The Abdus Salam International Centre for Theoretical Physics

2339-7

Workshop on Atmospheric Deposition: Processesand Environmental Impacts

21 - 25 May 2012

Ozone deposition and effects on terrestrial ecosystems

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CONTENT

- **Introduction, why we are interested in ozone**
- **Ozone production**
- **What will happen this century to ozone..probably**
- **Effects of climate change on ozone**
- **Effects of ozone on vegetation**
- **Ozone and Black carbon**

Impacts of ozone on health & environment

- Present-day annual ozone impacts in EU:
  - 20,000 deaths brought forward
  - 20 million respiratory hospital days
  - 50 million restricted activity days in young adults due to respiratory symptoms
  - €6.7 billion loss of arable crops
  - ?effects on semi-natural vegetation and carbon sequestration

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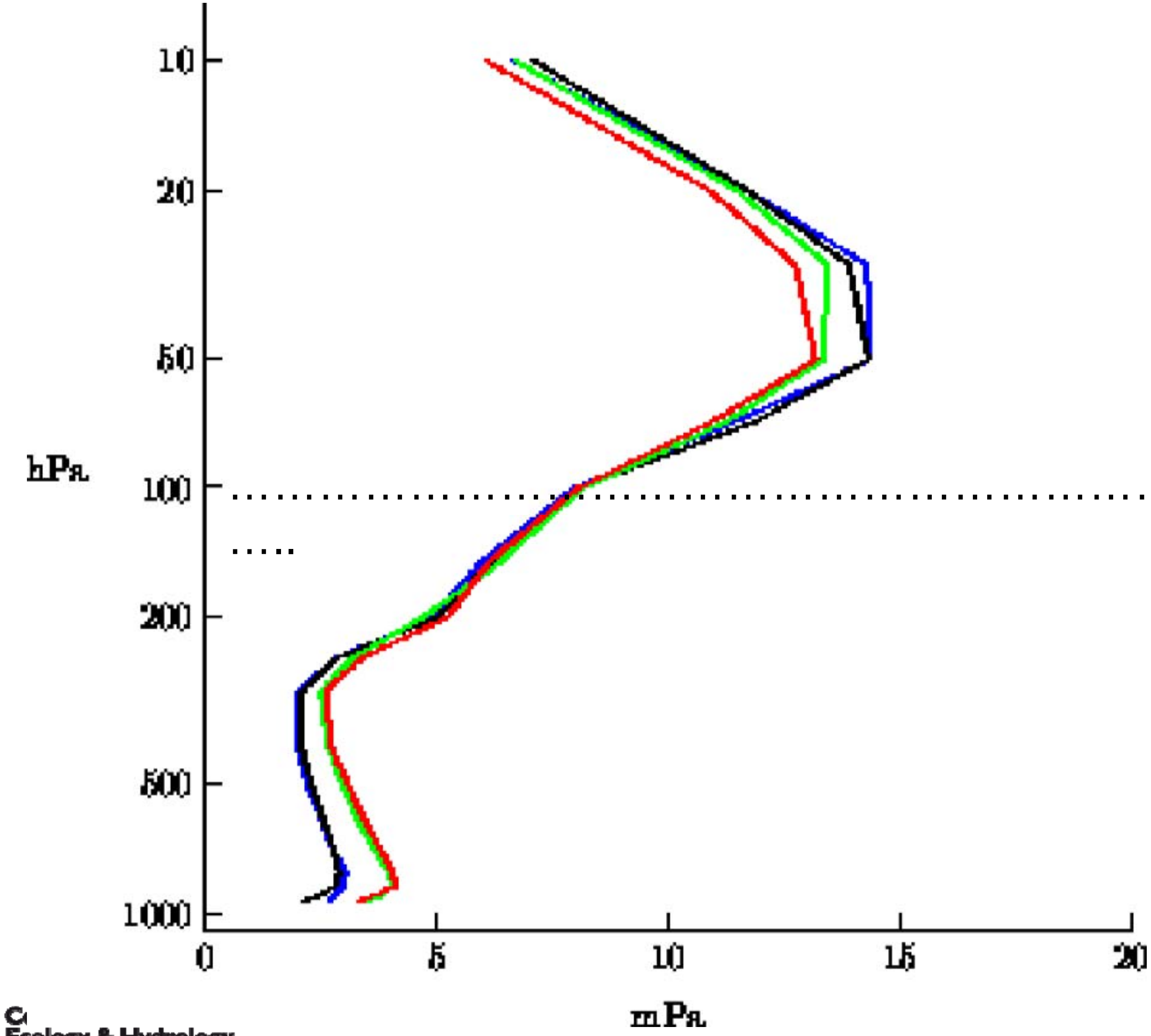
1990s -   1960s -



stratosphere

.....10 km......

tropopause

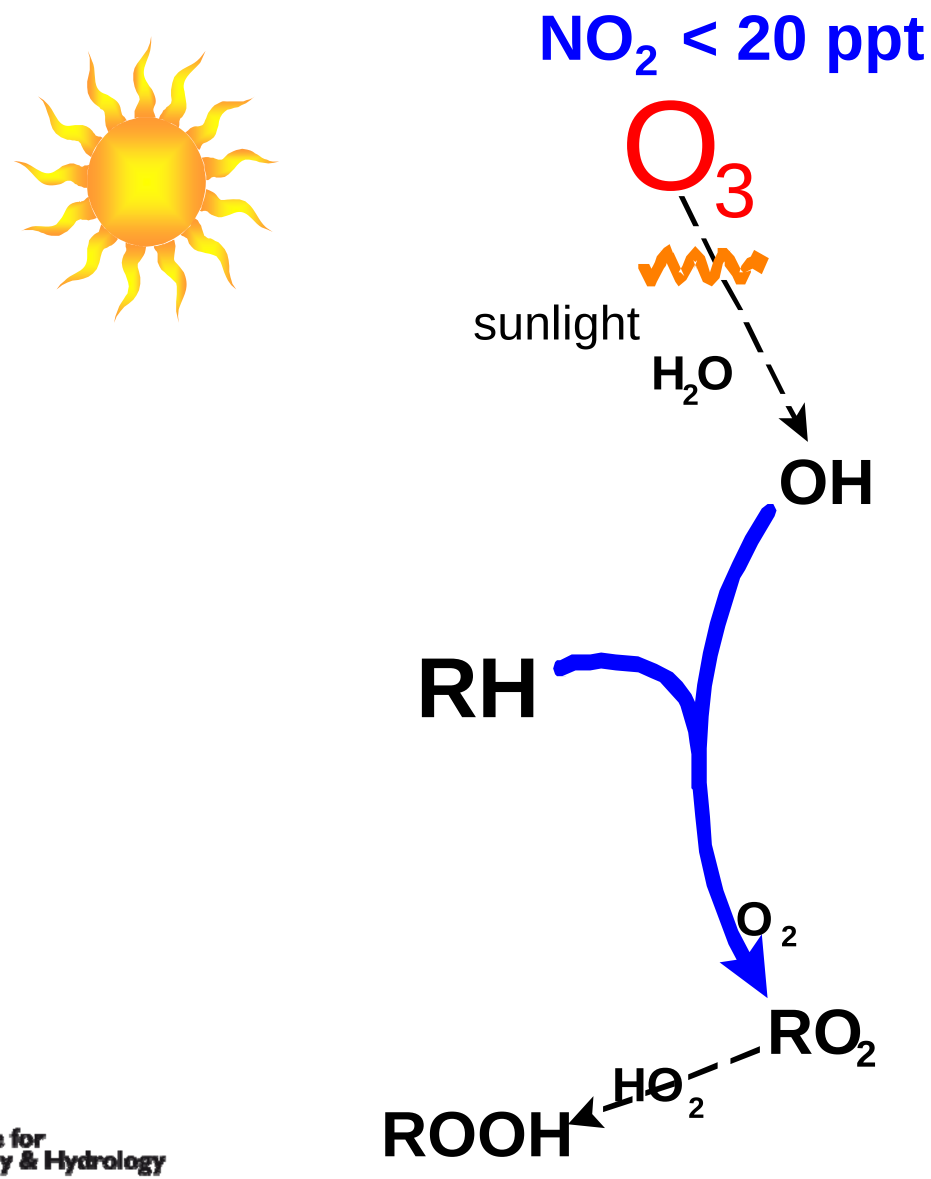
troposphere

Ecology & Hydrology

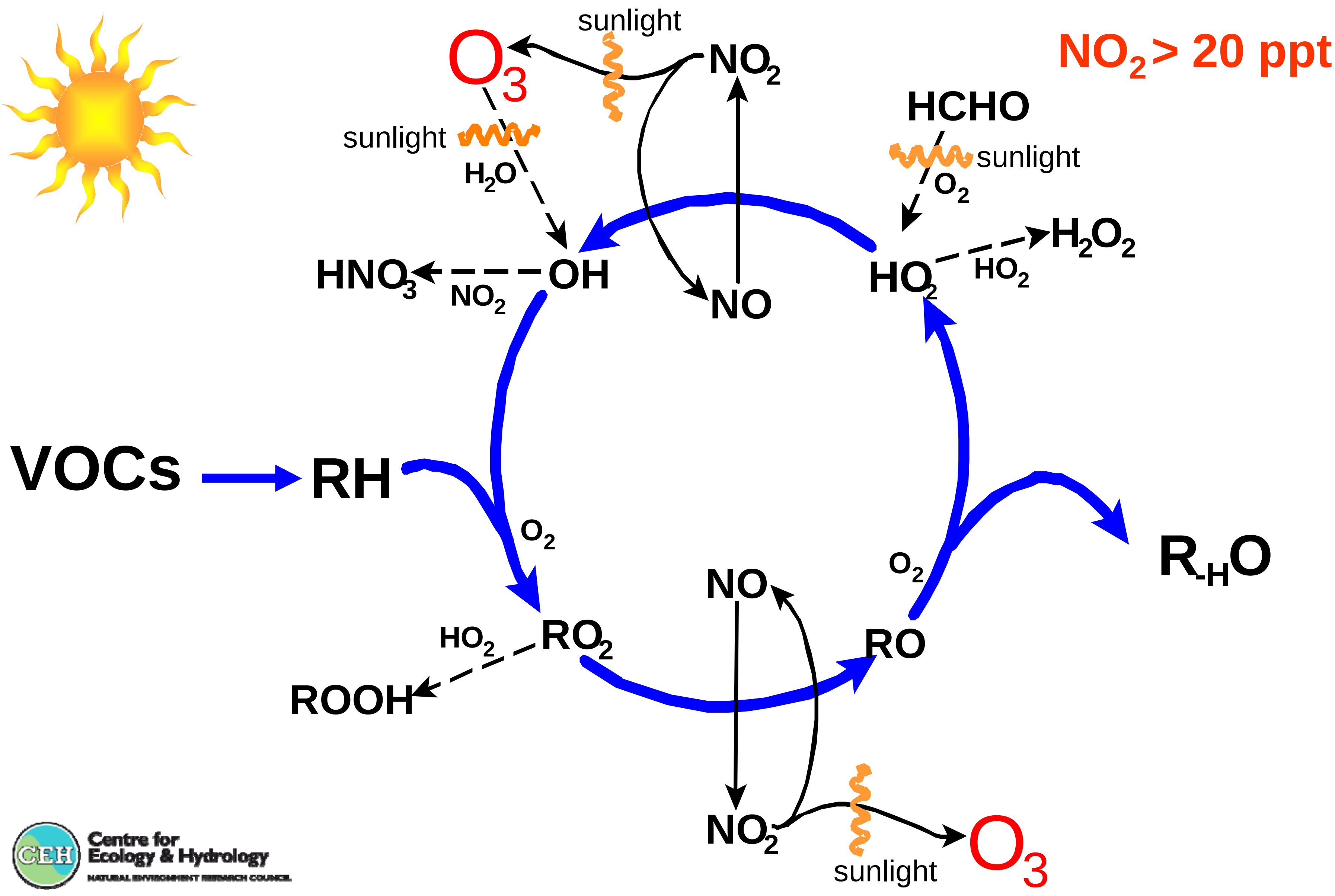
Ozone production

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

CLEAN ATMOSPHERE



POLLUTED ATMOSPHERE



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$$NO_2 \longrightarrow NO + O$$

$$O + O_2 \longrightarrow O_3$$

$$NO + O_3 \longrightarrow NO_2 + O_2$$

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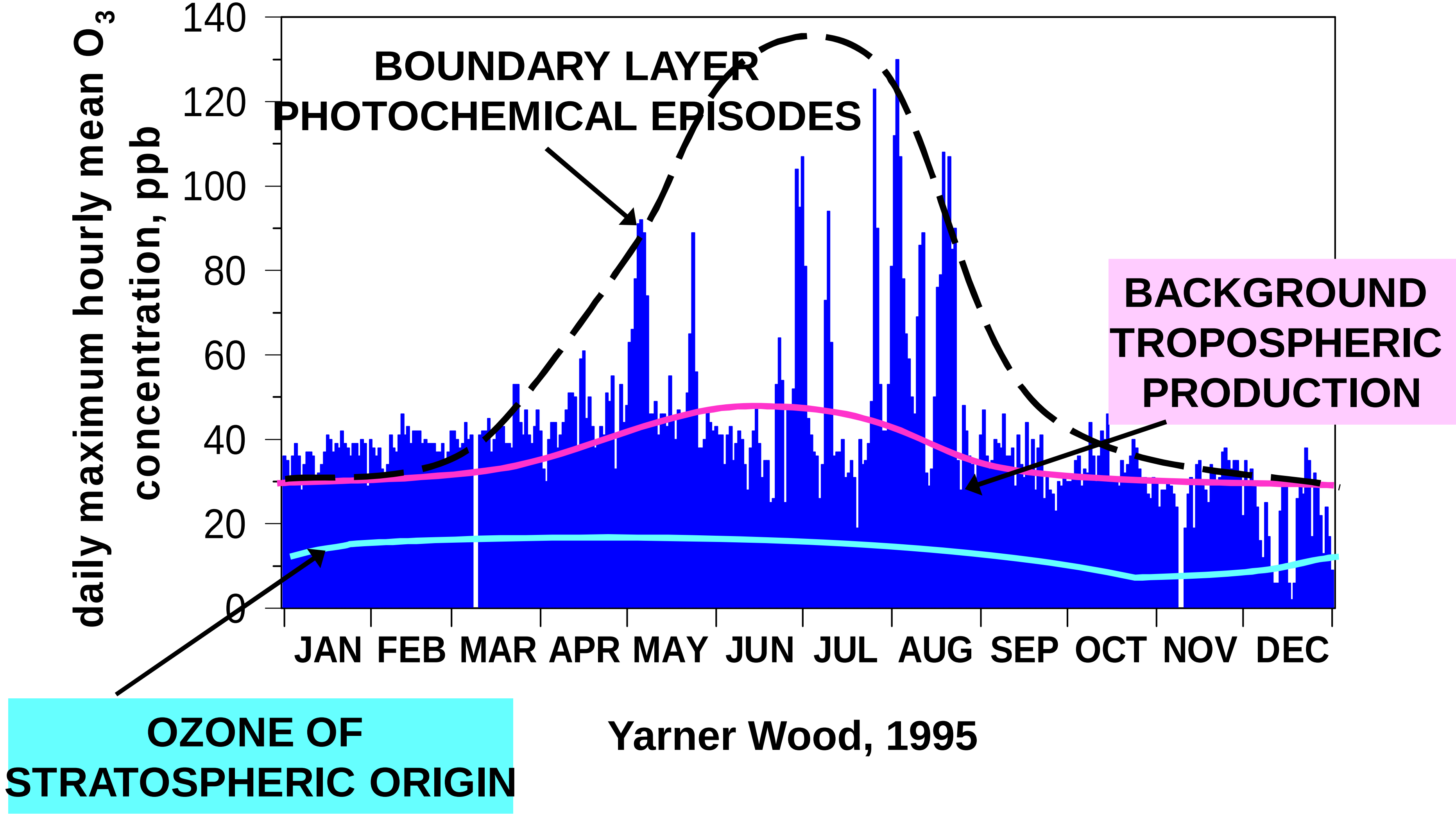

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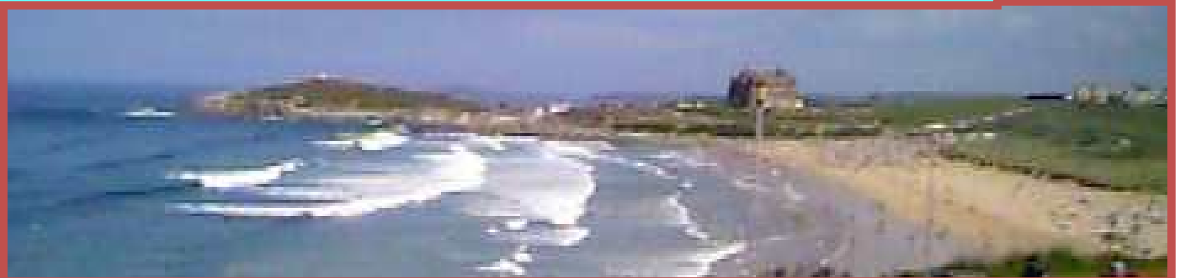
O_3 concentrations have roughly doubled since the early 1900's.



