# AQEG 3rd report
# Air Quality and Climate Change

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Met Office: Air Quality, Health and Climate Change

## Impact of climate change on air quality

Question 1: How could the likely impact of climate change on the general weather patterns and emissions of air pollutants and their precursors affect atmospheric dispersion and chemistry processes in general, and UK air quality in particular?

For example, might an increase in heatwaves affect air pollution episodes? Might the frequency and intensity of winter inversions decrease? If so, how will this affect air quality?

## Impact of air quality on climate change

Question 2: What are the links between the sources of emissions responsible for climate change and air quality? What are the main scientific issues associated with the interactions of GHGs and air pollutants in the atmosphere and their impacts on climate change and air quality?

Question 3: What do future trends in UK air pollutant emissions tell us about the potential impact on climate for the UK and Europe? Given that some air pollutants cause air quality concerns on a regional scale, over what scale will their impact on climate be felt?

# Air Quality
# and Climate Change Report 3

## Impacts of climate change policies on air quality and vice versa

Question 4: What current or potential air pollution mitigation measures are likely to be detrimental/beneficial to UK climate change and vice versa? In particular, which mitigation techniques are likely to produce win/win for both air quality and climate change and which will result in unavoidable trade-offs? Priority should be given to considering the energy, transport, and agricultural sectors along with any others deemed to be appropriate.

Question 5: In the case of road transport, for different potential mitigation options (e.g. low-emission vehicles) and fuels (e.g. water diesel emulsion, biofuels, diesel fitted with particle traps, hydrogen etc) what are the main trade-offs and synergies with regard to emissions that impact on climate change and local and regional air quality for the UK? It would be helpful to consider the effect of coupling the technical measure with different traffic management procedures (such as Low Emission Zones or Congestion Charging Zones etc).

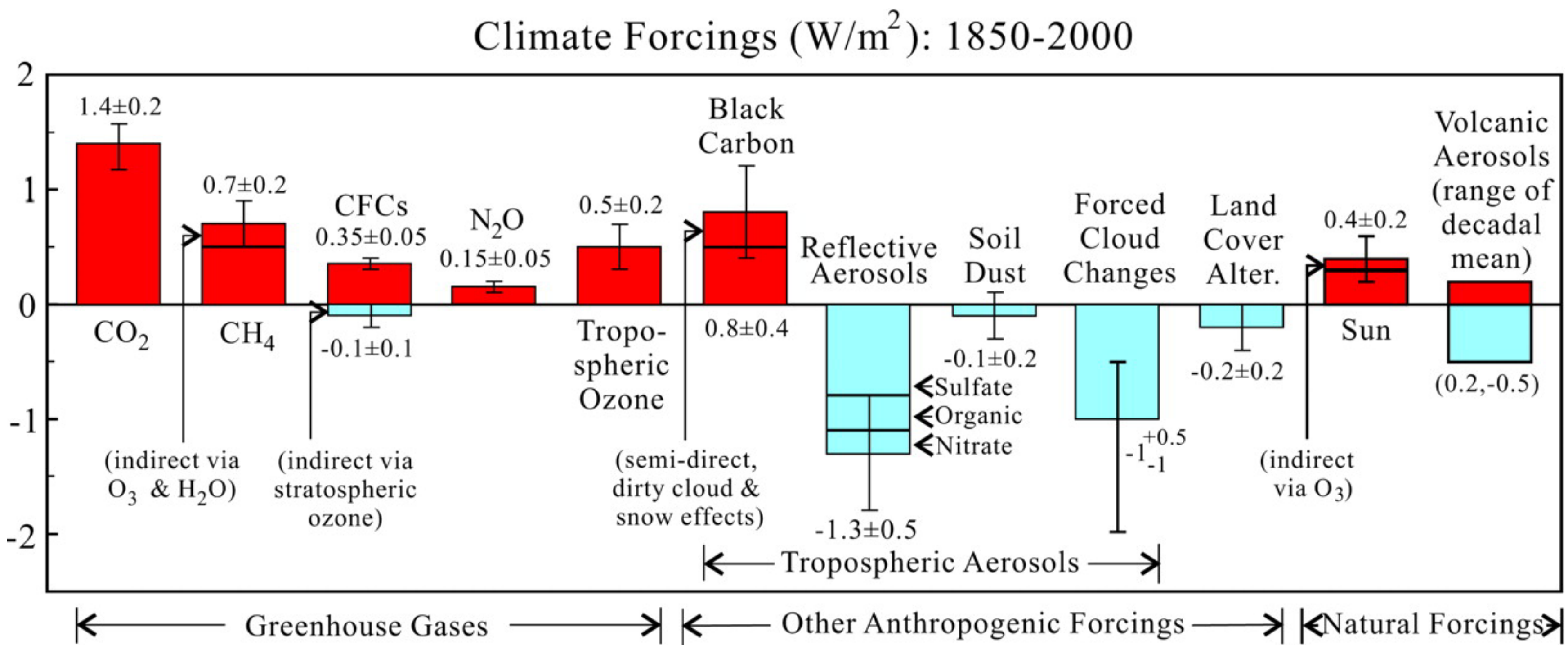
## Future research requirements

Question 6: What are the current gaps in our knowledge? Where should future research focus to provide appropriate scientific information to inform decisions about the comparative benefits of air quality and climate change mitigation measures? Are the currently available scientific tools sufficient to answer these gaps in our knowledge, and if not, what further developments are required?

