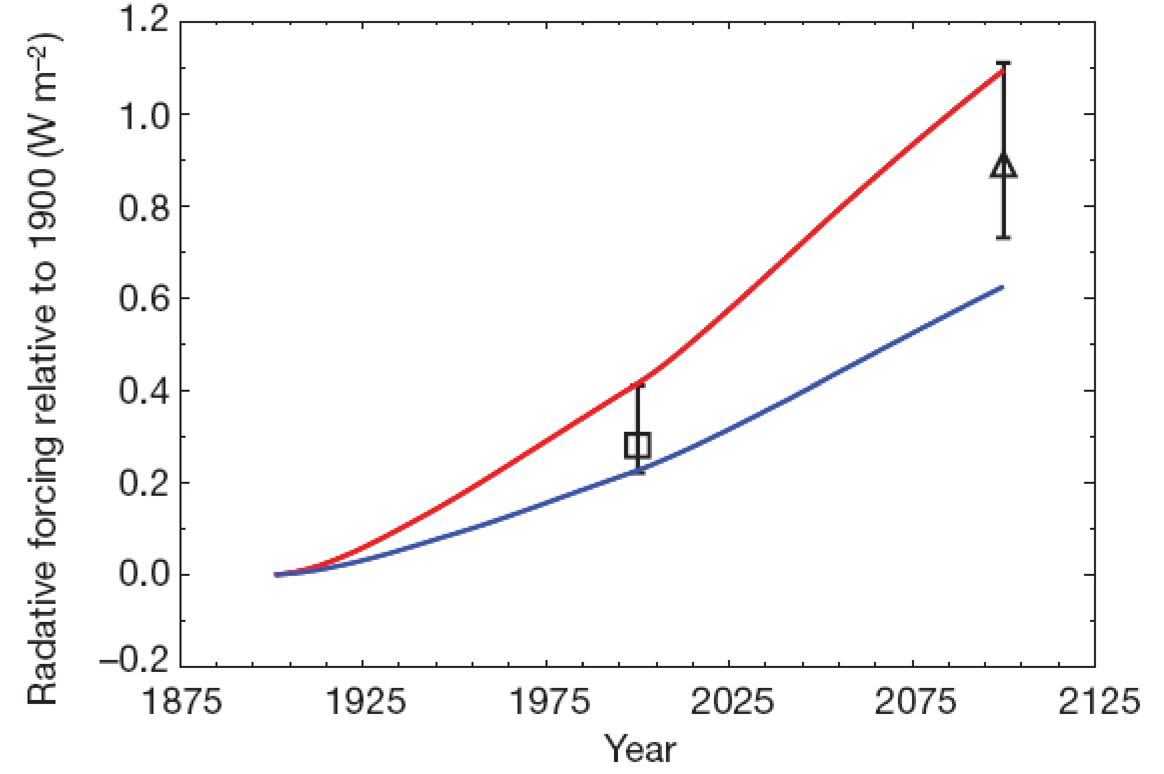
  Or is it even more important for climate?

- Ground level O_3 is a serious air pollutant (it is a reactive oxidant), affecting human health and damaging crops and natural vegetation.

AspenFACE: Exposure of tree stands to elevated CO_2 and O_3



Indirect and direct radiative forcings from tropospheric ozone



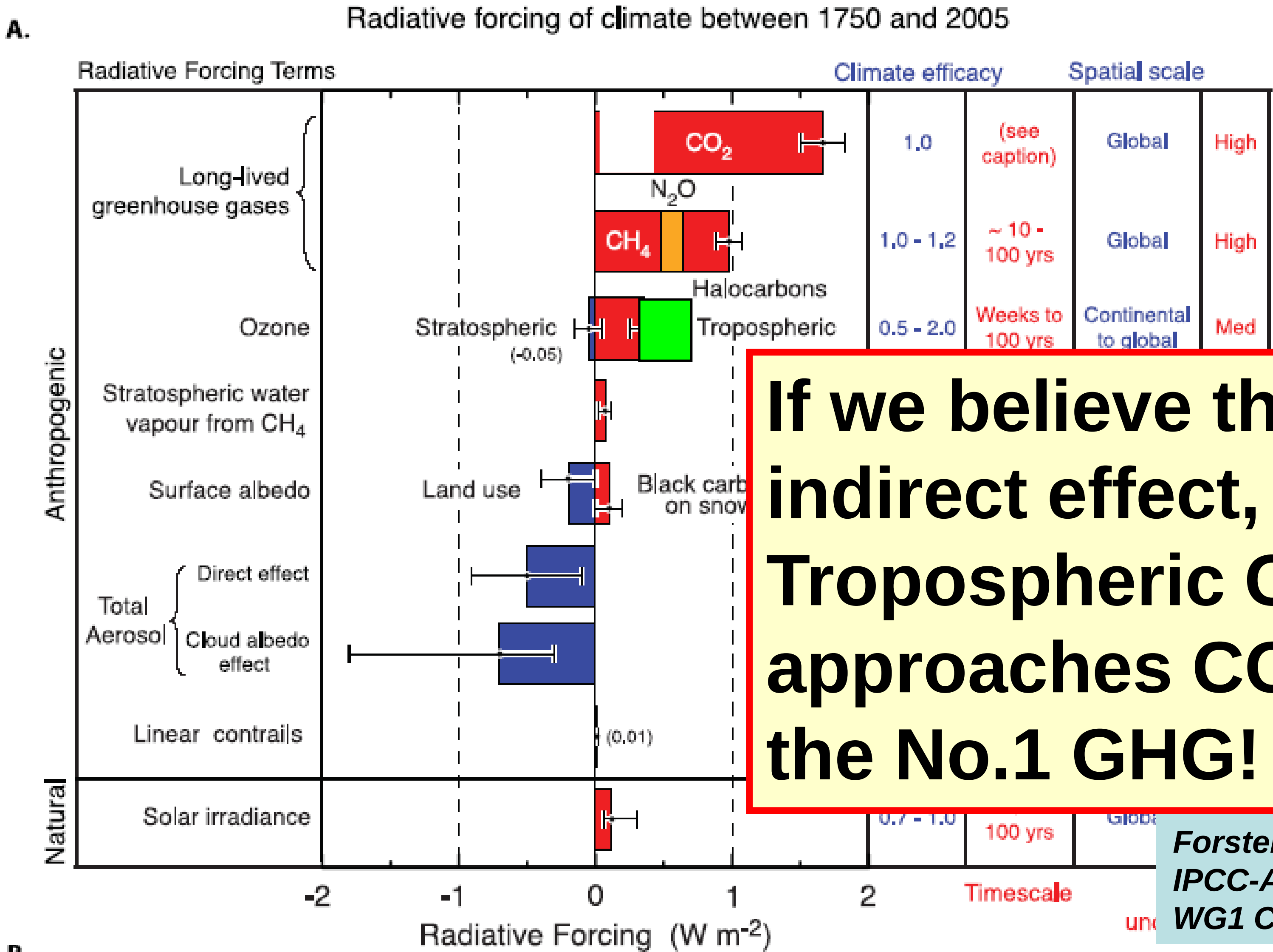
Symbols are direct forcings (IPCC, 2001)