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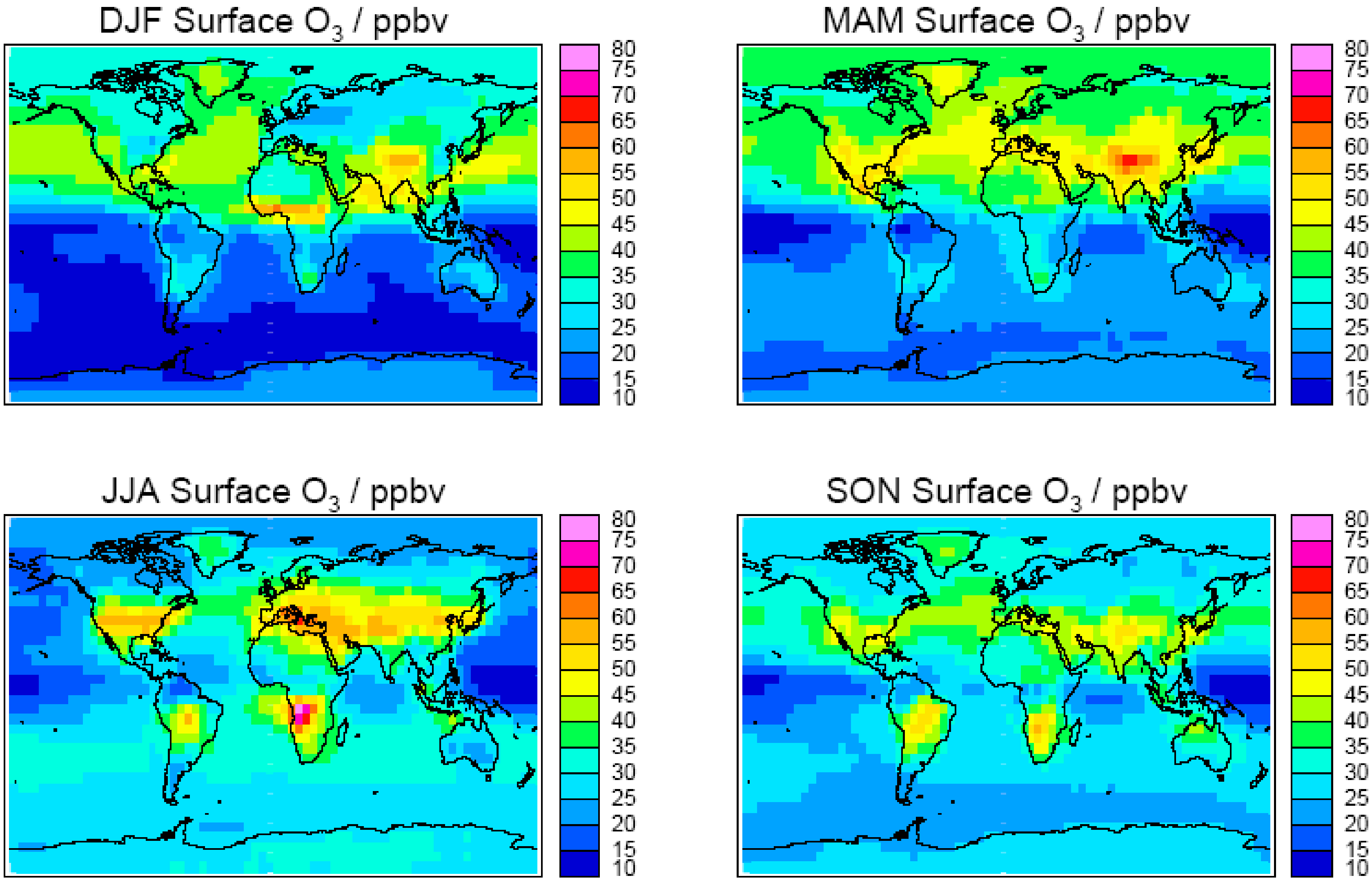
SEASONAL VARIATION OF SURFACE OZONE



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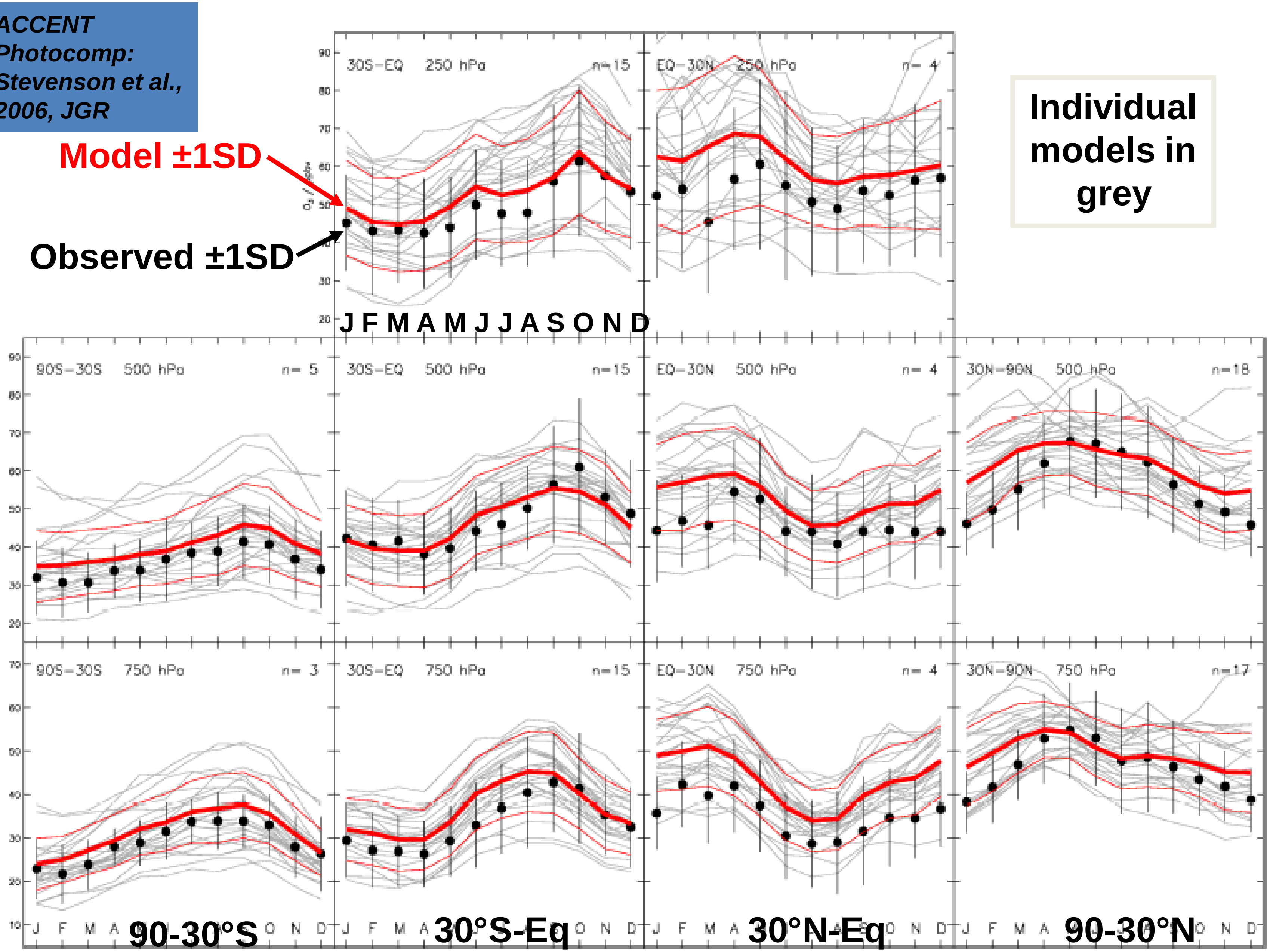
Ensemble mean of 26 ACCENT Photocomp models

ENSEMBLE MEAN MODEL V O_3 SONDE MEASUREMENTS

ACCENT Photocomp: Stevenson et al., 2006, JGR



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

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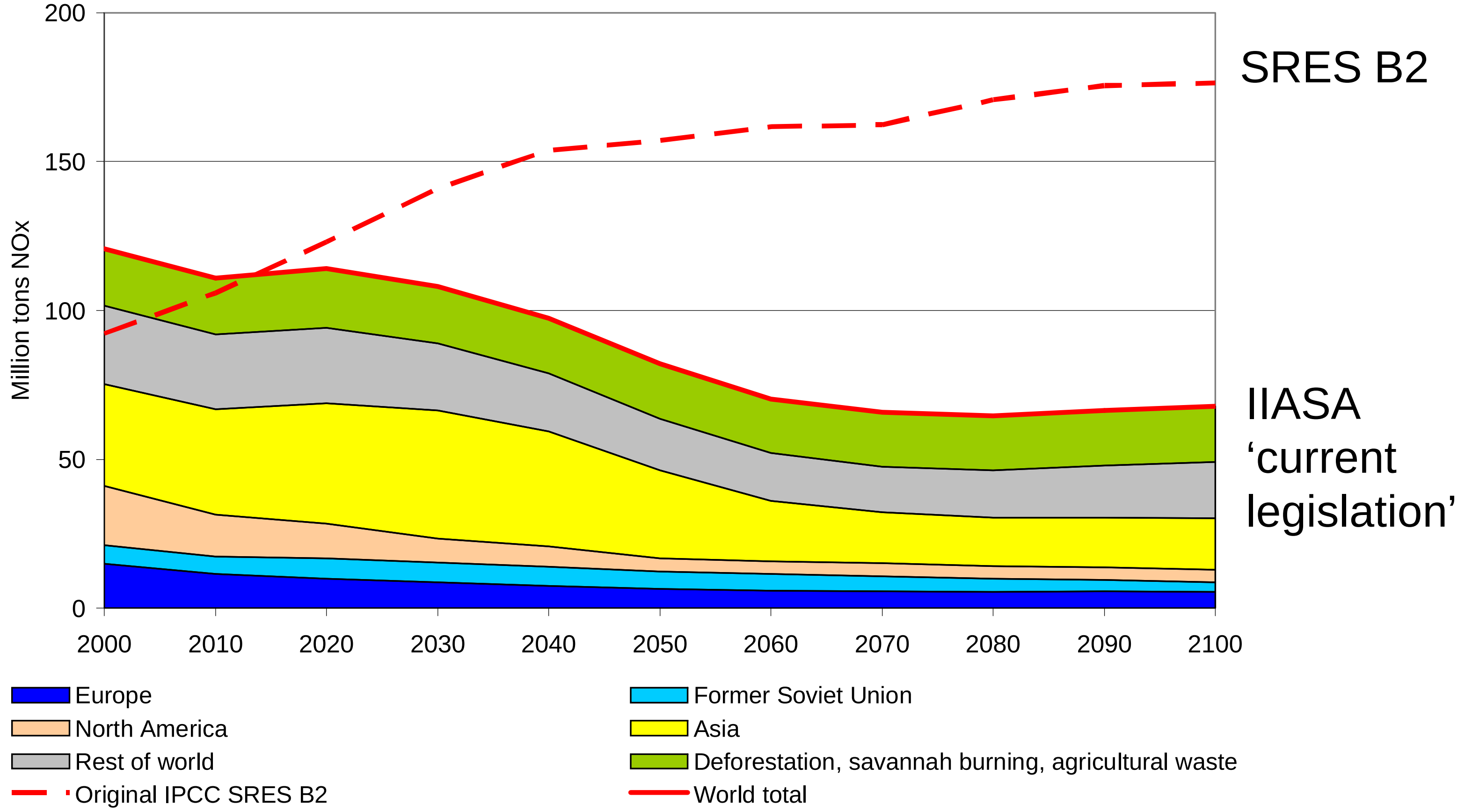
UNDER CURRENT LEGISLATION, NOX EMISSIONS SHOULD REDUCE IN MOST PLACES:



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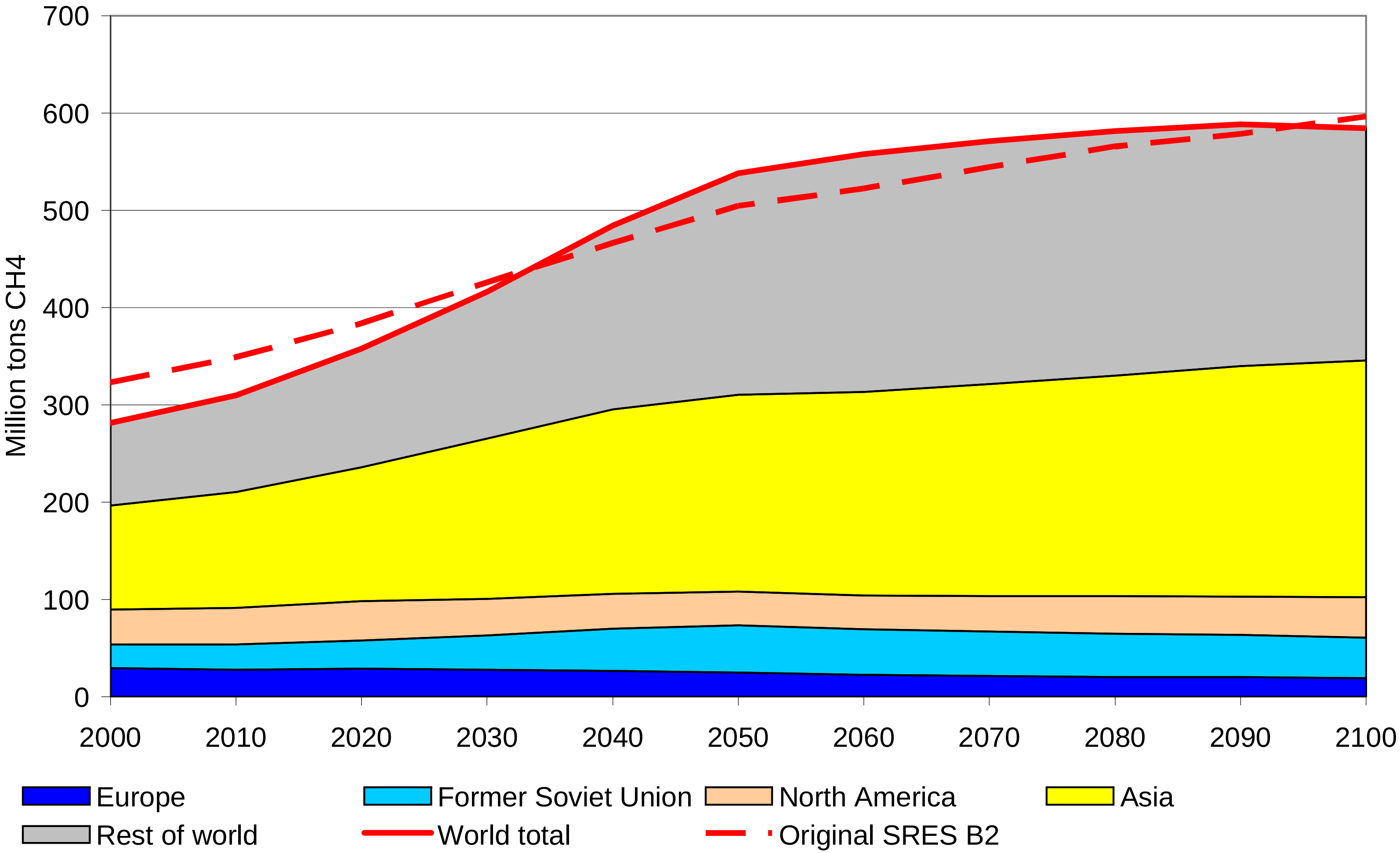
Markus Amann, IIASA