# Impacts of determinants of air quality on climate change

- Question 2: What are the links between the sources of emissions responsible for climate change and air quality?

# Climate forcing




**Hansen, James E. and Sato, Makiko (2001) Proc. Natl. Acad. Sci. USA 98, 14778-14783**

Climate (or radiative) forcing – change in the average net radiation at the top of the troposphere

# Global emissions of organic compounds and $NO_x$

# Organic compounds in the atmosphere – emissions sources

## Methane

Natural Sources (wetlands, termites, oceans…)

160 Tg($CH_4$)yr$^{-1}$

Anthropogenic Sources (natural gas, coal mines, enteric fermentation, rice paddies, biomass, landfill, animal waste …)

375 Tg($CH_4$)yr$^{-1}$ Total = 535 Tg($CH_4$)yr$^{-1}$

Main sink: reaction with OH

## VOCs

Anthropogenic

fuel production and distribution 17; fuel consumption 49; road transport 36; chemical industry 2; solvents 20; waste burning 8, other 10. Total 142 Tg yr$^{-1}$

Biogenic:

isoprene 503; monoterpenes 127; other reactive VOCs 260, unreactive VOCs 260; Total 1150 Tg yr$^{-1}$

# Global emissions of NOx

Global sources (Tg N $yr^{-1}$):

| | | | |
|---|---|---|---|
| Fossil fuel combustion | 21 | Biomass burning: | 12 |
| Soils | 6 | Lightning | 3 |
| Ammonia oxidation | 3 | Aircraft | 0.5 |
| Transport from strat | 0.1 | | |

# Role of chemistry in climate change

- Methane is removed from the atmosphere almost exclusively by reaction with OH. What determines [OH]? Is [OH] (and with it the oxidising capacity of the atmosphere ) changing ?

- Ozone is a significant greenhouse gas with a ‘medium’ uncertainty in climate models. It is produced by chemical reactions in the troposphere and stratosphere. How will its concentration change and how is it influenced by anthropogenic emissions?

- Aerosols represent a major uncertainty in climate prediction. A significant fraction of aerosols – secondary organic aerosols – are formed in the troposphere by the oxidation of $SO_2$, DMS, $NO_x$ and organic compounds.

# Chemistry

- The oxidising capacity of the atmosphere is closely related to the atmospheric concentration of the hydroxyl radical, OH.
- OH is formed from the photolysis of ozone in the presence of water vapour.
- Volatile organic compounds (VOCs) are removed by reaction with OH. In the presence of $NO_x$, these reactions lead to ozone production.
- In the absence of $NO_x$, these reactions lead to ozone destruction. Importance of the region in which the VOC is emitted.
- Increased $H_2O$ leads to increased OH and can lead to decreased ozone
- $NO_x$ is transported from polluted to clean environments through the agency of PAN – peroxy acetyl nitrate.
- Secondary aerosol is formed from e.g. $SO_2$ and VOCs through oxidation via OH

# Atmospheric lifetimes and burdens of emitted gases

- Organic compound X is removed mainly by reaction with OH
- Atmospheric lifetime of volatile organic compound X:

$$\text{Lifetime of X} = \tau_X = \{k_X[OH]\}^{-1}$$

$$\tau_{CH4} \sim 6 \text{ y}; \tau_{benzene} \sim 10 \text{ days} \quad ; \tau_{isoprene} = 3 \text{ h}$$

Affects the distribution – global, regional, local

- Concentration of e.g. methane in the atmosphere:

Rate of production (emission) ≈ rate of loss

$$R(\text{emission}) = k_{CH4}[CH_4][OH]$$

$$[CH_4] = R(\text{emission})/k_{CH4}[OH]$$

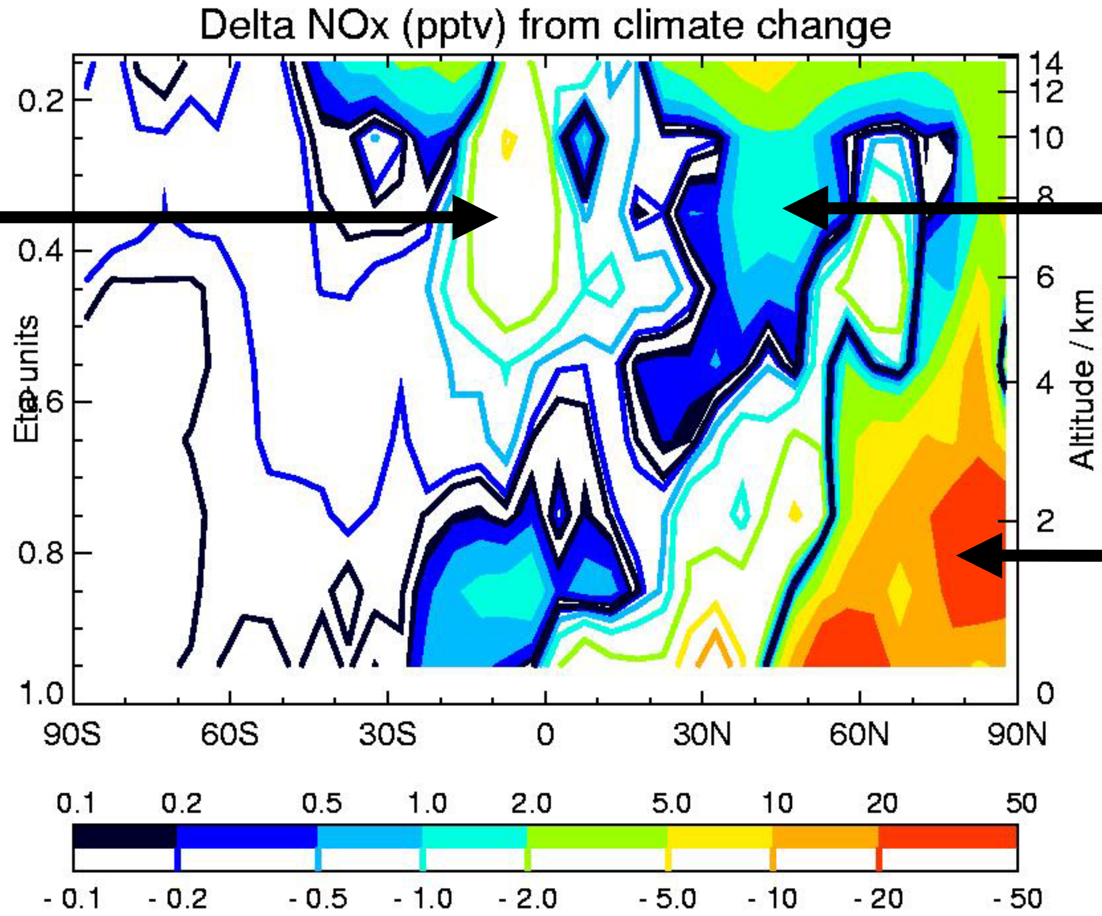
# The atmospheric concentration of OH

- OH is removed by reaction with VOCs, but regenerated by subsequent reactions involving NO
- Ozone formation from OH + VOCs also depends on these reactions with NO
- Thus the impact of a VOC on the OH concentration (and hence on methane) and on the formation of ozone depends on the availability of NOx
- Given its main sources, NOx concentrations are highest in the temperate NH.
- As T increases, the lifetime of PAN decreases and it is less able to transport NOx into less polluted regions