Blue and red curves are indirect ozone forcing, due to ozone impacts on vegetation (high ozone sensitivity) (low ozone sensitivity)

Suggests that the indirect forcing may be similar in magnitude to the direct forcing.

Sitch et al. (Nature, 2007)

Radiative forcing from tropospheric O_3



If we believe this O_3 indirect effect, then Tropospheric O_3 approaches CO_2 as the No.1 GHG!

Forster et al. (2007) IPCC-AR4 WG1 Chapter 2

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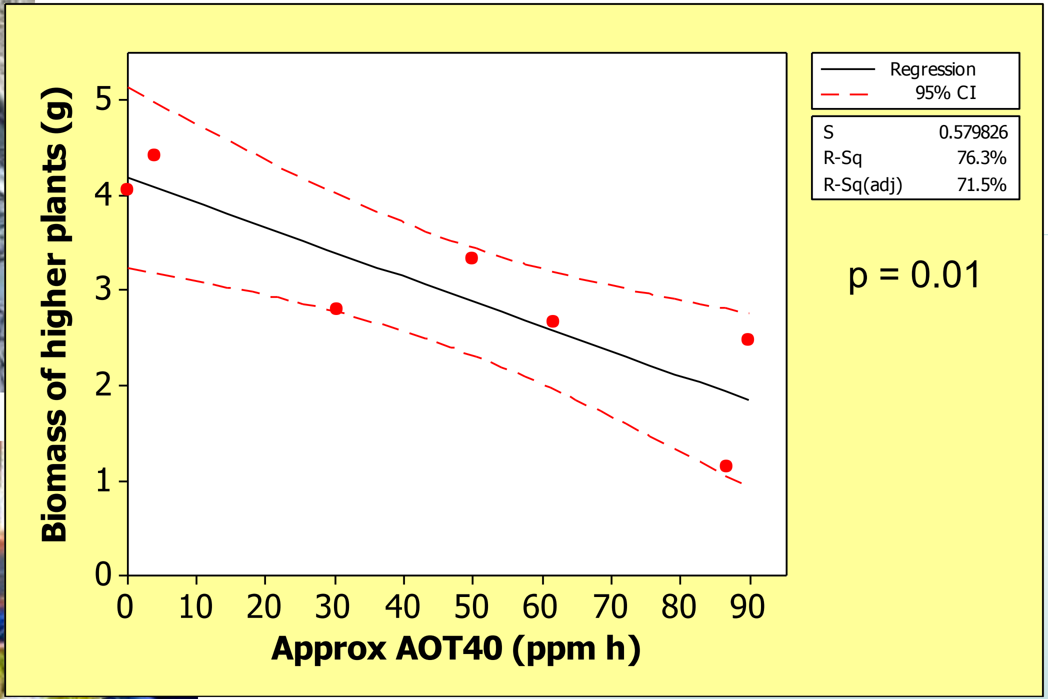
Ozone effects on biodiversity