METHANE EMISSIONS 2000-2100



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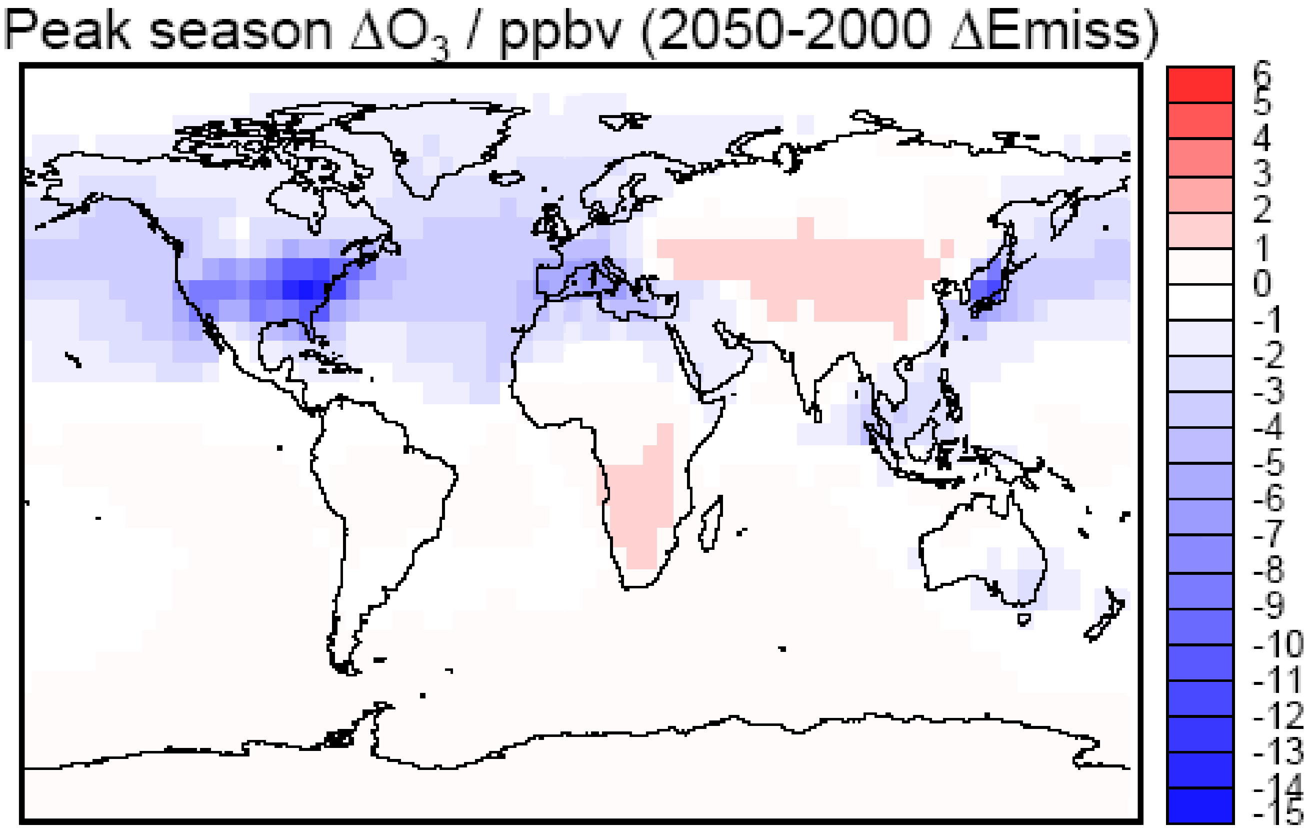
Courtesy Markus Amann, IIASA

PROJECTED CHANGES IN SURFACE O_3 (2050-2000)
DURING THE PEAK O_3 SEASON DUE TO ***EMISSIONS CHANGES***



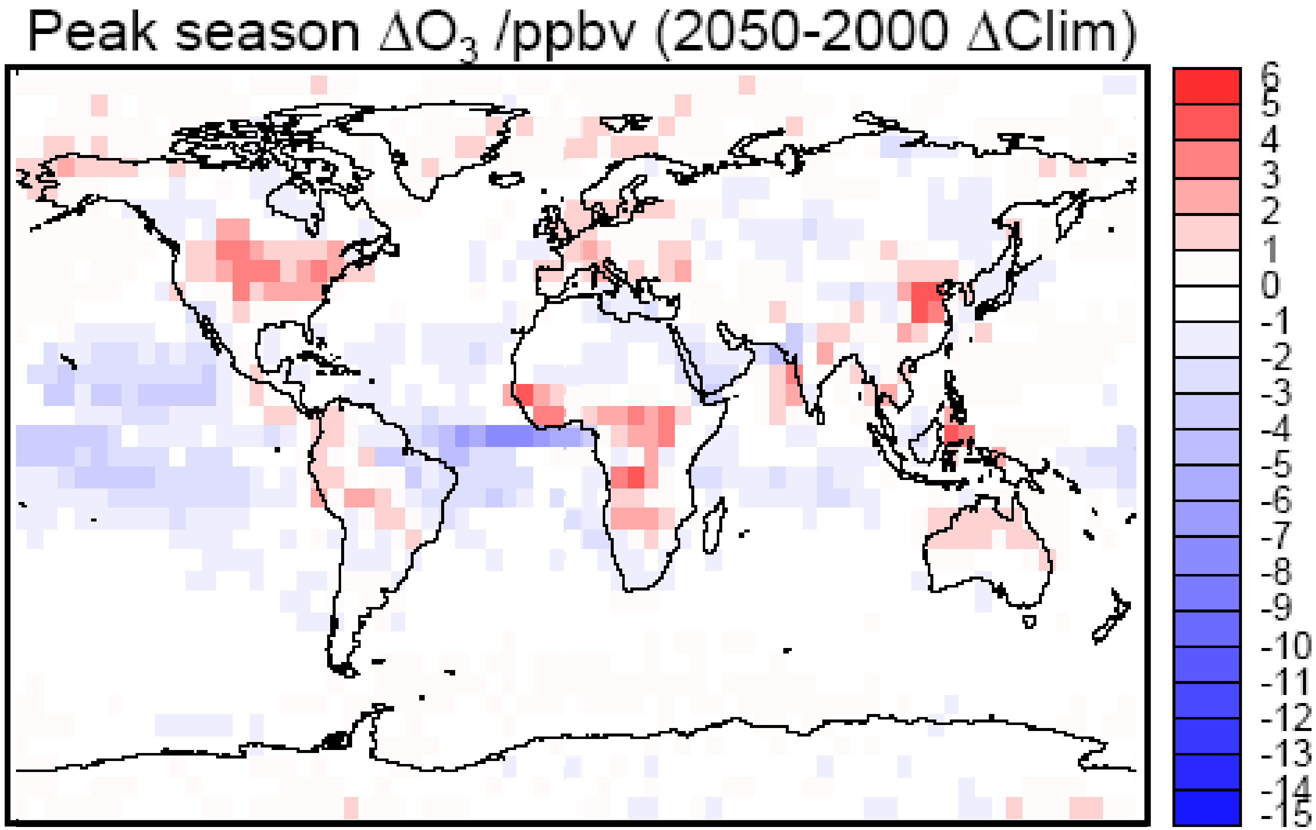
Mean of 5 models

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

What will happen as the climate changes?

- Ozone concentrations are expected to increase (doubling this century?) due to emissions (NO_x VOC) throughout the N Hemisphere.
- Surface temperatures will increase
- Water Vapour pressure deficits and CO_2 concentrations at the surface will increase reducing stomatal conductance
- Non-stomatal sinks become more efficient
- The partitioning of radiant energy at the surface will change, increasing sensible heat and reducing ET

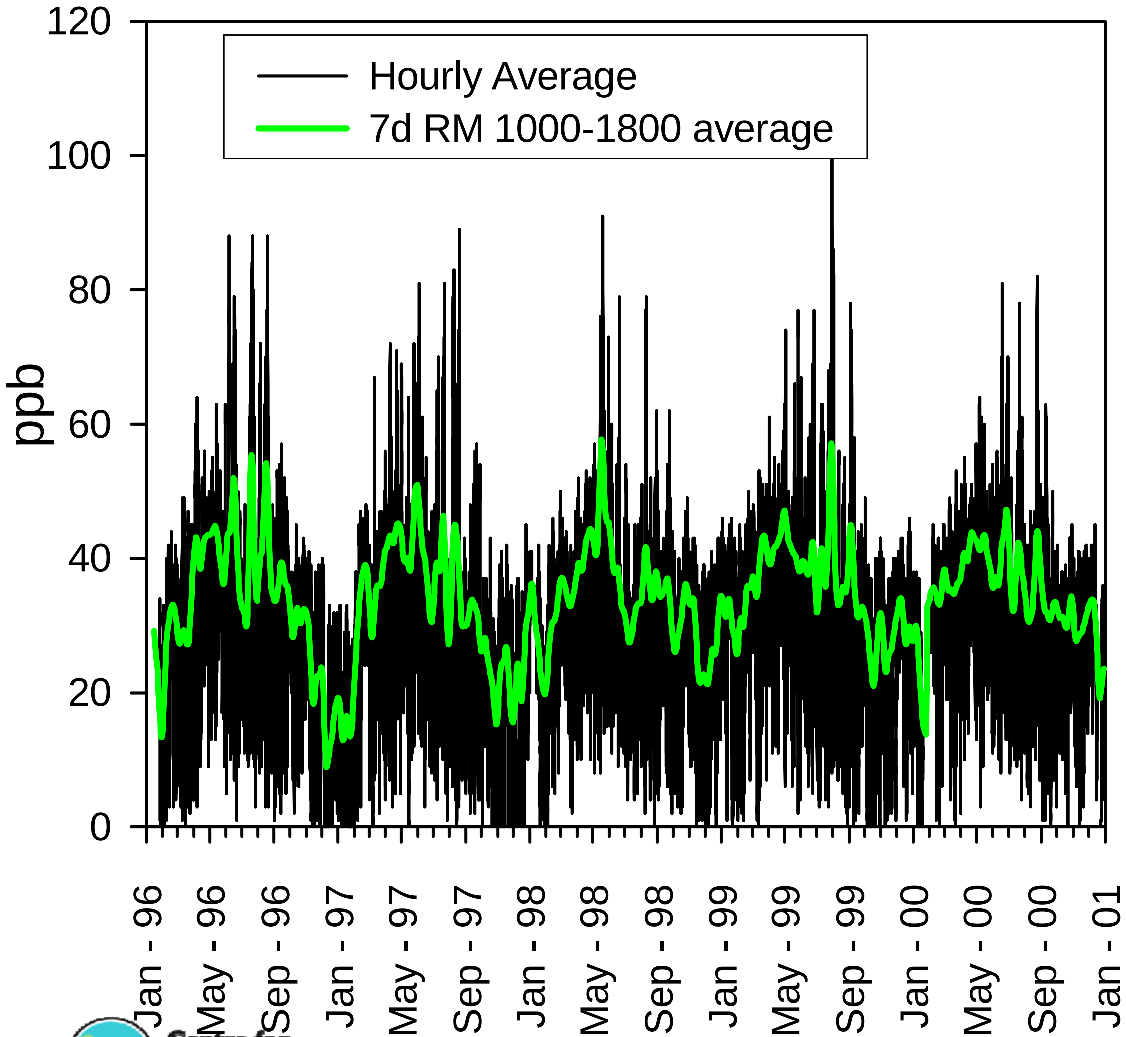
PROJECTED CHANGES IN SURFACE O_3 (2050-2000) DURING THE PEAK O_3 SEASON DUE TO ***CLIMATE CHANGE***