## Zonal mean $NO_x$ change 2020s (climate change – fixed climate) (Stevenson et al)

High NOx increases ozone formation and also OH regeneration

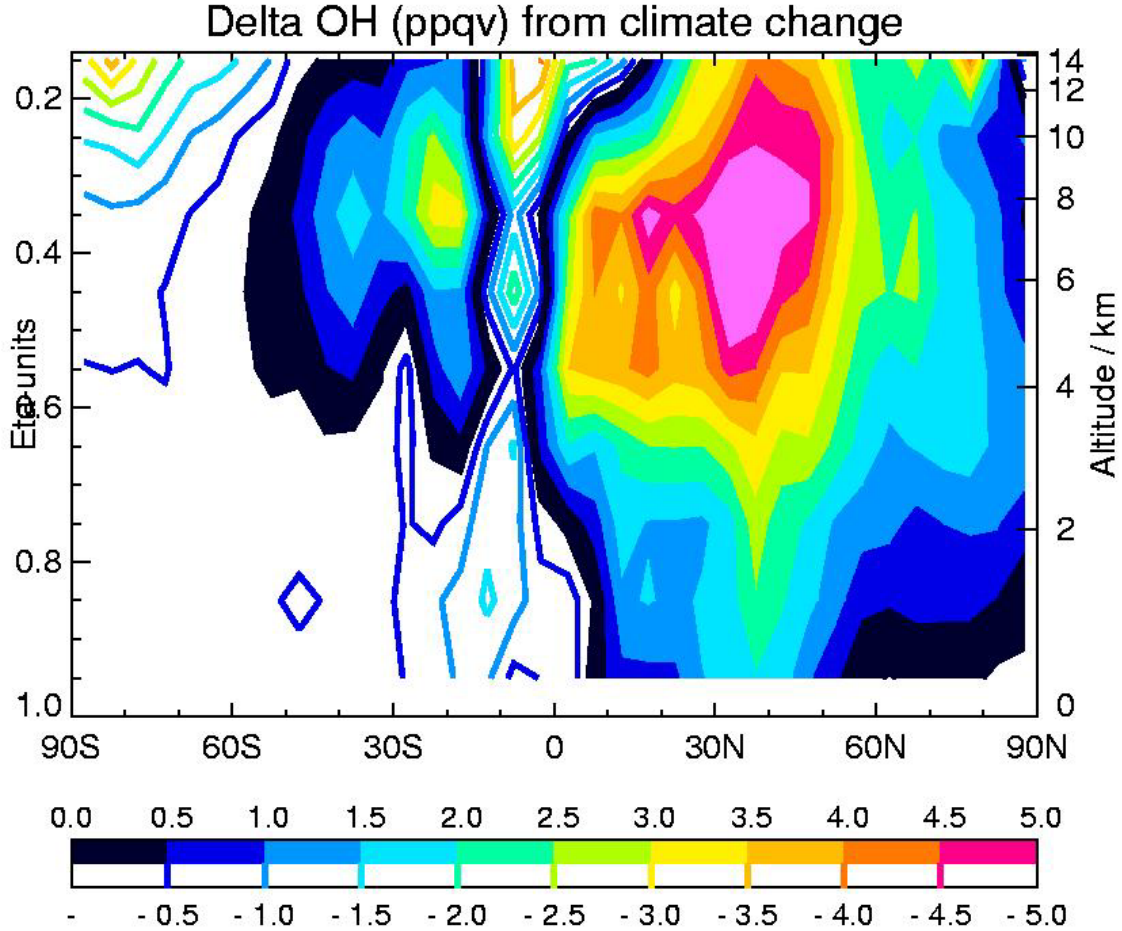
Less tropical convection and lightning




Increased N mid-lat convection and lightning

Increased PAN decomposition

# Zonal mean OH change 2020s (climate change – fixed climate) (Stevenson et al)




Increased OH reduces $CH_4$ and hence its contribution to global warming

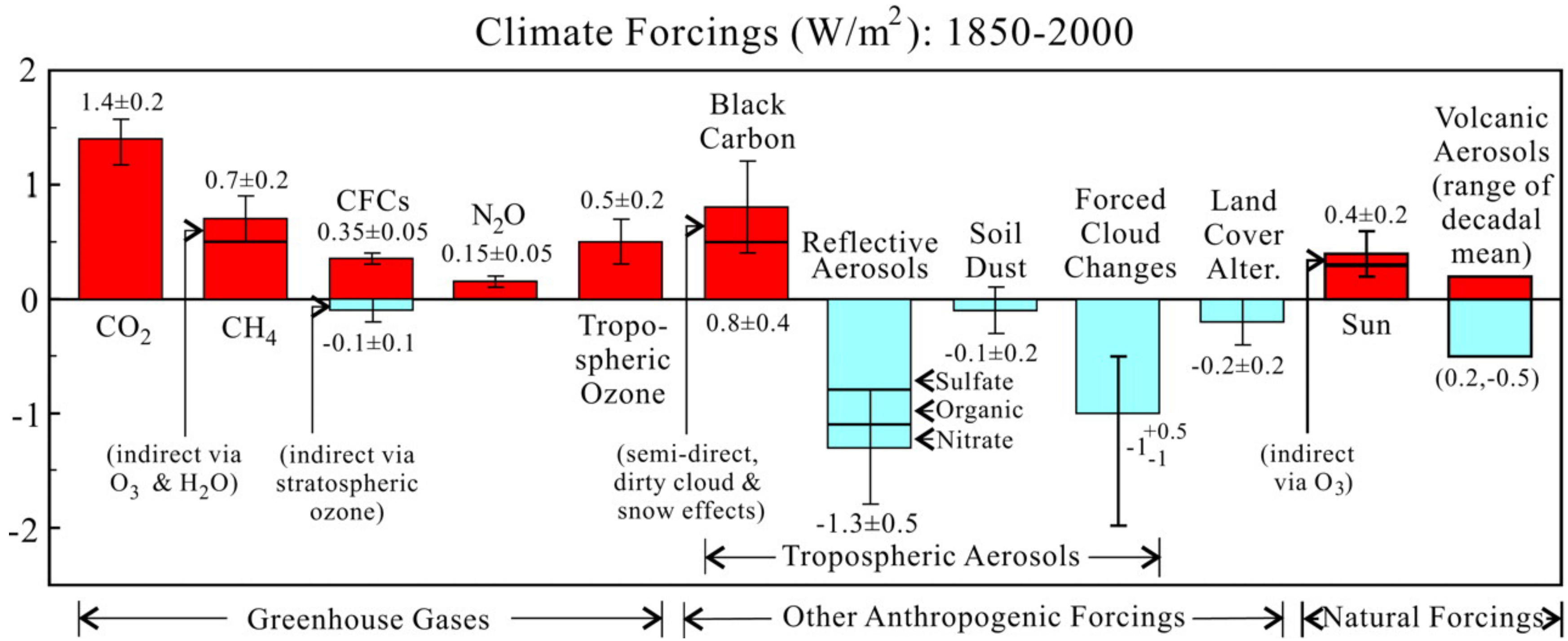
Question 3: What do future trends in UK air pollutant emissions tell us about the potential impact on climate for the UK and Europe? Given that some air pollutants cause air quality concerns on a regional scale, over what scale will their impact on climate be felt?