Effects on UK (semi-)natural vegetation

Growth of higher plants in bog mesocosms



- Ozone exposure for 4 months reduced the emergence and growth of higher plants

Williamson, CEH Bangor,

Effects on UK (semi-)natural vegetation

Effects on competition

MG3(b) mesocosms in Open Top Chambers, Newcastle University

- **5 years of ozone exposure**
- **Simulated ambient and 2050 climates**

Effects on species composition

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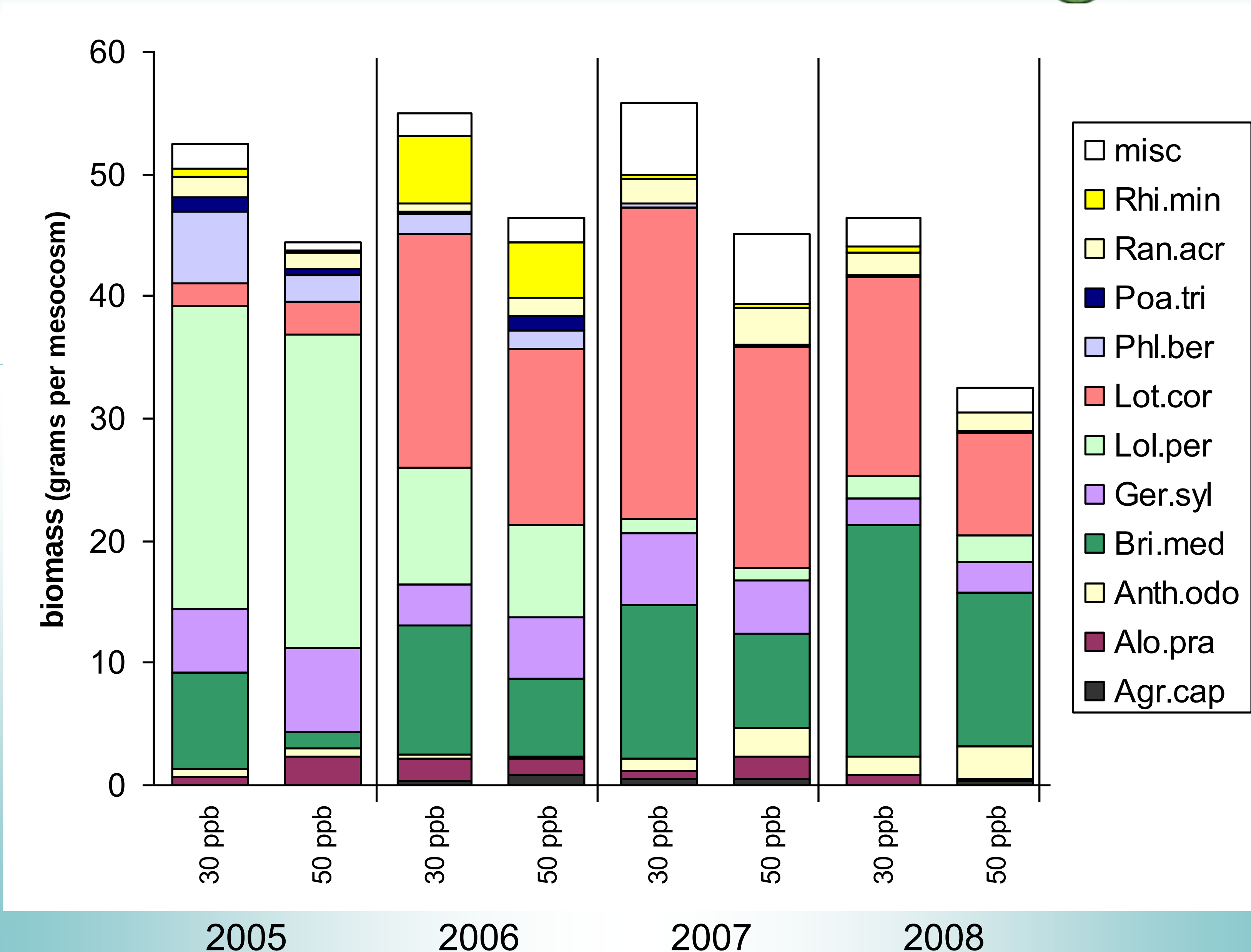
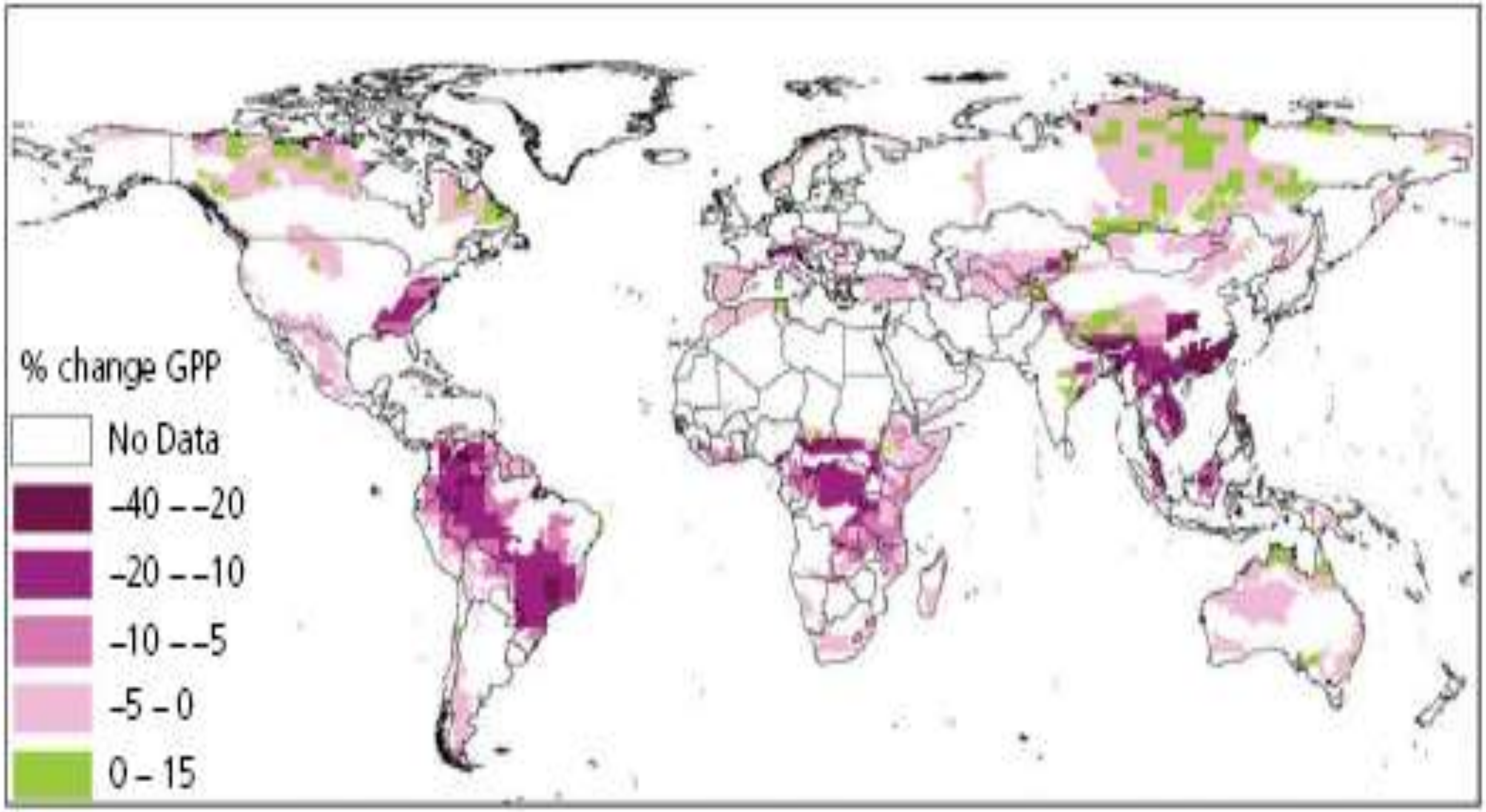