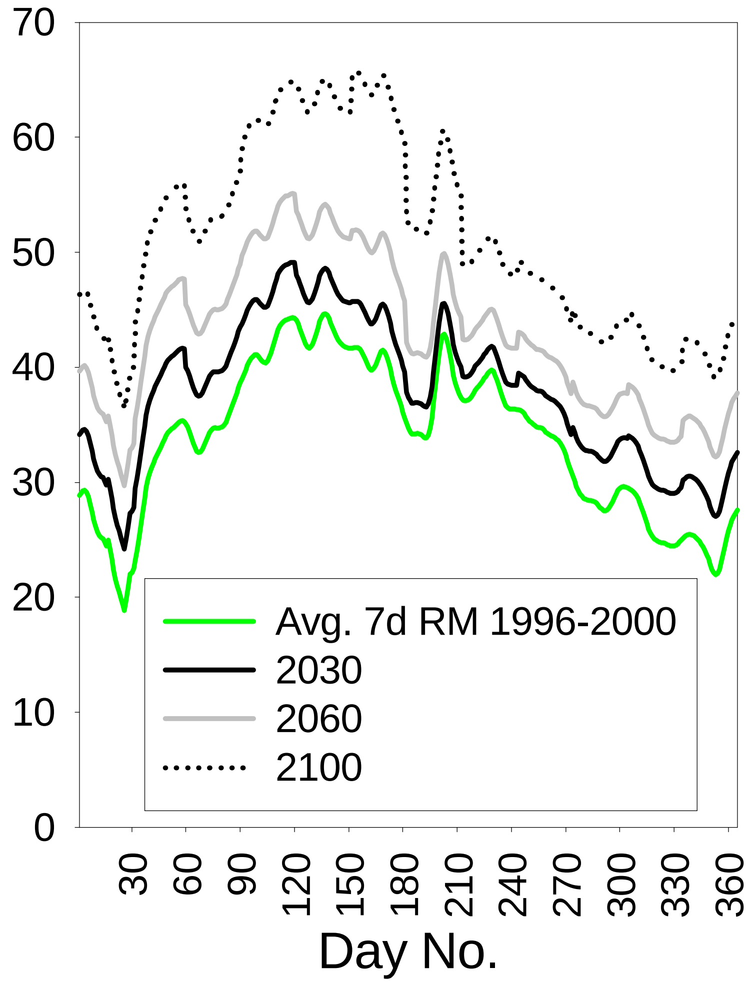


Mean of 3 models

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

Somerton - Enhanced Background Concentrations





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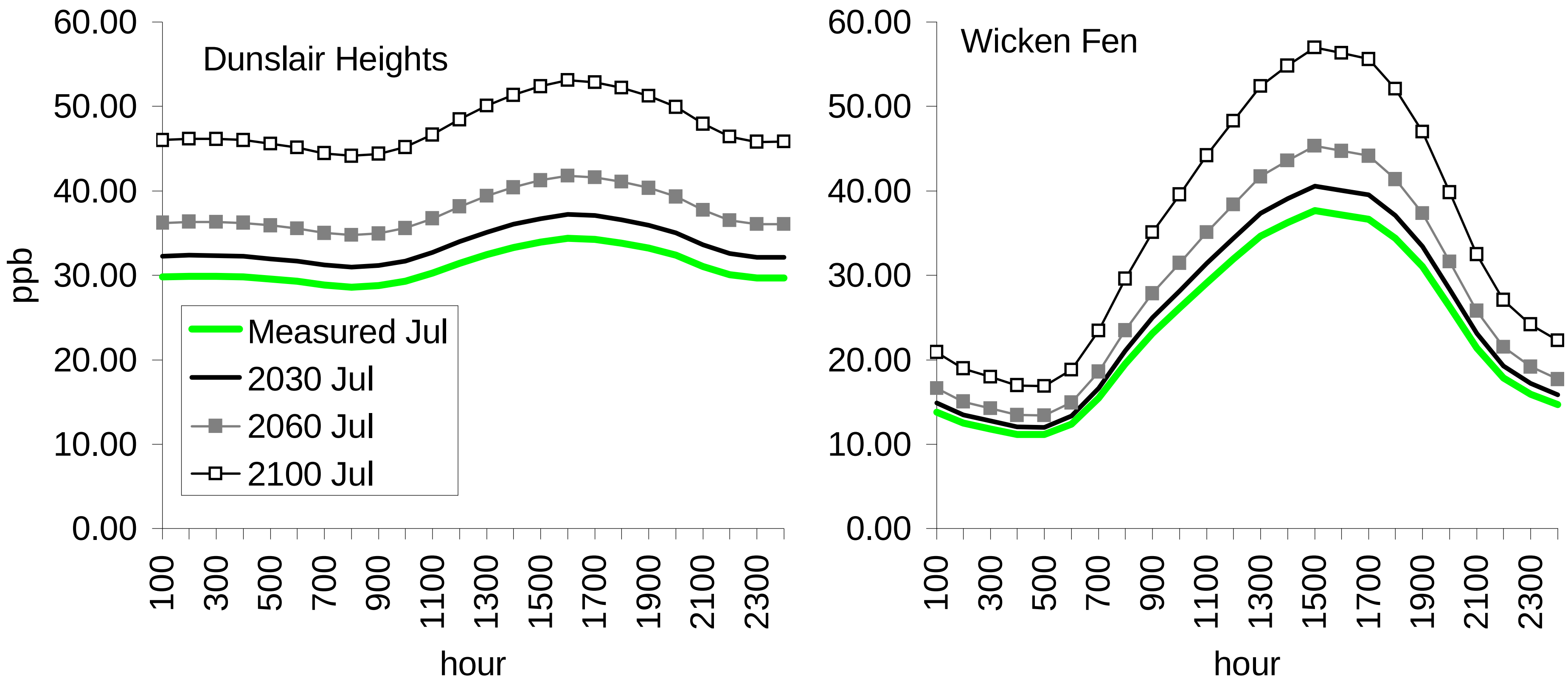
July Diurnal Cycles



Hill tops

Low elevation

The exposure and dose will depend on topography

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OZONE EFFECTS

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

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.

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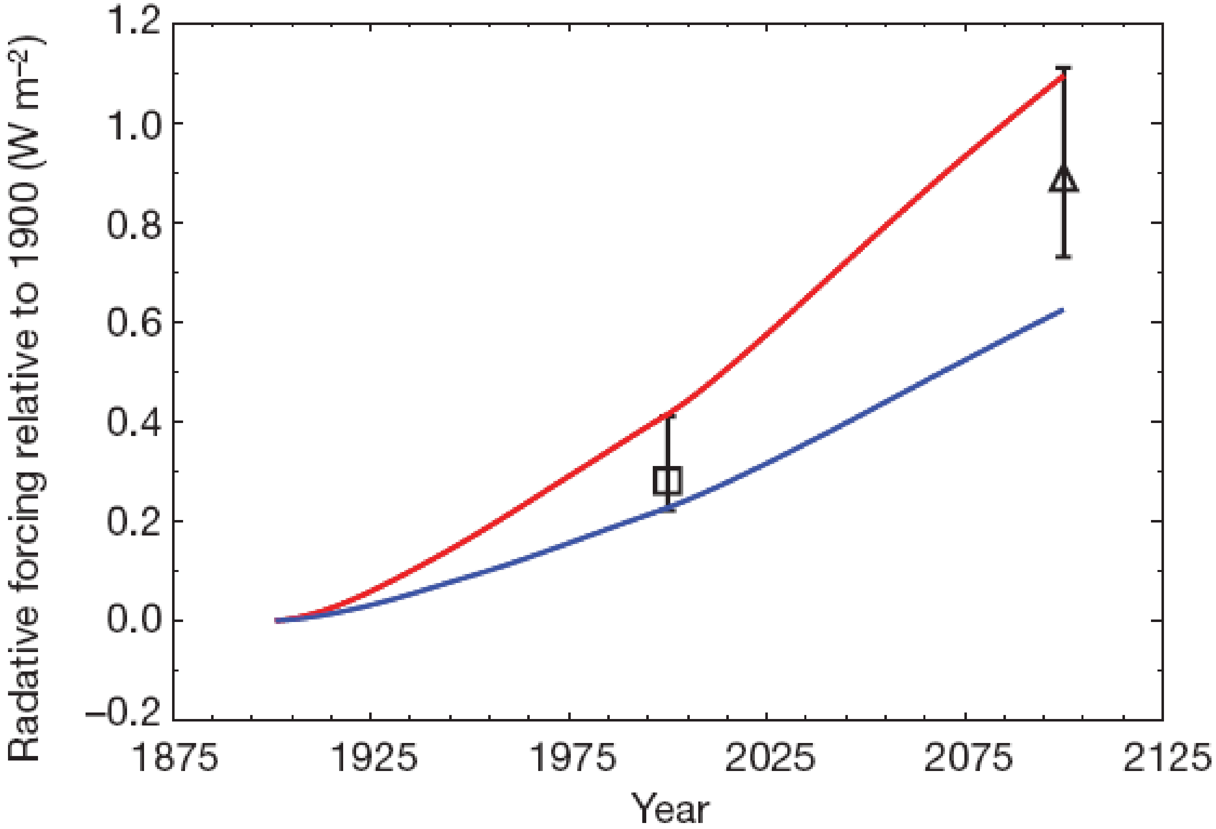
THE ROYAL SOCIETY

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)

THE ROYAL SOCIETY

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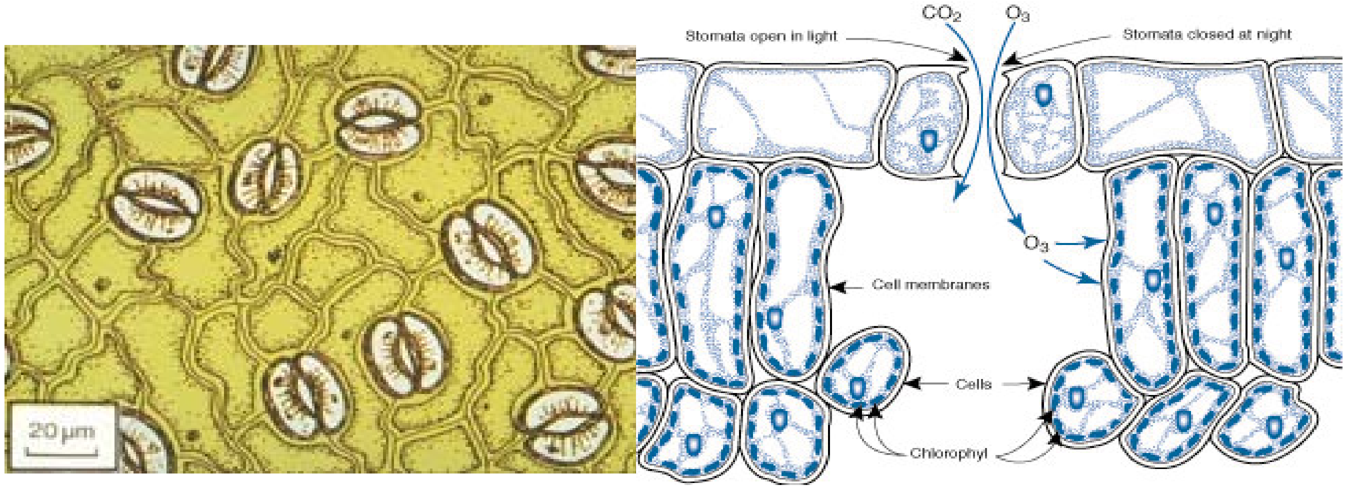
HOW WILL CONTROL OF OZONE PRECURSORS INFLUENCE AIR QUALITY AND CLIMATE?

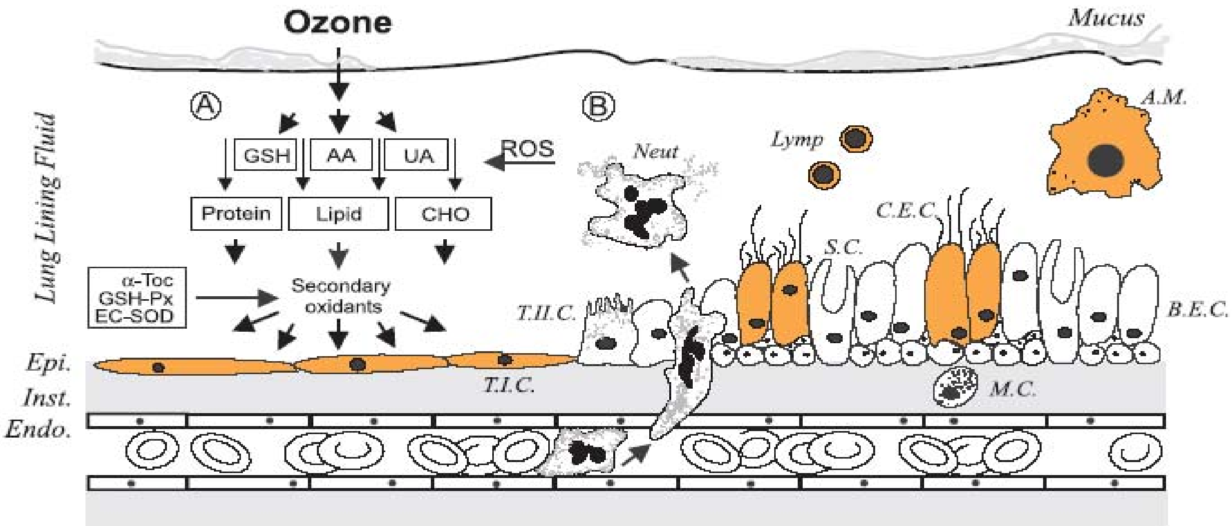
- Current legislation should modestly reduce ozone in Europe and North America
- Ozone in rapidly developing regions is projected to increase
- Climate changes will erode benefits of CLE and may lead to higher ozone in most low and mid latitude regions
- Fully interactive Earth system models are required to simulate the full range of feedbacks

- Ozone is clearly important and is likely to remain so for some time
- So….what are the effects on terrestrial ecosystems?

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)

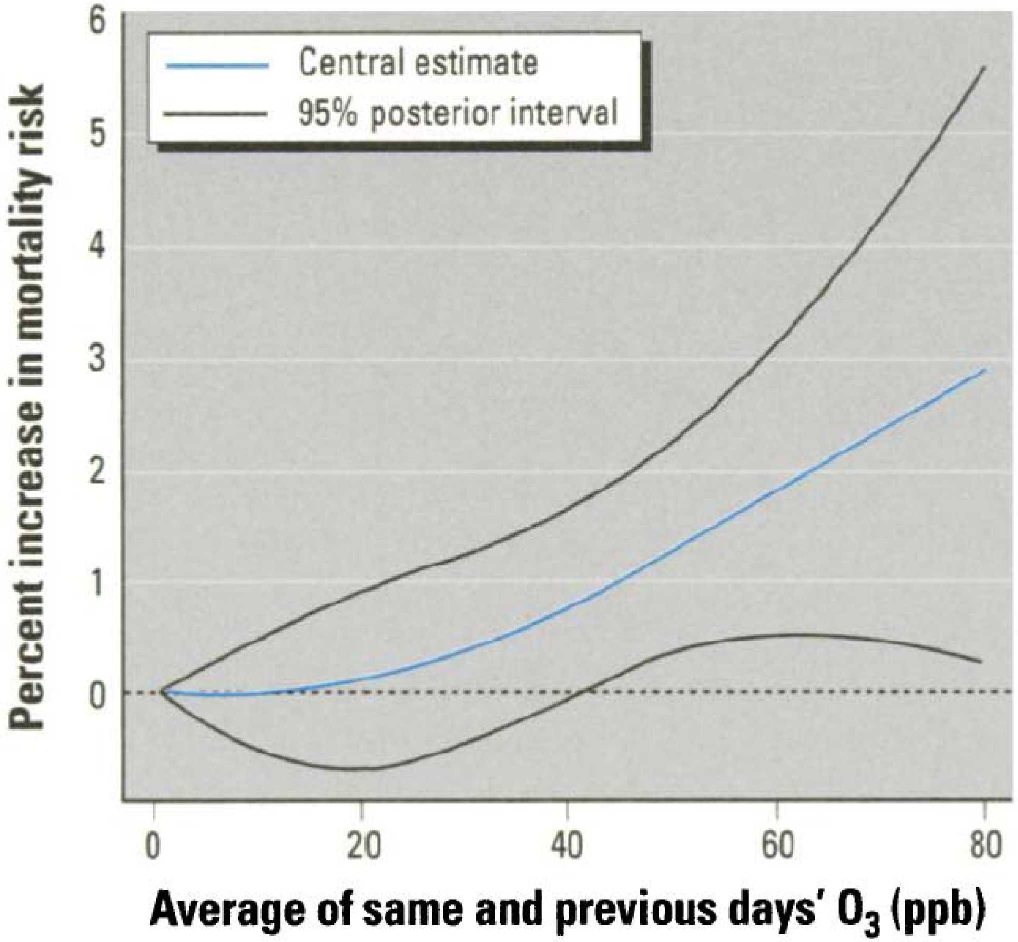


Figure 3. Exposure–response curve for O_3 and mortality using the spline approach: percentage increase in daily nonaccidental mortality at various O_3 concentrations.