# Global warming potentials (GWPs) for VOCs (Collins et al)

- Oxidation of VOCs can lead to an increase in ozone and to an increase in methane via OH removal, depending on the NOx concentration.
- The impact of a given VOC depends on its atmospheric lifetime and on the location of its emission.
- Collins et al calculated GWPs for VOCs, via their impact on 'excess' ozone and methane formation:

| | $GWP^{CH4}$ | $GWP^{O3}$ | $GWP^{CO2}$ |
|---|---|---|---|
| Ethane | 2.9 | 2.6 | 2.9 |
| propene | -2.0 | 3.8 | 3.1 |
| Isoprene | 1.1 | 1.6 | |

# Magnitude of Aerosol Forcing

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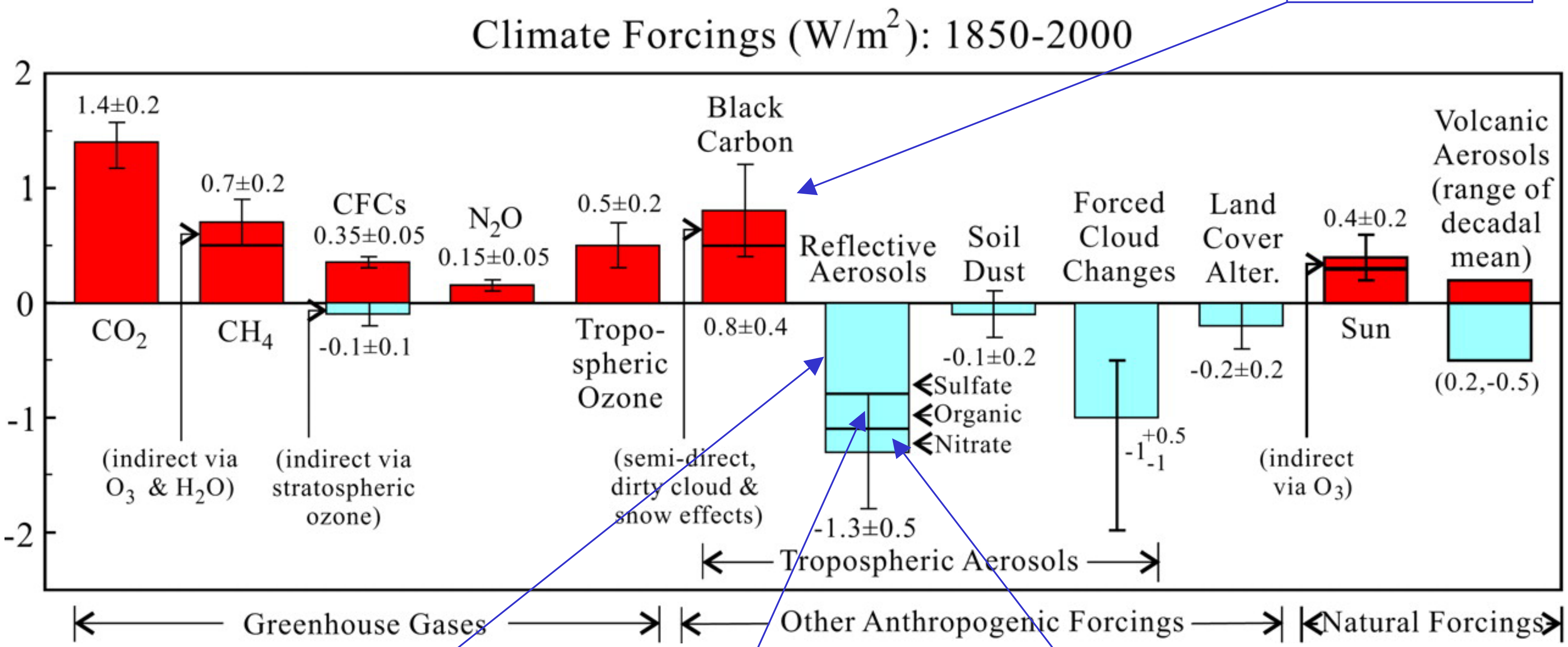
# Magnitude of Aerosol Forcing