Barnes & Peacock, University of Newcastle, Defra Annual Reports

Assessment of key biodiversity areas at high risk of ozone impacts (using the global 200 priority areas and Sitch et al 2007)

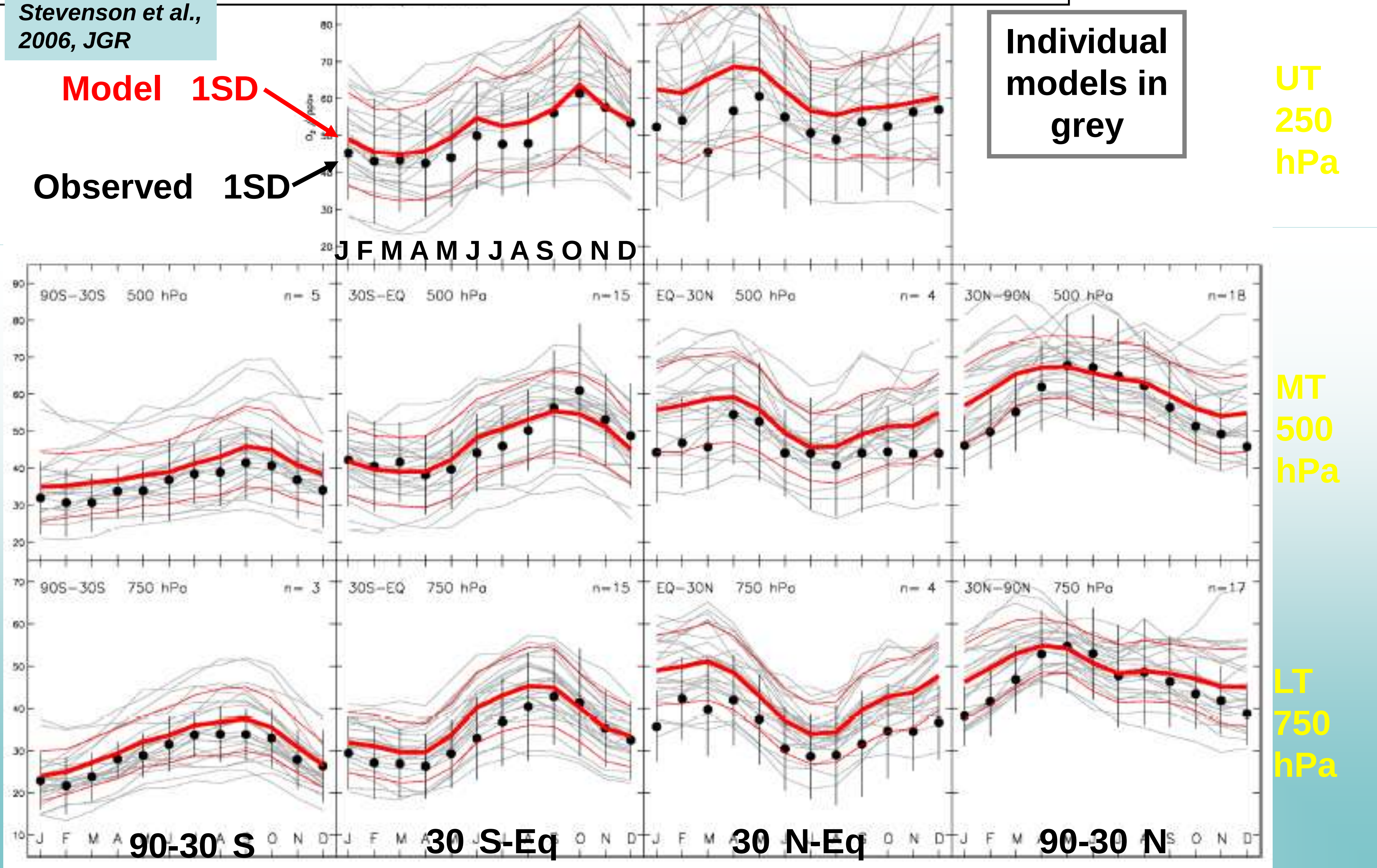


What can models tell us?