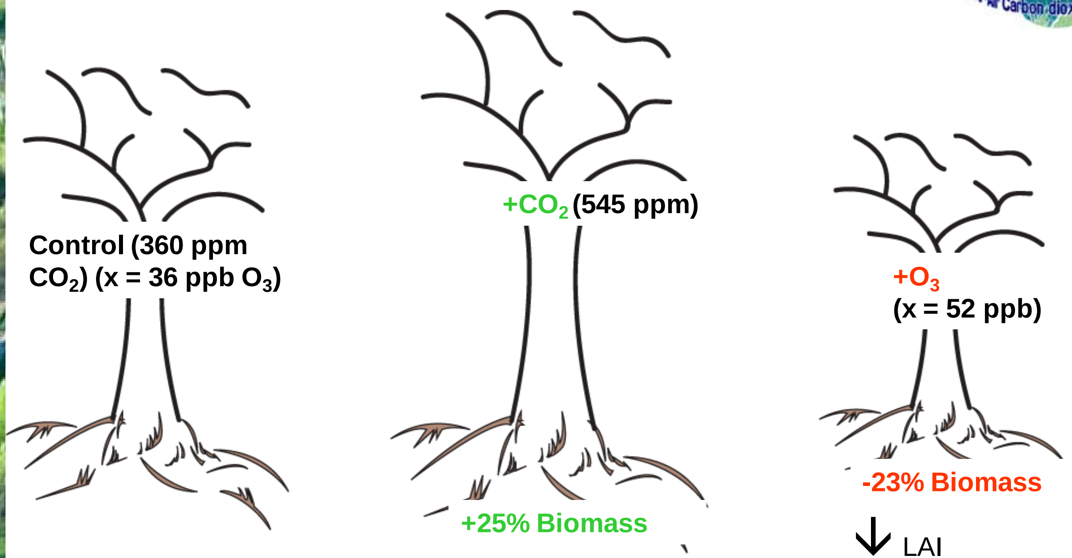
High levels of ozone increase human mortality

Meta-analysis based on 98 US cities

Bell et al. (2006, Environmental Health Perspectives)

ASPENFACE: EXPOSURE OF TREE STANDS TO ELEVATED CO_2 AND O_3

Components of Aspen Productivity (NPP)



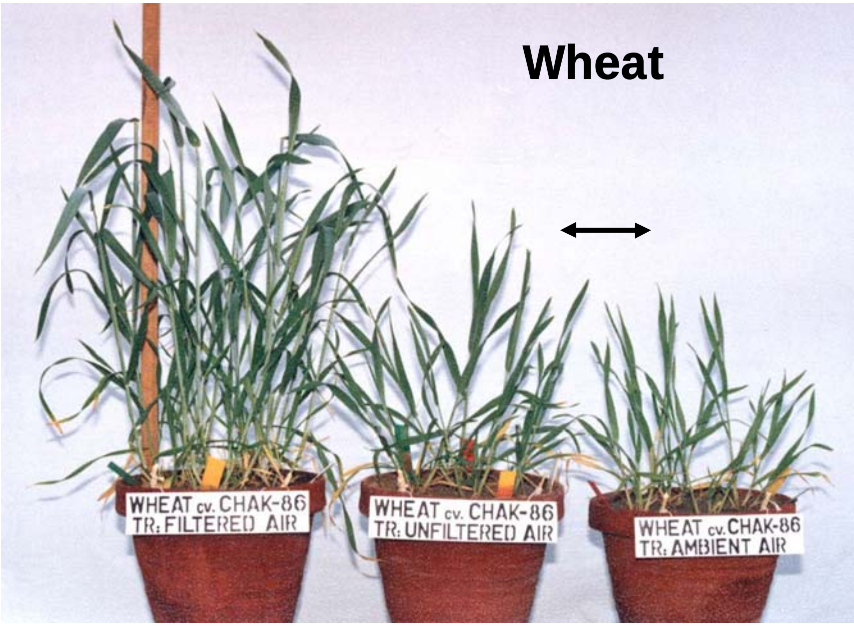
NPP estimates for aspen from King *et al.* 2005. New Phytol. 165:623-636.

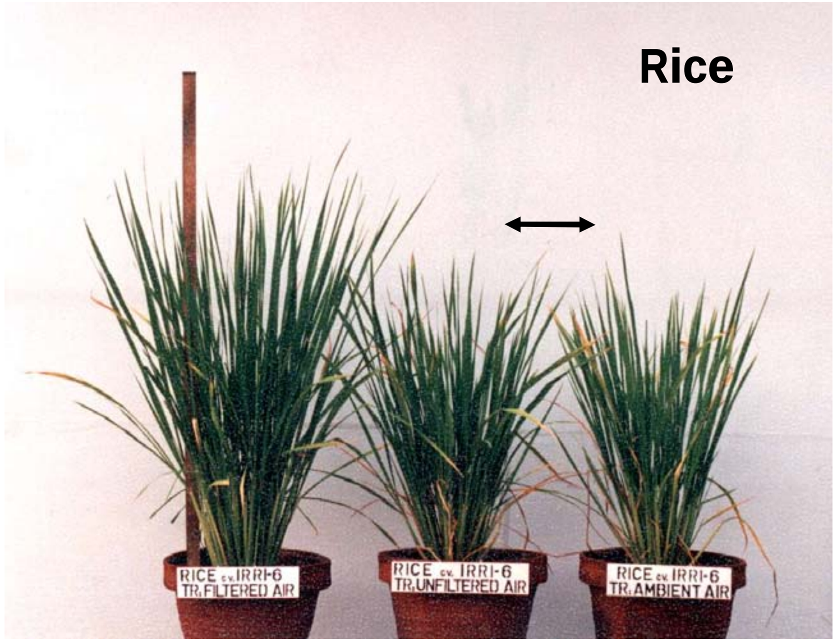
↑ LAI
↑ Leaf duration
↑ Leaf size
↑ Ps
↓ Water stress

↓ LAI
↓ Leaf duration ↓
Leaf size
↓ Ps
↑ Pests
↑ Water stress
↑ Antioxidant gene expression

What are the impacts to crops caused by O_3?

Reduced growth





Plants grown in ambient air with high levels of O_3 pollution

Plants grown in filtered air (pollutant free), Lahore, Pakistan

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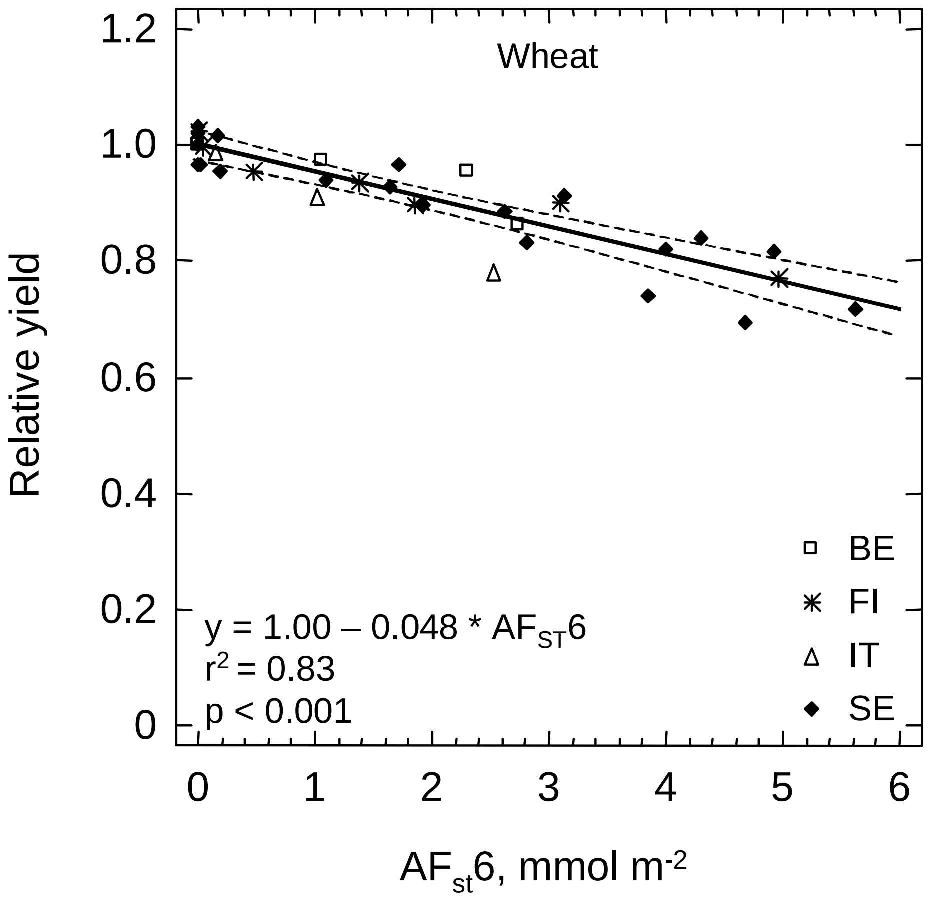
Courtesy of Prof. A. Wahid

Effects of ozone on wheat



Pleijel et al, 2004, 2007

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Soybean responses to elevated [O_3] under FACE

Dr Andrew Leakey **Institute for Genomic Biology, UIUC**

leakey@life.uiuc.edu

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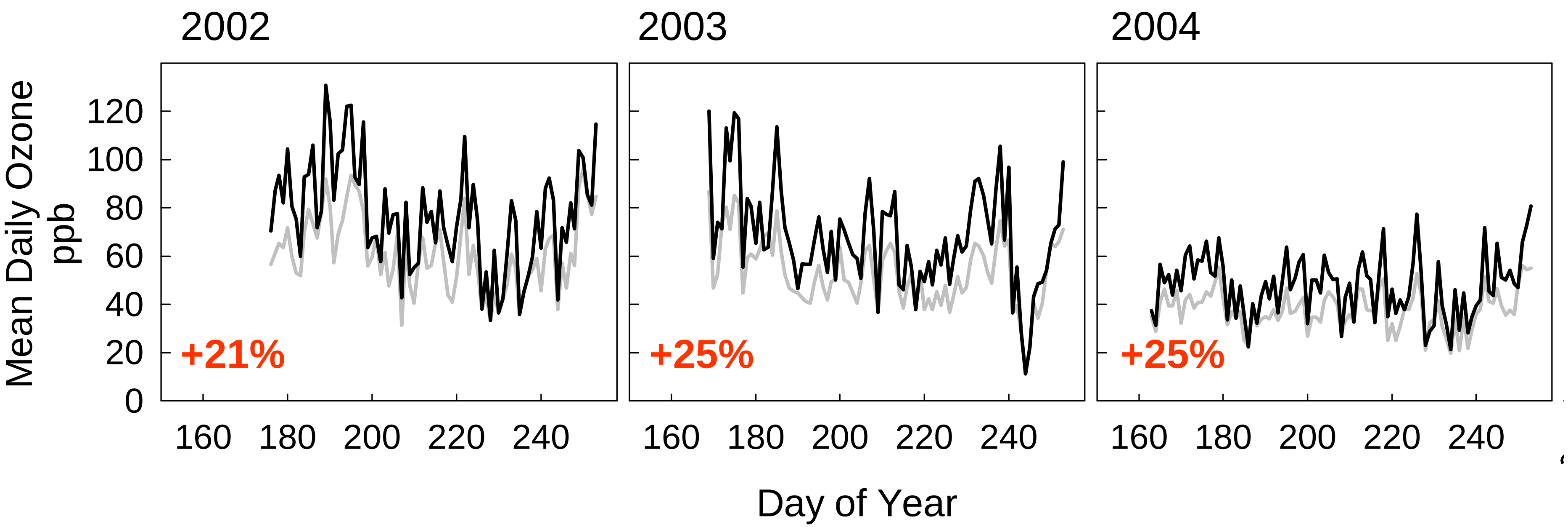
O_3 treatment at SoyFACE



Fumigation when:

- Daylight
- Leaves dry

25% increase in ambient O_3

approx 2025, =-17%NPP

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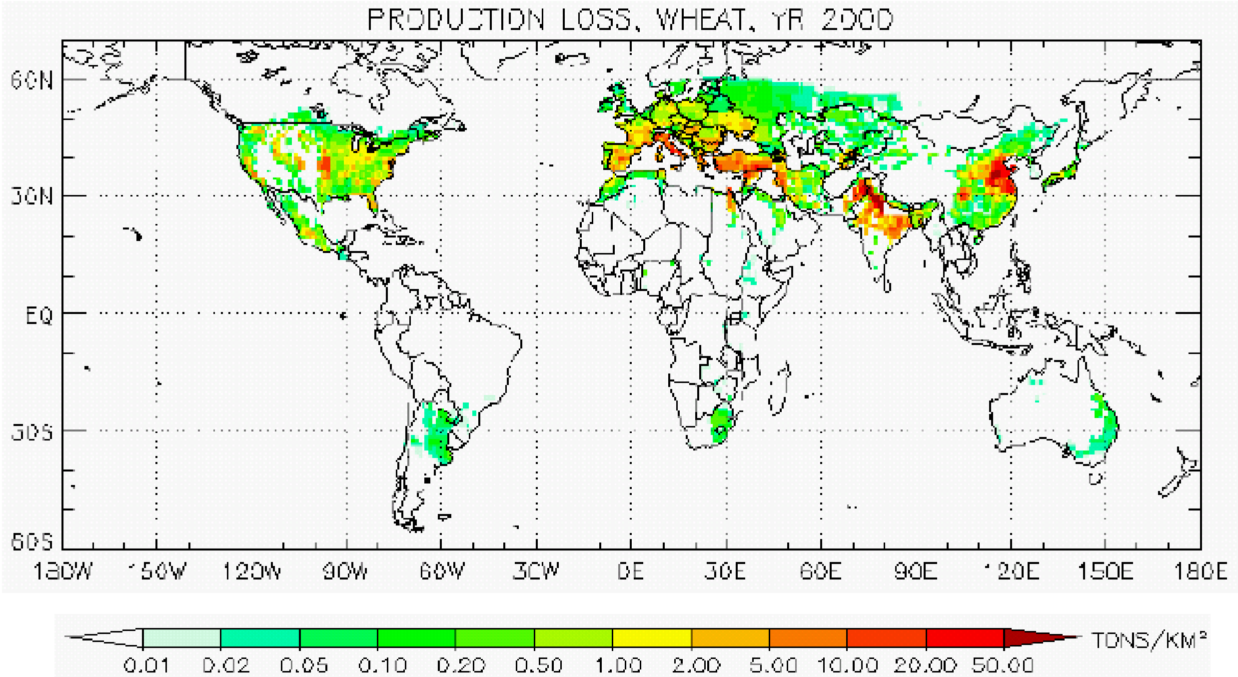
These dose-response relationships have been used to perform risk assessments to estimate yield losses…



Van Dingenen et al, 2009

Year 2000 global economic losses estimated to cost $14-26 billion

For economies largely based on agriculture , O_3 induced damage is estimated to offset a significant portion (20 – 80%) of the year 2000 GDP growth rate.

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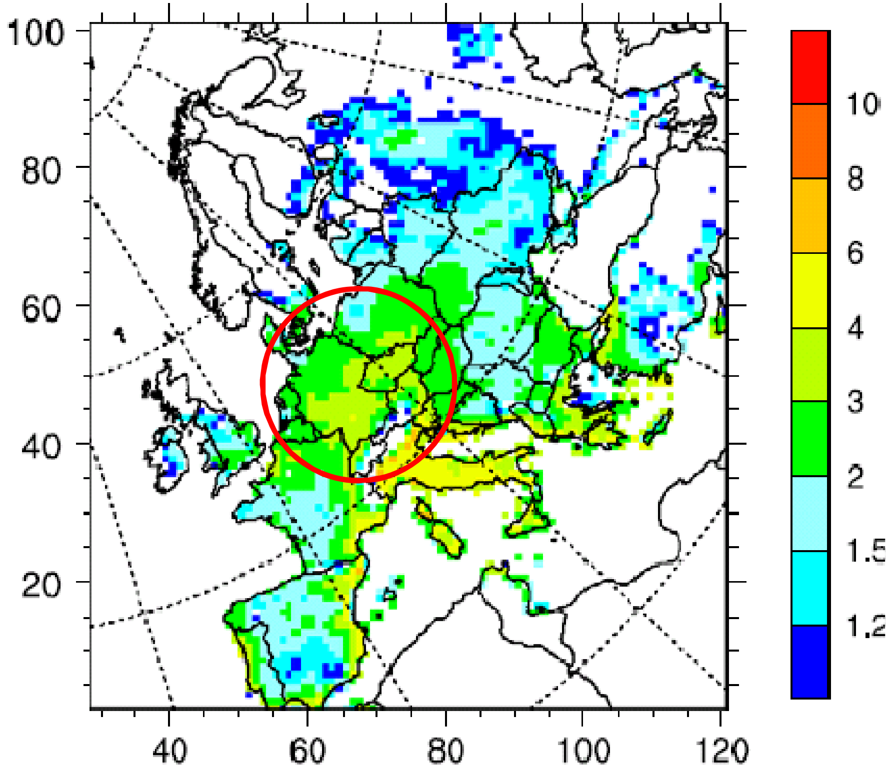
Concentration (AOT40) vs. stomatal flux (AFstY) risk assessments