Combustion
Fossil fuel
Biomass

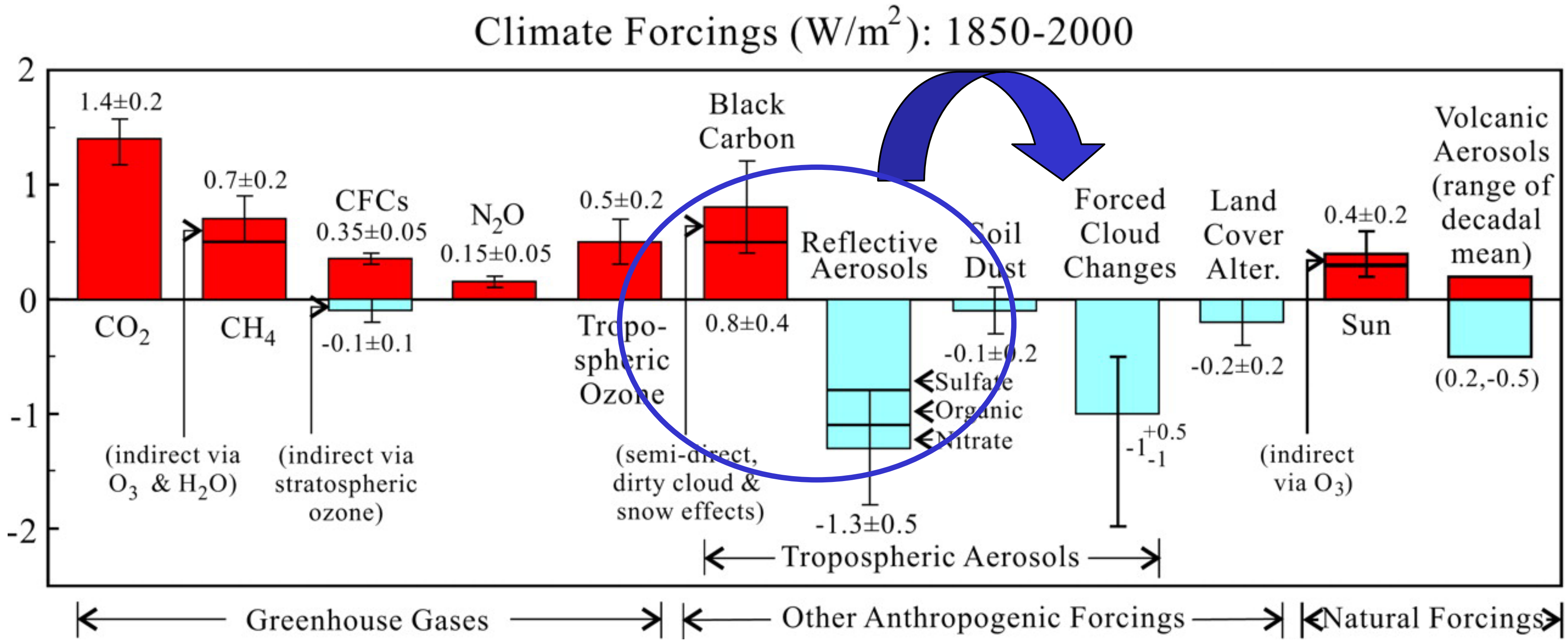



$SO_2$,DMS
oxidation

VOC oxidation
Biogenic, anthropogenic

$NO_x$
oxidation

# Magnitude of Aerosol Forcing

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Question 1: How could the likely impact of climate change on the general weather patterns and emissions of air pollutants and their precursors affect atmospheric dispersion and chemistry processes in general, and UK air quality in particular?