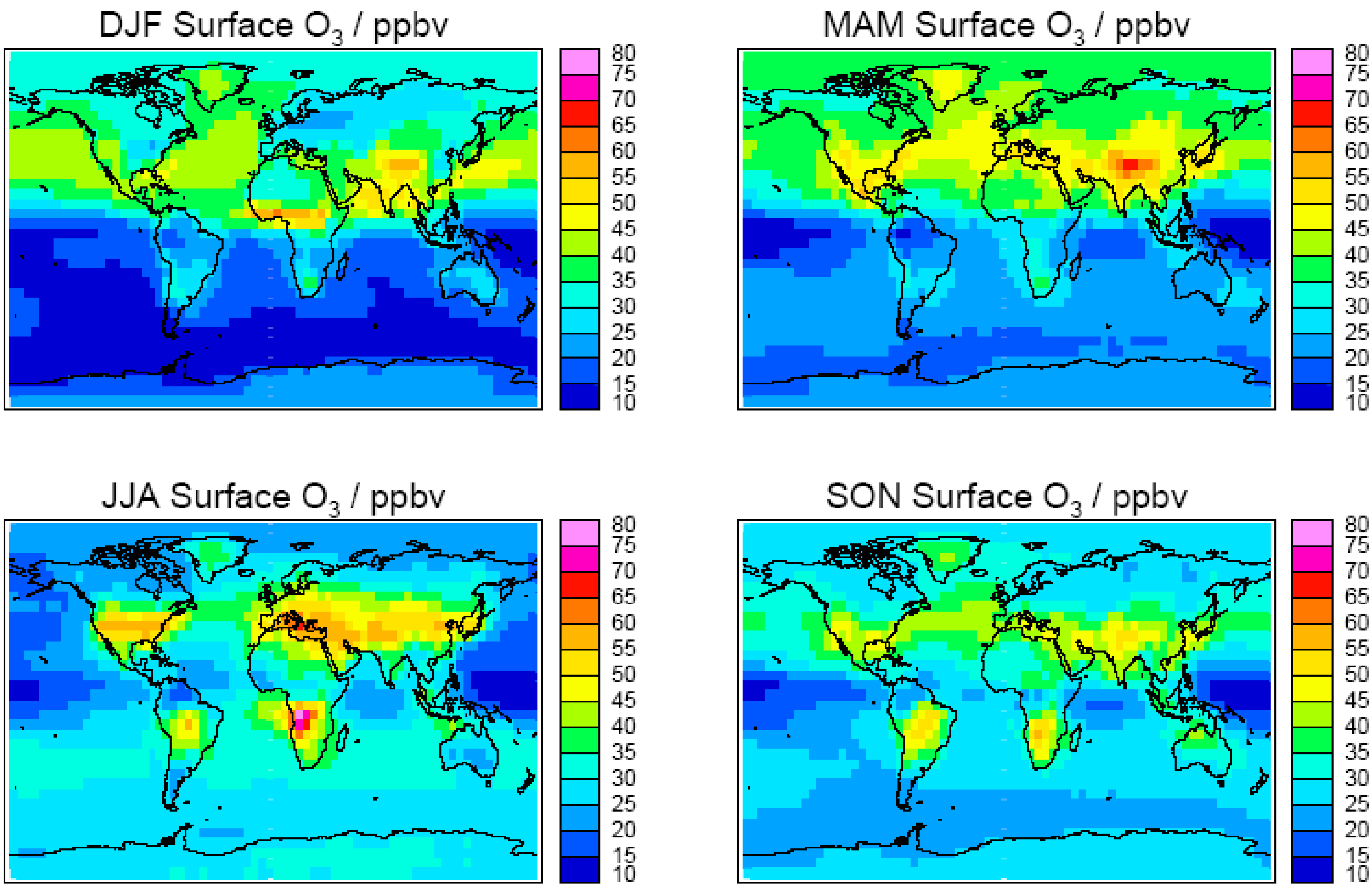
- Give a global view of the spatial and temporal distribution of ozone and its precursors (more detail than observations alone)
- Allow us to diagnose when and where ozone chemical production and destruction is taking place
- If we have faith in the models, we can use them for hindcasts/forecasts, and sensitivity experiments (e.g., what happens to ozone if emissions and/or climate change?)

Comparison of ensemble mean model with O_3 sonde measurements

ACCENT Photocomp: Stevenson et al., 2006, JGR

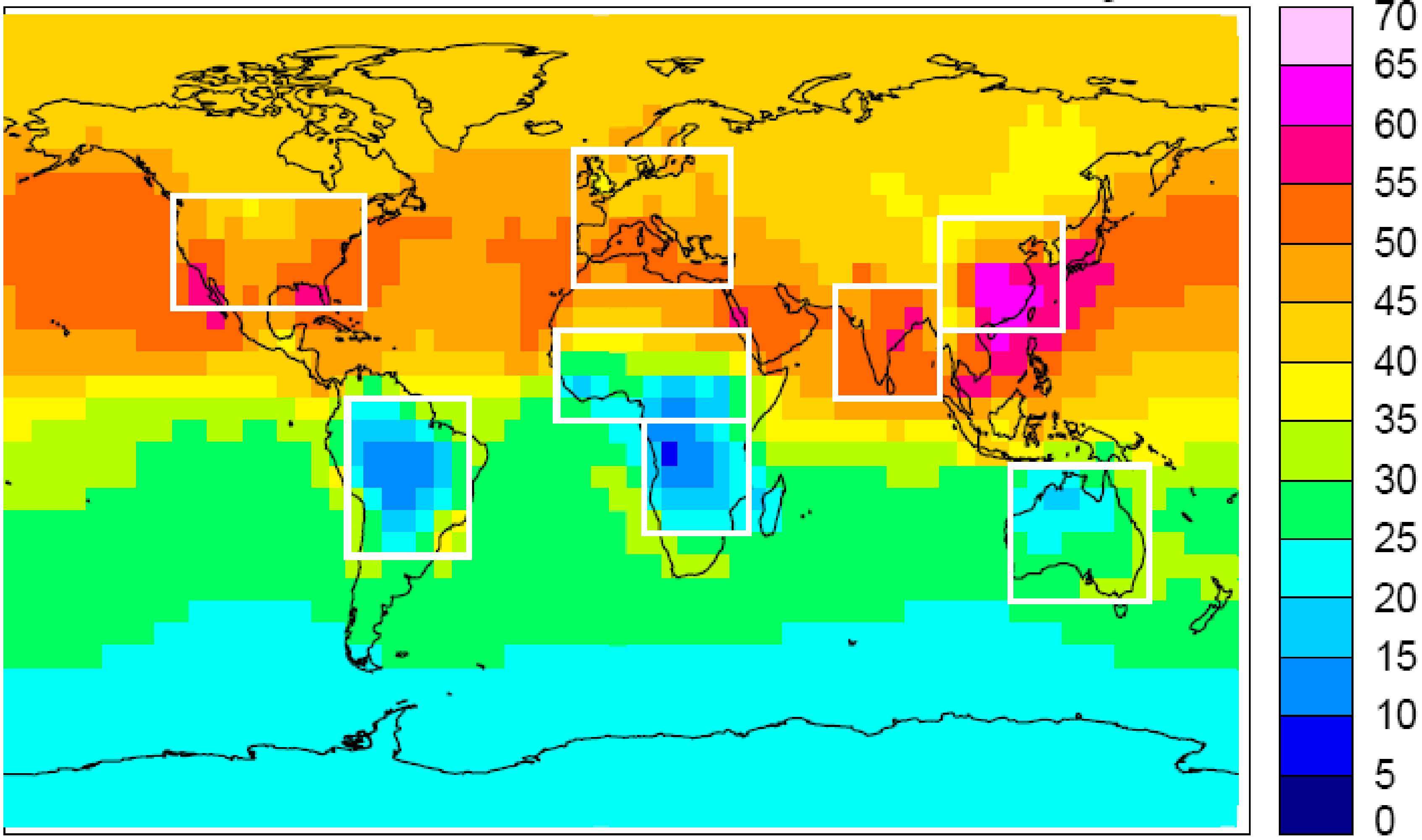


Seasonal variation of surface ozone



Ensemble mean of 26 ACCENT Photocomp models

Annual mean anthropogenic surface O_3 (%)