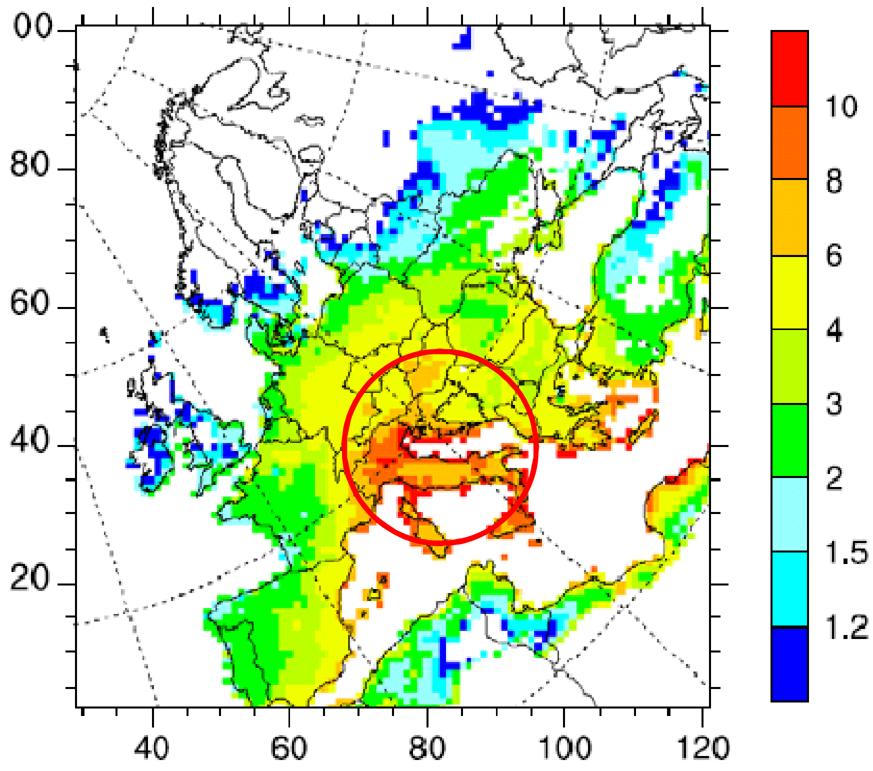
2000

CL: AFstY Generic wheat



$R_{CL}(AF_{st}6)$ - Crops

CL: AOT40 - Crops



R_{CL} ($AOT40_f$)

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Simpson et al (2007)

Ozone feedback

- Ozone effects will become chronic throughout the Northern Hemisphere in cropland and semi-natural vegetation

- Crop breeding programmes could moderate yield effects

- The largest effects may be in reducing the Carbon sink of semi-natural vegetation, especially forests

UNEP

World Meteorological Organization

Integrated Assessment of Black Carbon and Tropospheric Ozone

Summary for Decision Makers

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Outline

- The current state of the global atmosphere, and UNFCCC
- A process to identify sensible control measures with many benefits and few losers (win-wins)
- Why focus on short term radiative forcers?
- The UNEP BC and Ozone assessment process and its outputs

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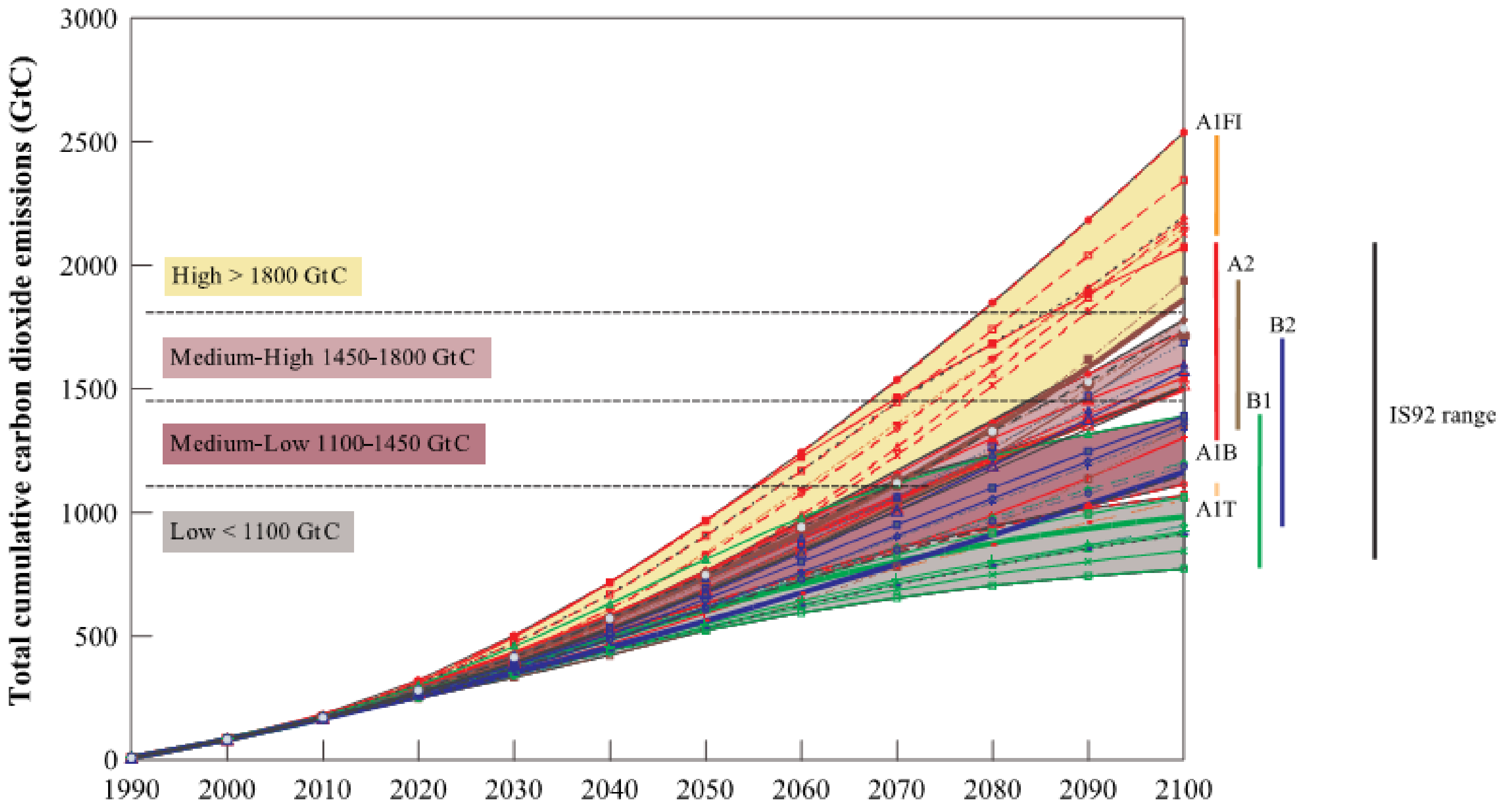
IPCC AR4



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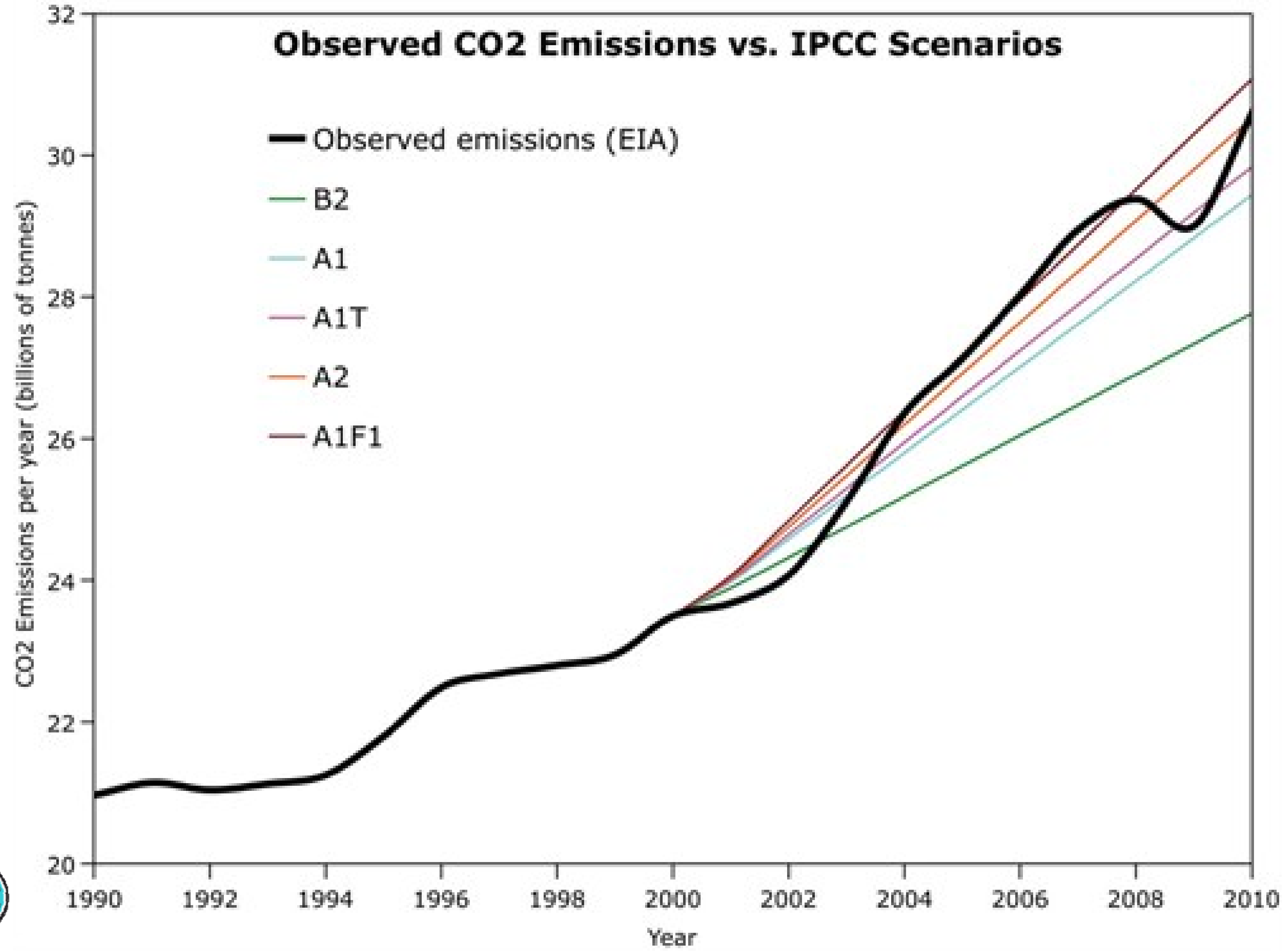
We are on track for 4 deg C warming



Progress in controlling global emissions

- Some countries /regions are committed to large reductions in emissions e.g. 80% by 2050 for the UK
- Some countries have not agreed to control GHG emissions.
- UNFCCC has not proved to be very successful so far……and the process is difficult

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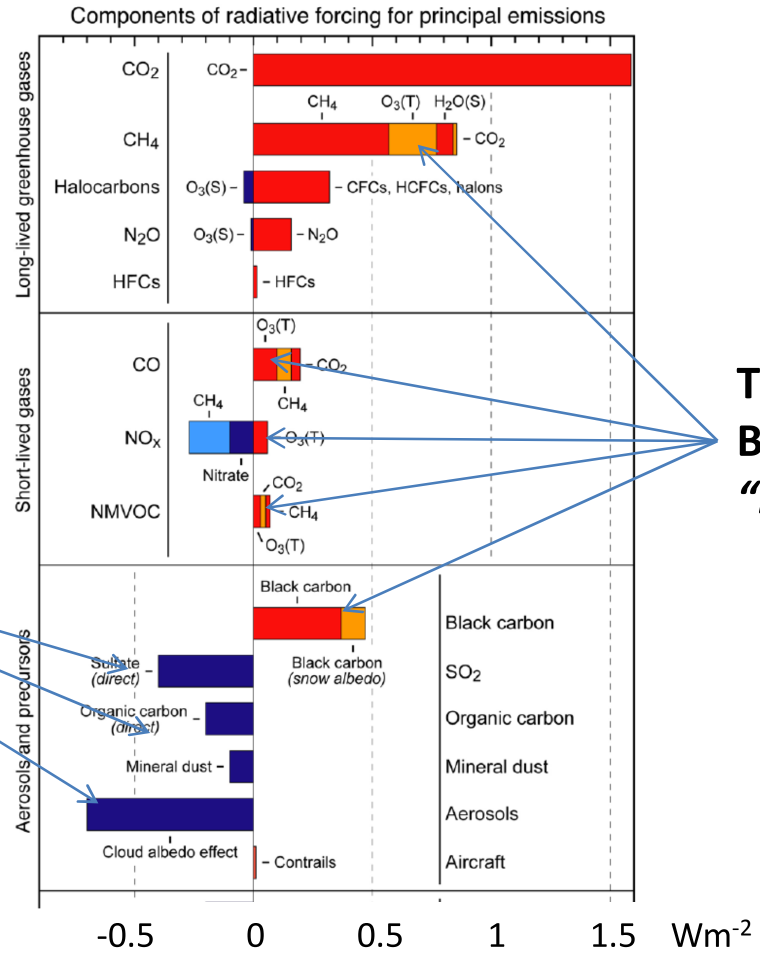
Global radiative forcing of past emissions

Inorganic Aerosols
Organic Carbon Aerosols
"Good" SLFCs



Tropospheric O_3
Black Carbon:
"Bad" SLFCs

IPCC 4AR, 2007

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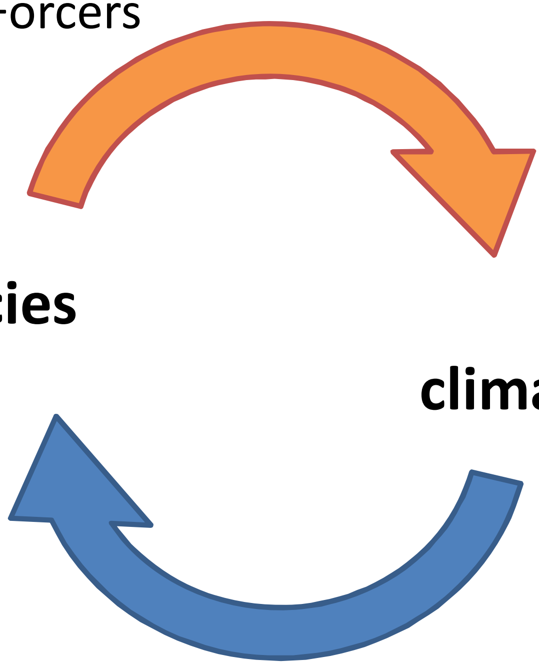
air pollutants as
Short-Lived Climate Forcers



air pollution policies
air pollution

climate
climate change policies

- EU Climate and Energy Package
- Decarbonisation

UNEP Assessment

- Accept that we still need to act on CO_2 emissions, large reductions are necessary
- Therefore not interfere with UNFCCC
- However there are many problems we can address:
- Black carbon and ozone damage human health and climate,
- There are many proven measures which could reduce both BC and ozone

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To simulate the control measures we need:

- Global model(s) of emission, atmospheric chemistry and removal processes
- Detailed spatial resolution within regions to identify the damage and benefits of reduction measures
- Integrated assessment models to compare costs of damage and control measures