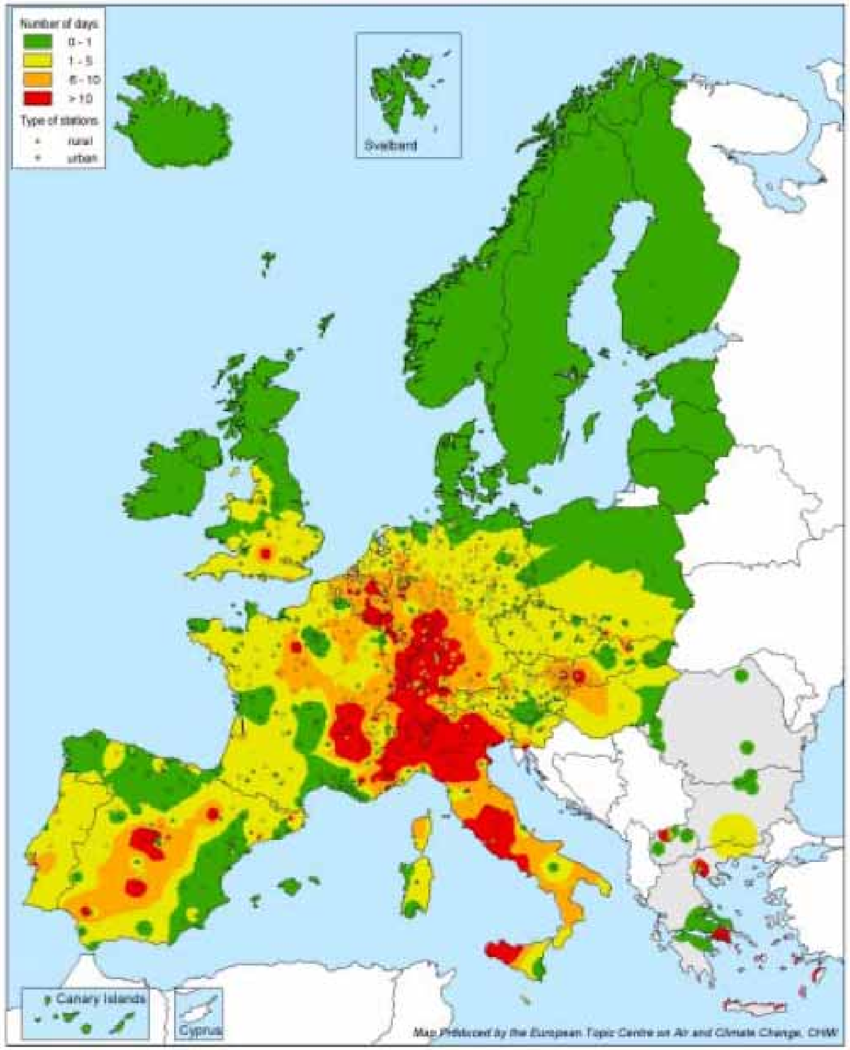
# QUANTITIES RELEVANT TO AQ

- Temperature (reaction rates, natural emissions)
- Precipitation (rainout). Wetter winters, but large regional variations.
- Dynamics (winds, strat-trop exchange, BL).
- Stagnation events – summer and winter air pollution episodes.
- Insolation (photolysis)
- Cloud amount (in-cloud reactions, washout)
- Water vapour (supply of $H_2O$)

# Ozone episodes: Summer 2003

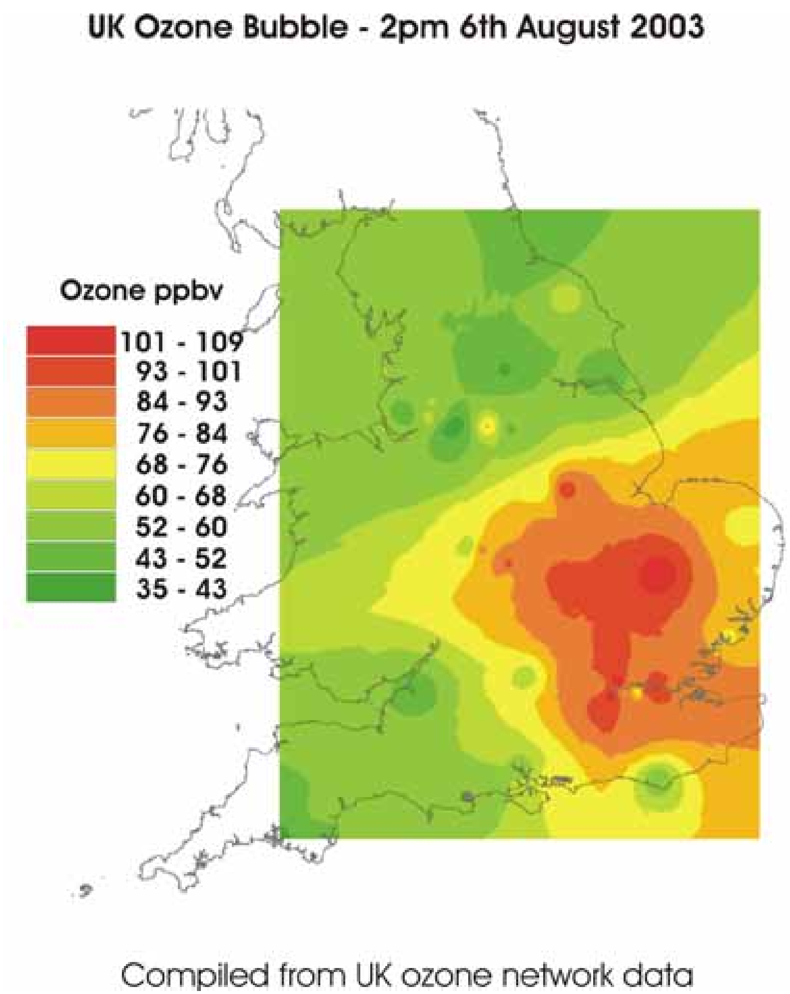
Exceedance of the 180 µg/m3 ozone information threshold
Interpolated around urban and rural stations

Reference period: summer 2003 (April - August)



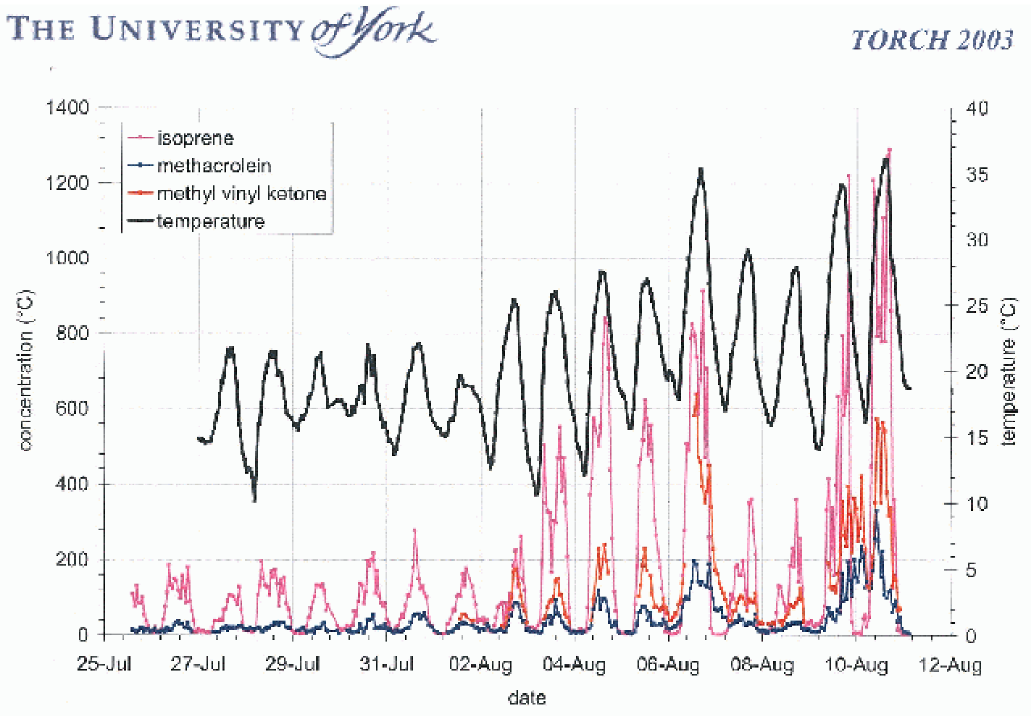
# Summer, 2003. Photochemical smog episode