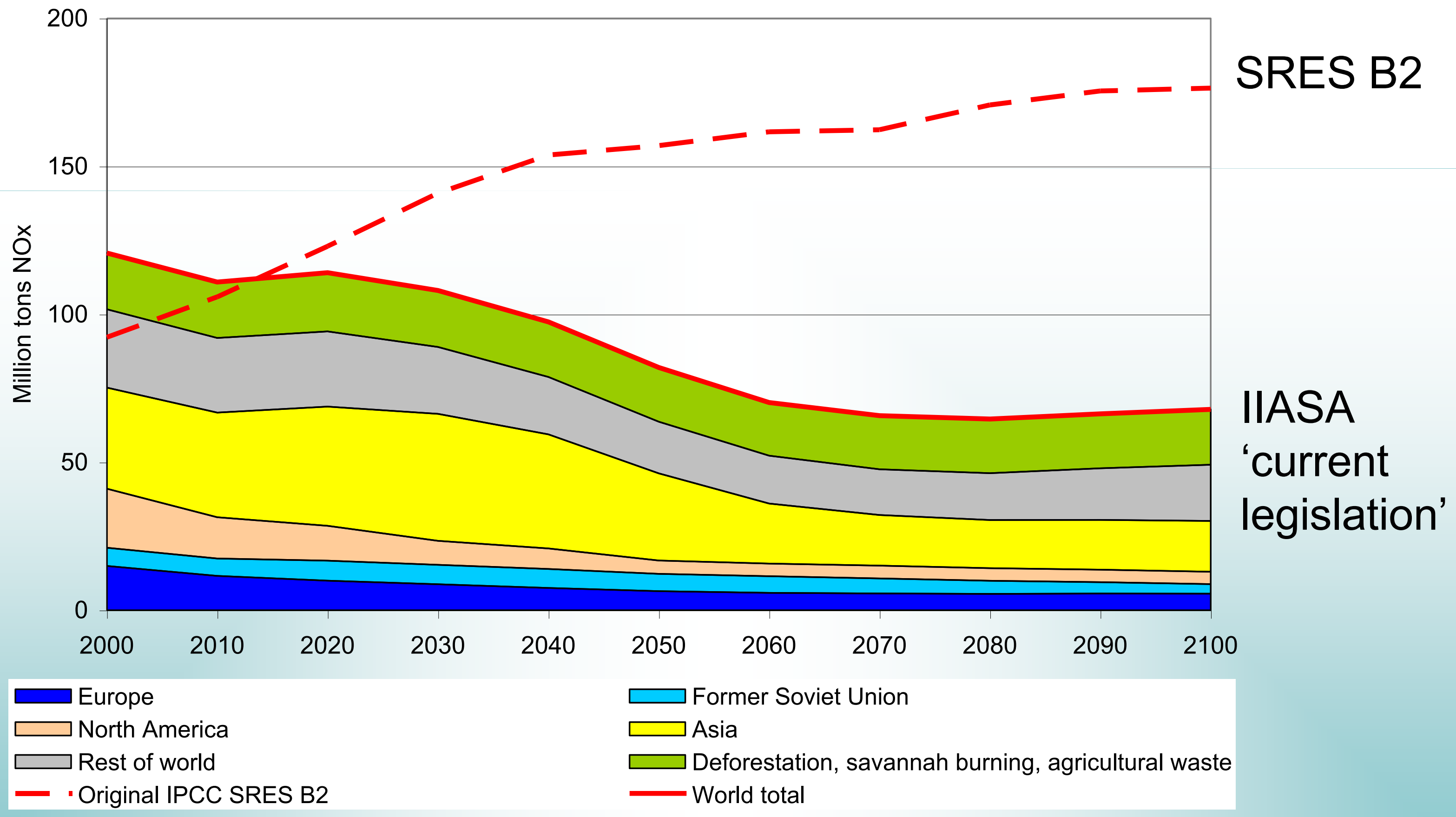


Assumes no change in biomass burning or soil NOx between P-I and present

Ozone in the future…

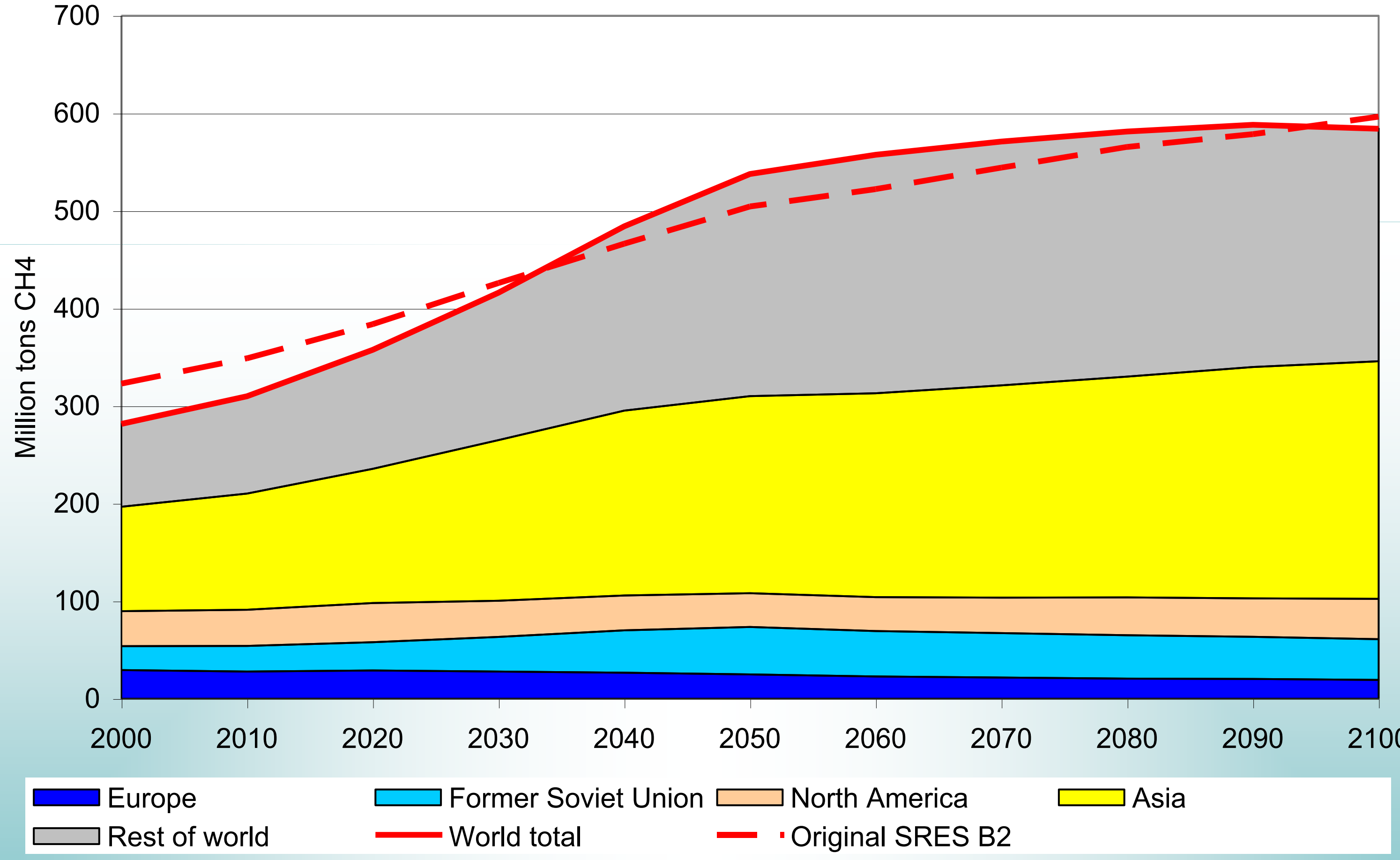
- Will depend strongly on the trajectory of anthropogenic emissions, in particular NOx, but also CH_4, CO and VOCs.
- IPCC SRES probably too pessimistic; new projections from IIASA expect air quality legislation to significantly reduce NOx emissions by 2050
- Climate change is likely to impact ozone

Under current legislation, NOx emissions should reduce in most places:



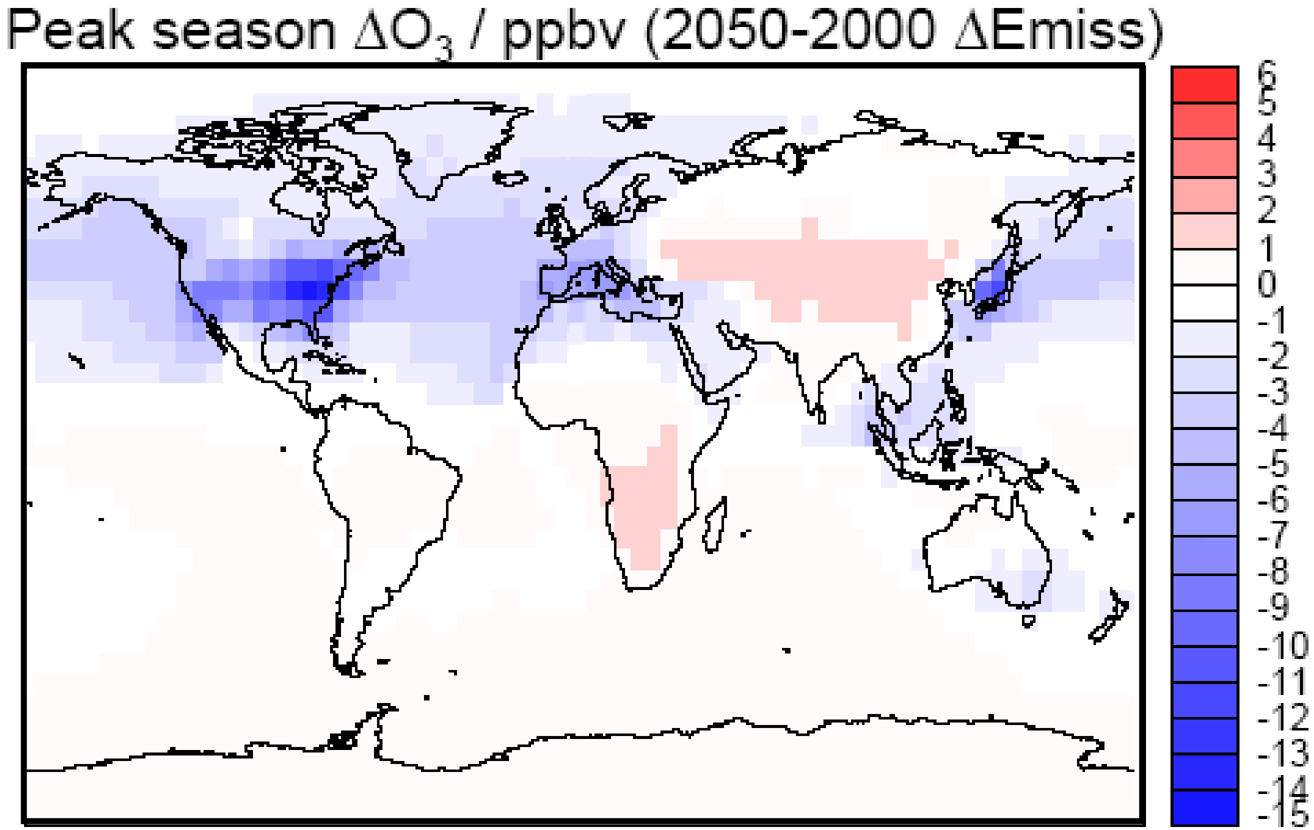
Courtesy Markus Amann, IIASA

Methane emissions 2000-2100



Courtesy Markus Amann, IIASA

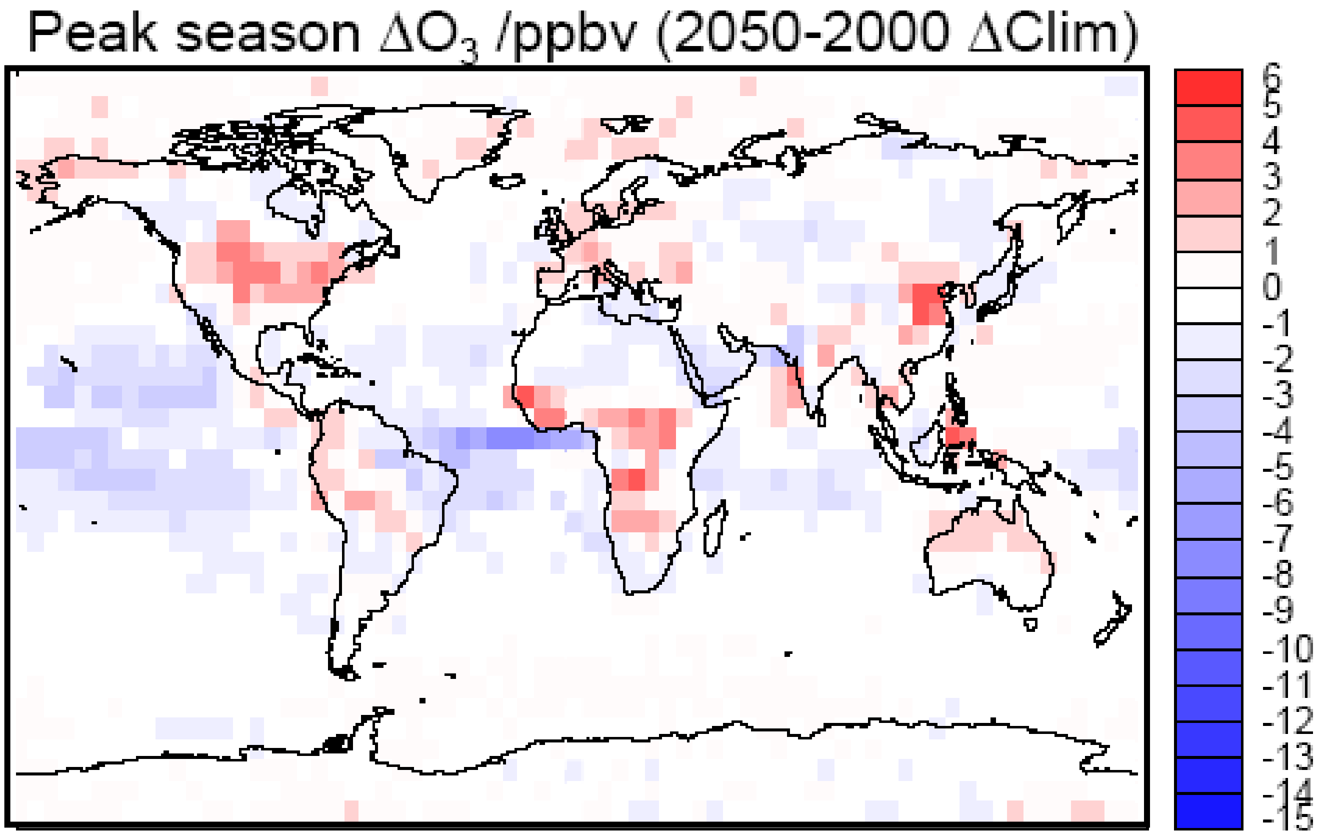
Projected changes in surface O_3 (2050-2000) during the peak O_3 season due to ***emissions changes***



Mean of 5 models

Impact of IIASA CLE 2050 emissions changes only (relative to 2000)

Projected changes in surface O_3 (2050-2000) during the peak O_3 season due to ***climate change***



Mean of 3 models

Impact of 2000-2050 climate change only (prescribed future climate: HadGEM SRES A1B)

Conclusions (past & present O_3)

- The direct radiative forcing from tropospheric ozone is +0.35 W m^{-2} (range +0.25 to +0.65 W m^{-2})
- An indirect effect of O_3, via reduced growth of vegetation, may add a further 0.2 to 0.4 W m^{-2}, suggesting O_3 may approach CO_2 in terms of radiative forcing
- O_3 affects human as well as plant health, and legislation exists in most countries to limit emissions of O_3 precursors
- Ozone precursor emissions from ships and aircraft are not currently regulated, and are growing fast
- Strong legislation to reduce all emissions will bring important benefits for both air quality and climate, and may be an important short- to medium-term tool to reduce radiative forcing, especially if O_3 does have a larger forcing than currently thought

Science Summary

- **Local emissions controls help to reduce episodic peak ozone**
- **But, with lower local NO_x emissions, urban populations increasingly exposed to background ozone**
- **Hemispheric/global emissions controls (on NO_x, CH_4, CO and NMVOC) needed to reduce background ozone**
- **Climate change may locally counteract ozone regulation through emissions controls**
- **Current Legislation scenarios, if implemented, will generally reduce ozone, but:**
  - **Ozone increases over Asia for the next 2 decades**
  - **Shipping and aviation emissions not covered**

Science Summary

- **Effects of ozone on human health, crop production and carbon sequestration are important globally.**
- **Projected increases in ozone in SE Asia may be a greater threat to food security than climate change.**
- **Natural plant communities have received much less attention in ozone research, but available evidence shows them to be as sensitive to ozone as crop plants.**

Priorities for research and policy

- CBD to include ozone as a new and emerging issue
- Research to underpin impact assessment processes (UK, Int)
- Biodiversity, Food security, carbon cycle
- International mechanism for regulating ozone (hemispheric+)
- UNFCCC recognition of benefits of ozone control
- Capacity building in developing countries