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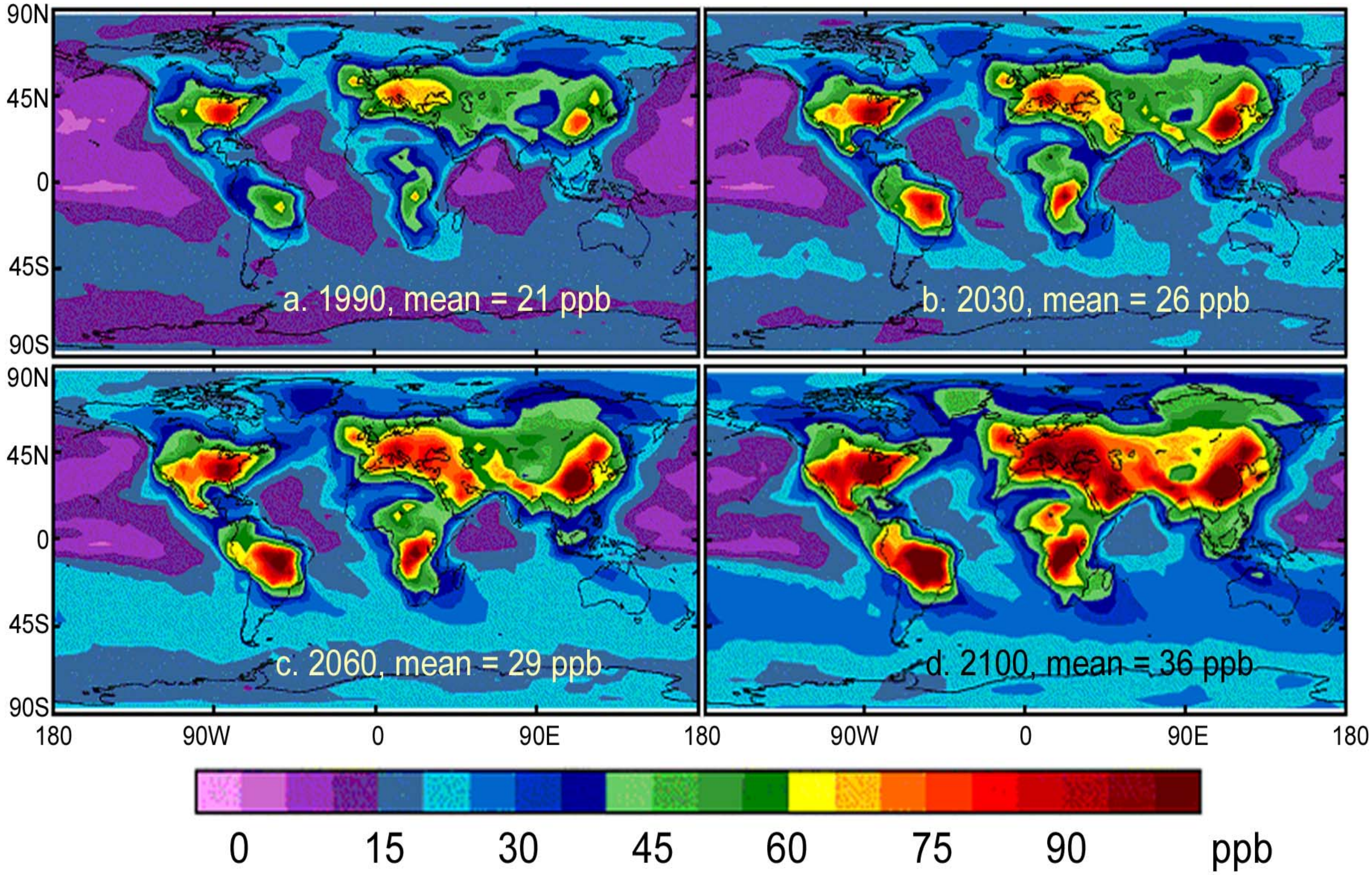
Modelled surface ozone concentration



THREE GROUPS OF PROMISING MEASURES (UNEP, 2011) BASED ON IIASA/GAINS EMISSIONS FOR 2005 + GWP100S FROM LITERATURE

"CH_4" measures

1. Recovery of coal mine gas
2. Production of crude oil and natural gas
3. Gas leakages at pipelines and distribution nets
4. Waste recycling
5. Wastewater treatment
6. Farm-scale anaerobic digestion
7. Aeration of rice paddies

Technical "BC" measures

1. Modern coke ovens
2. Modern brick kilns
3. Diesel particle filters
4. Briquettes instead of coal for heating
5. Improved biomass cook stoves
6. Pellets stoves and boilers (in industrialized countries)

Non-technical measures

1. Ban of high-emitting vehicles
2. Ban of open burning of agricultural waste
3. Elimination of biomass cook stoves

130 measures (out of 2000) reduce warming, the selected 16 reduce 90% of it.

A 100% implementation of the measures is assumed in the study

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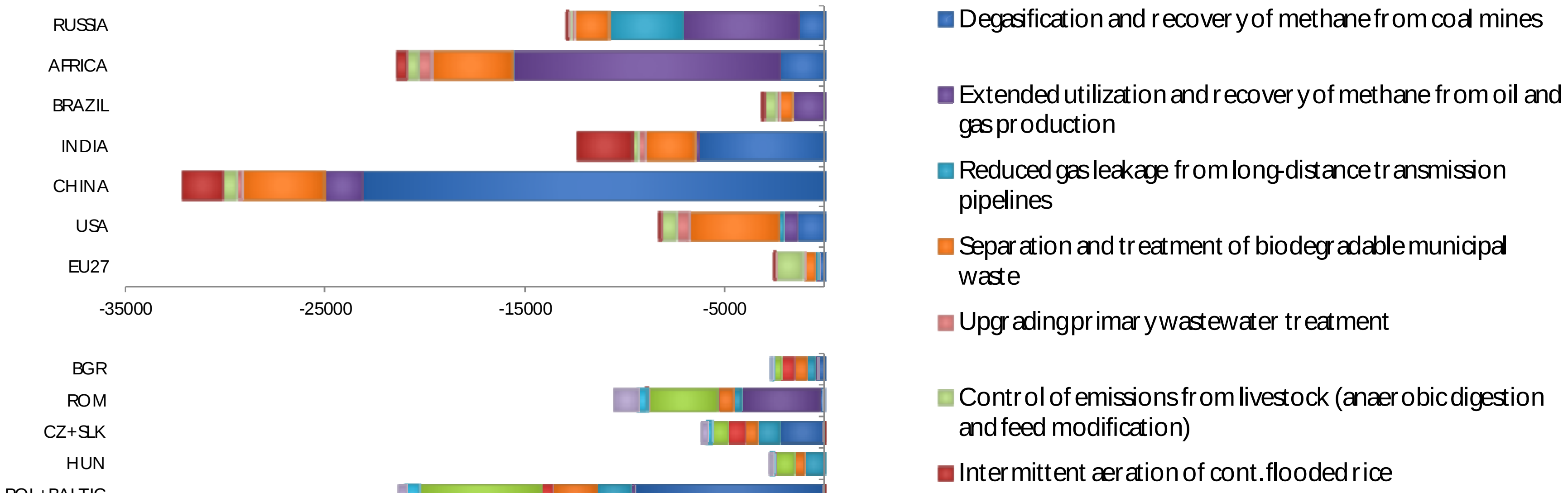
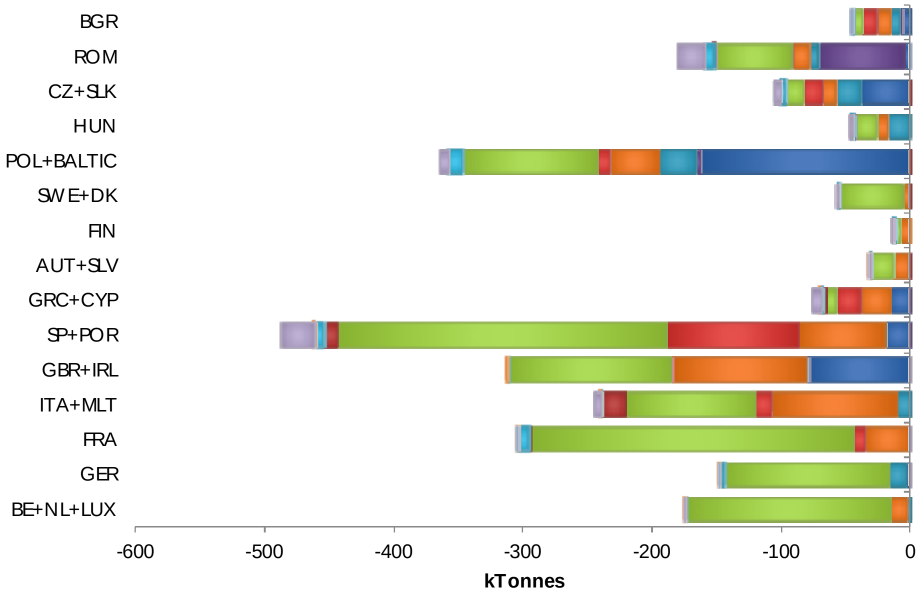
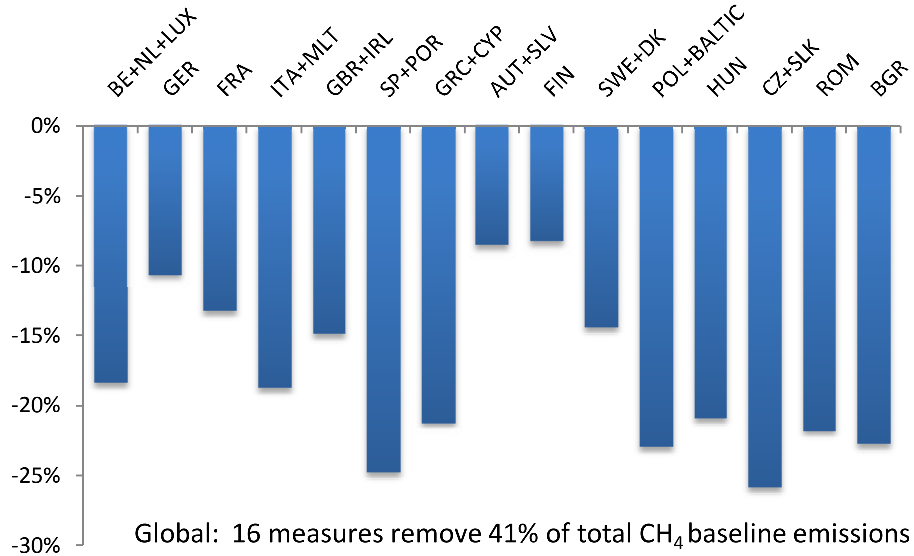
UNEP outcome applied to EU27

Methane emission reductions from measures







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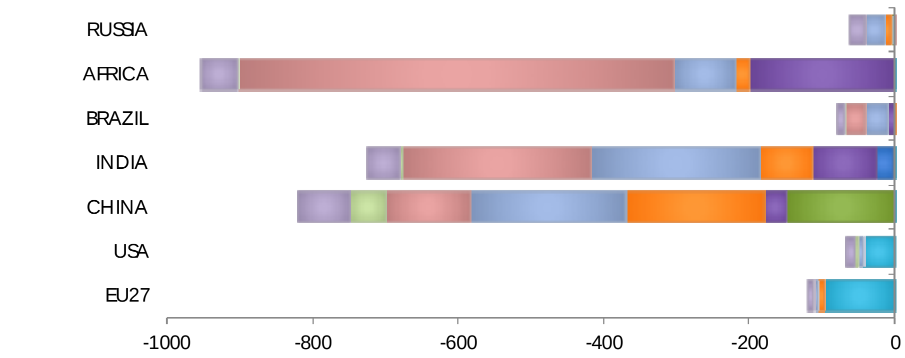
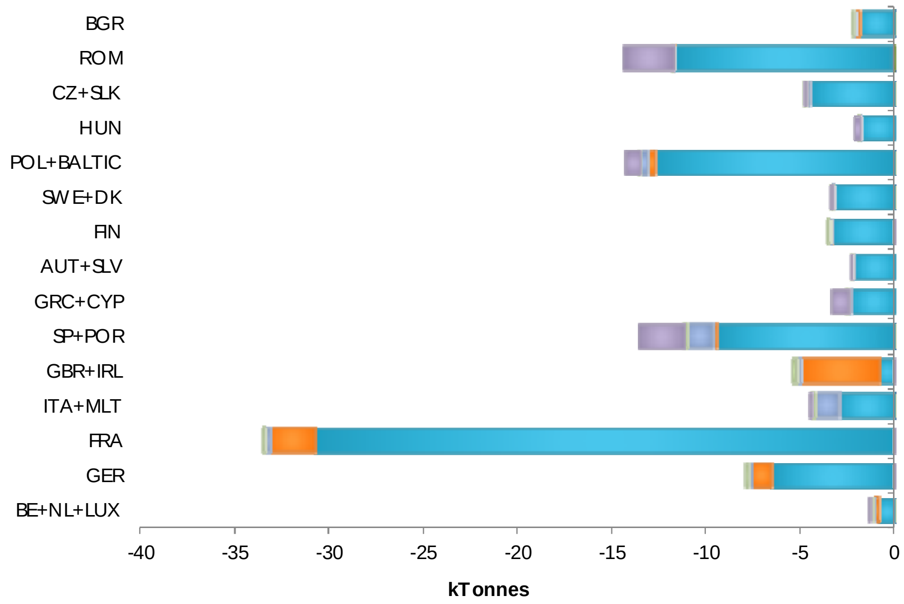
JRC-IES, 2011

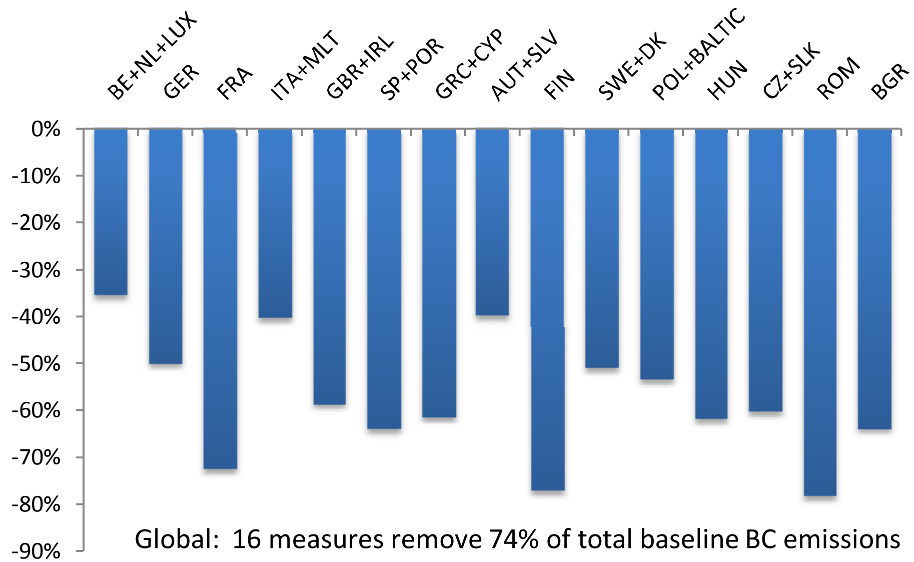
UNEP outcome applied to EU27

Black Carbon emission reductions from 16 measures





- Replacing traditional coke ovens with modern ones
- Replacing traditional brick kilns with more modern ones
- Introduction of improved cookstoves in developing countries
- pellet stoves and boilers
- Replacing coal with briquettes in cooking and heating stoves
- EURO VI (including DPF)
- Eliminating biofuel cookstoves in developing countries
- Elimination of high emitters
- Ban of open burning of ag residue



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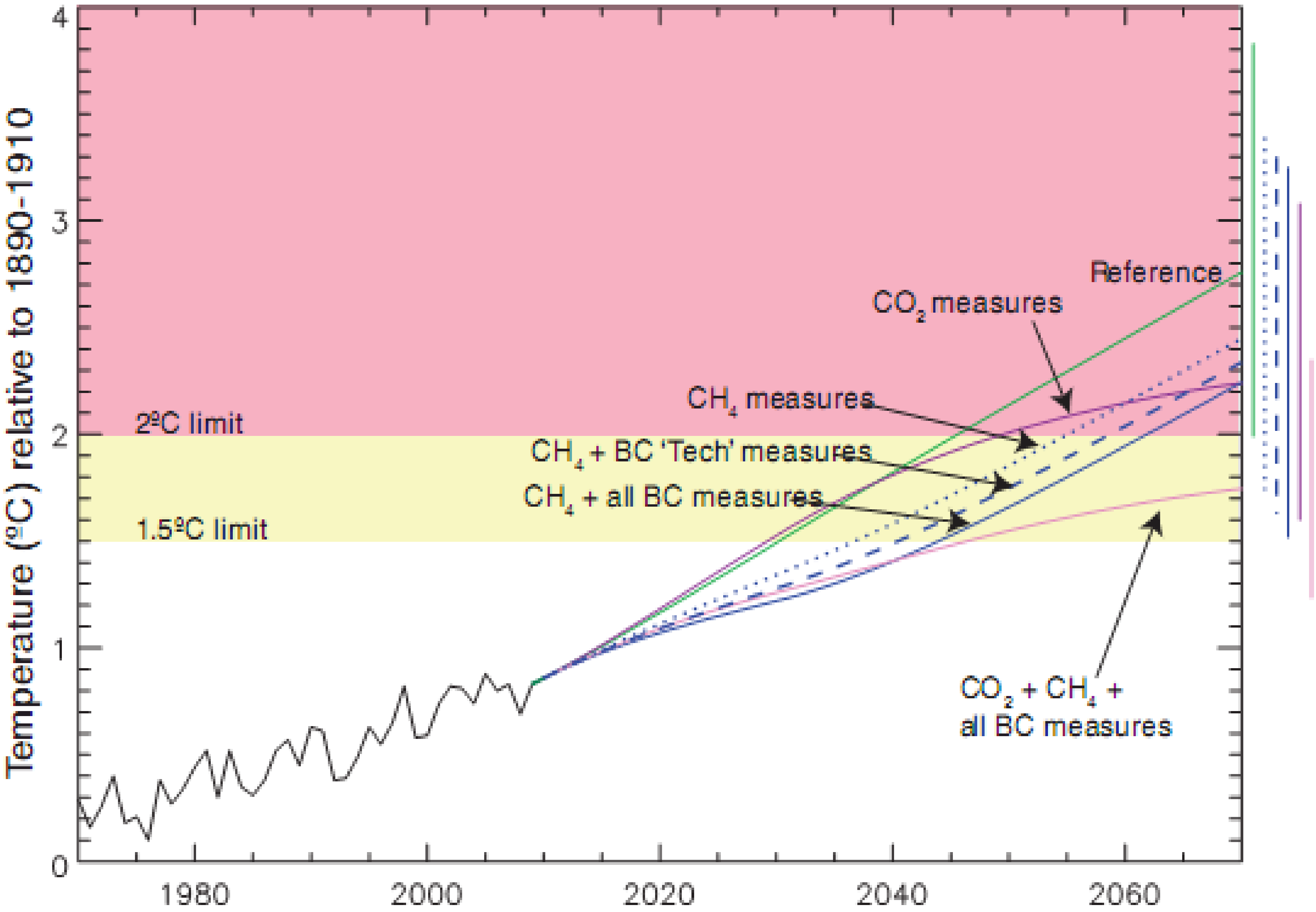
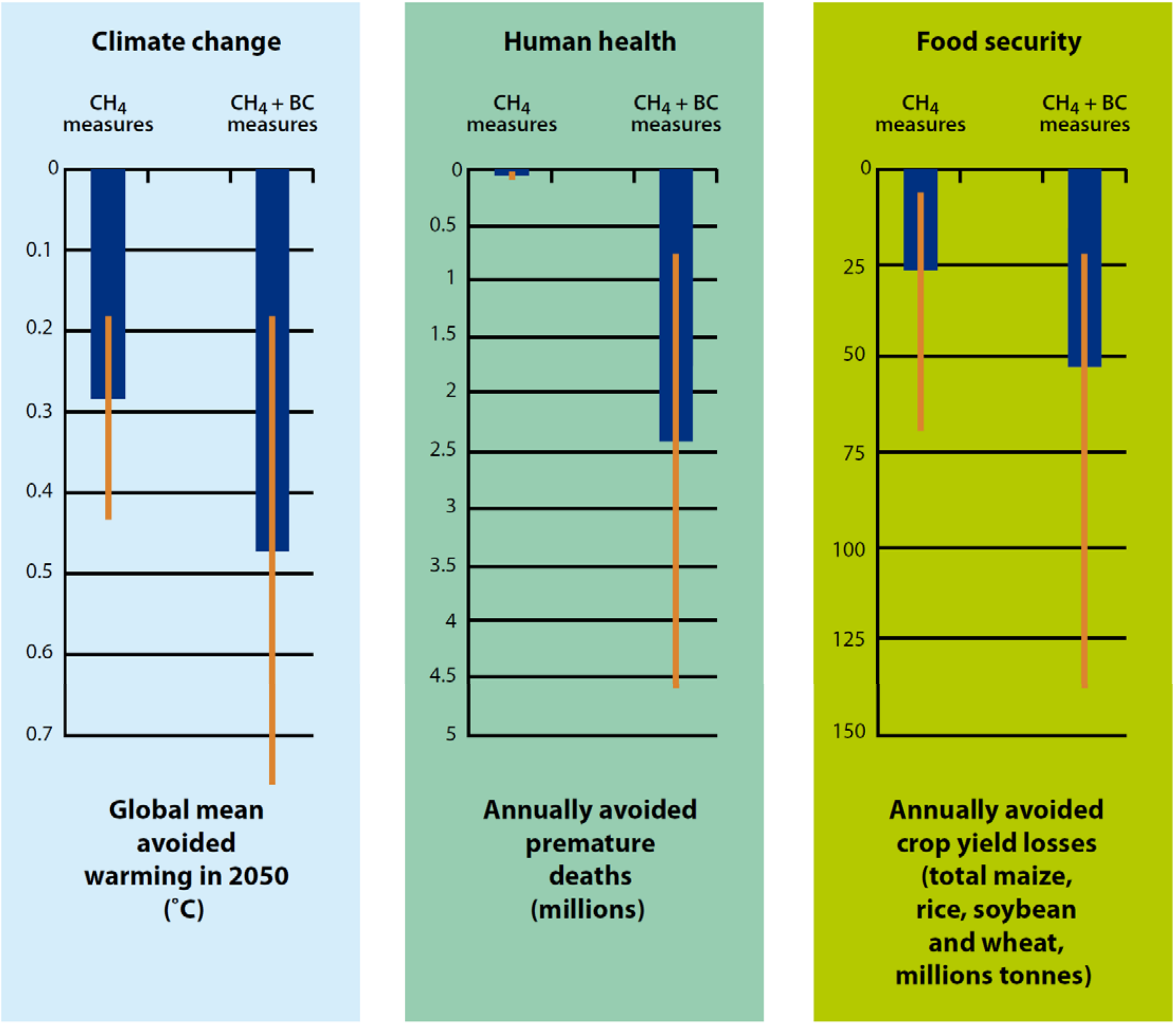
Effect of BC and Ozone controls on global temperature

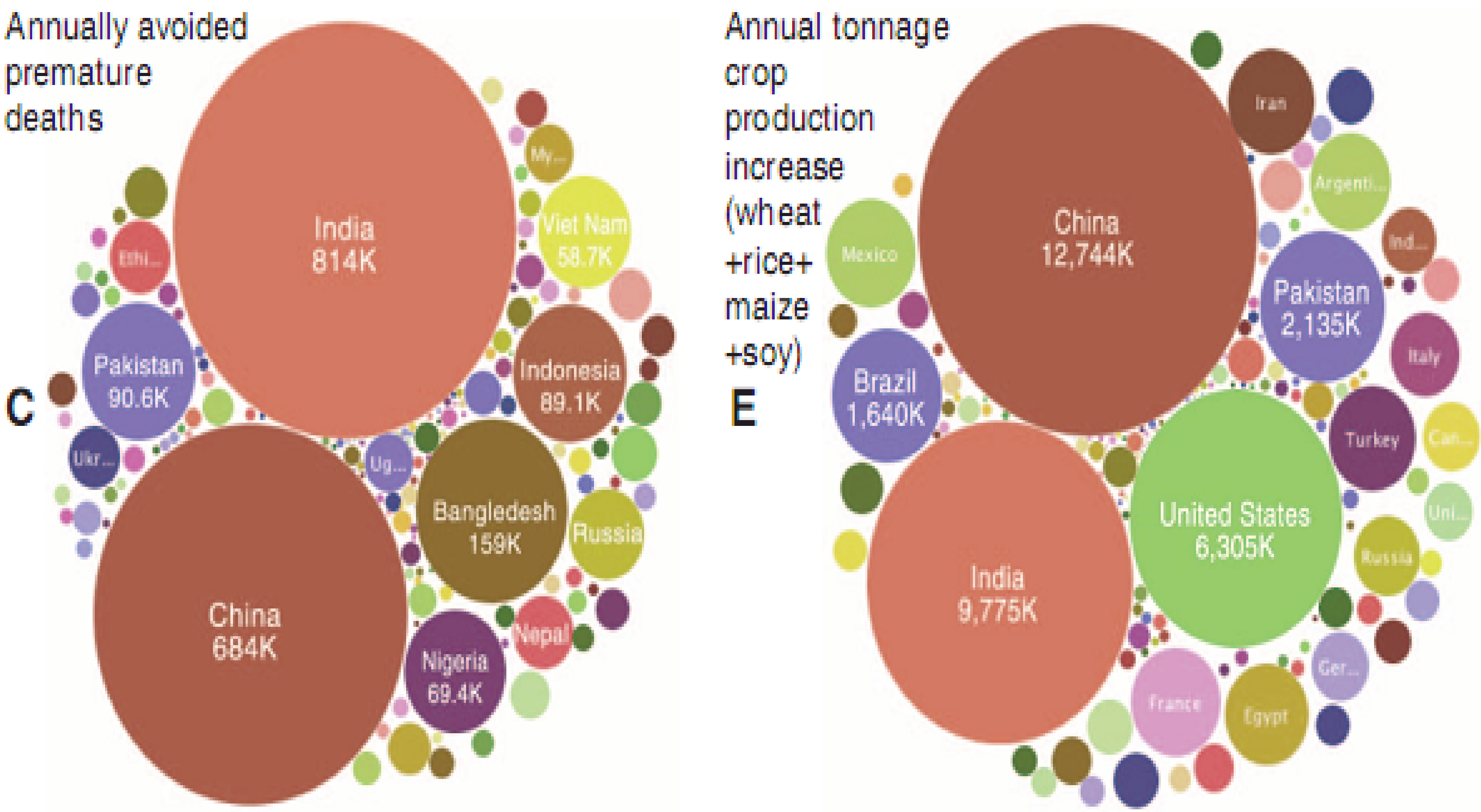


Global benefits of 16 selected CH4 – O3 – BC control measures



UNEP, 2011

Benefits of control measures at country scale



Benefits

	CH_4 measures	BC Tech measures	BC Reg measures
Physical Impacts			
Avoided warming in 2050 (°C)	0.28 ± 0.10	0.12 (+0.06/−0.09)	.07 (+.04/−0.09)
Annually avoided crop yield losses (millions metric tons; sum of wheat, rice, maize, and soy)	27 (+42/−20)	24 (+72/−21)	2 (+13/−3)
Annually avoided premature deaths (thousands)	47 (+40/−34)	1720 (+1529/−1188)	619 (+639/−440)
Valuation			
Climate, billions $US	331 ± 118	142 (+71/−106)	83 (+47/−106)
($US per metric ton CH_4)	(2381 ± 850)		
Crops, billions $US	4.2 ± 1.2	3.6 ± 2.6	0.4 ± 0.6
($US per metric ton CH_4)	(29 ± 8)		
Health, billions $US	148 ± 99	3717 (+3236/−2563)	1425 (+1475/−1015)
($US per metric ton CH_4)	(1080 ± 721)		

conclusions

•Worldwide implementation of 16 measures will have a relatively rapid impact on global mean temperature (GMT) : 0.5° C (80% of expected GMT within 20 yrs!).

•Reduction of 0.7 to 4.7 million premature deaths avoided (mainly in S and E Asia

• 30 to 135 million metric tonnes yield increase in cereal crops

•Ozone reduction measures, especially through CH_4, are an absolute no- regret policy for air pollution and climate. CH_4 – O_3 benefits in crop yields occur at hemispheric scale.

•We still have to greatly reduce CO2 emissions, but the measures presented by this assessment provide an excellent opportunity to contribute to reducing climate change, and offer important benefits for human health and crop production

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Published in Science January 2012

Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security

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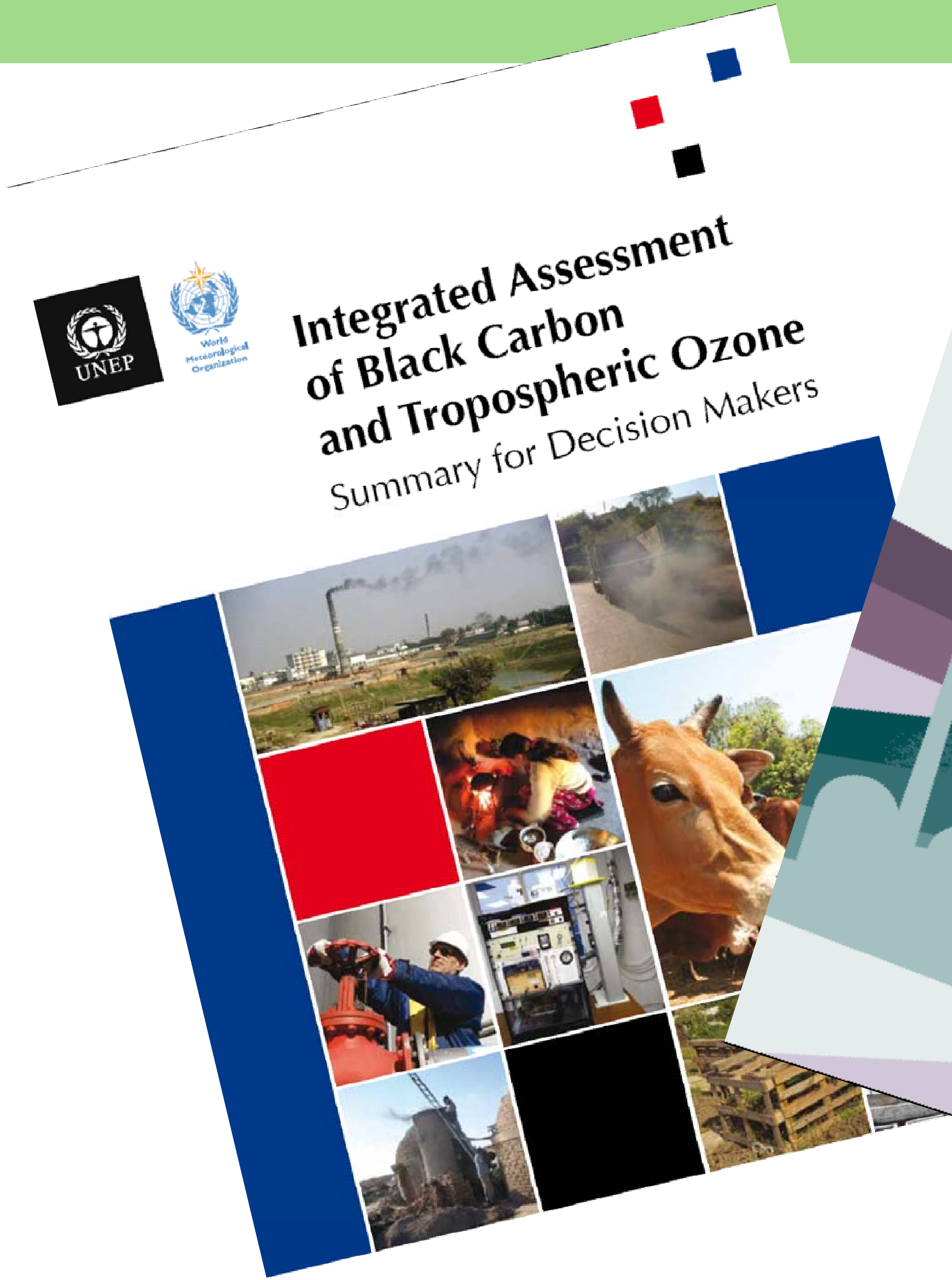
UNEP
World Meteorological Organization
Integrated Assessment of Black Carbon and Tropospheric Ozone
Summary for Decision Makers


UNEP
Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers
A UNEP Synthesis Report