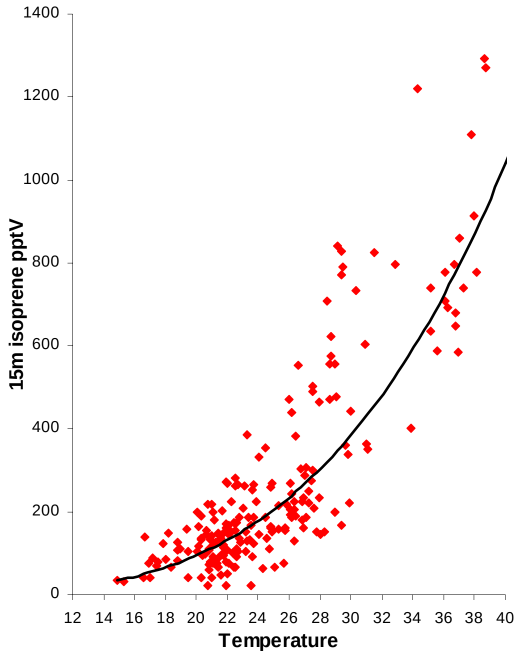
- Episodes of photochemical smog, with high $O_3$, occurred regularly in the 80s and early 90s, but have recently been less prevalent.
- High ozone concentrations (> 100 ppb) observed on 6 consecutive days during the heatwave, 'stagnant' air period in August 2003.
- Estimated up to 700 extra deaths attributable to air pollution ($O_3$ and PM10) in UK during this period



# Climate effects on emissions
# TORCH campaign (NERC) at Writtle, Essex

- Isoprene is emitted by vegetation. The rate of emission depends on temperature and light intensity.
- Isoprene reacts very rapidly with OH and has a lifetime of < 1h. It is very efficient at generating ozone, provided there is NOx and sunlight.
- Note the high isoprene concentrations occur on days with high T.



# Marylebone Road, 2003 (Analysis by John Stedman)

Figure 1 Marylebone Road isoprene daily average and London Heathrow maximum daily temperature, 2003

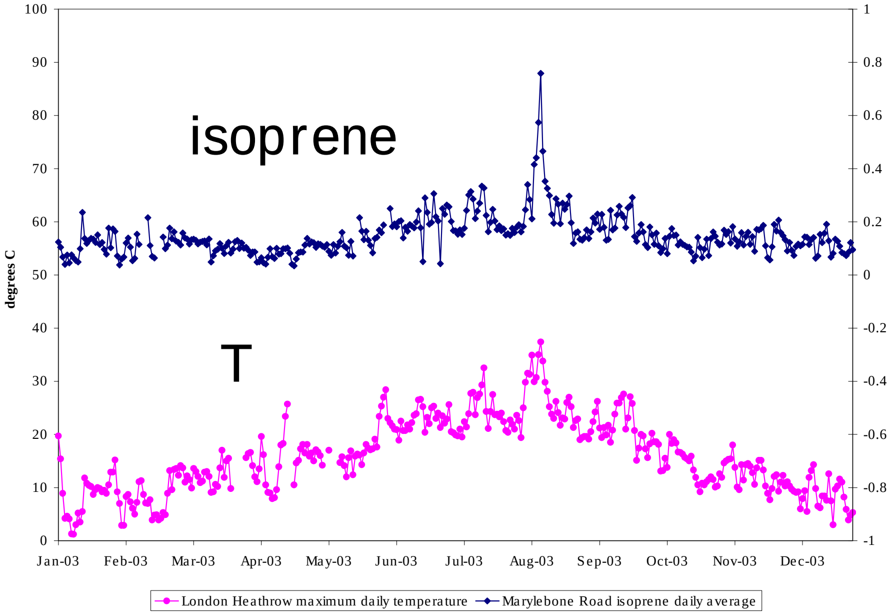



Figure 2 Marylebone Road 2003 isoprene and benzene time series

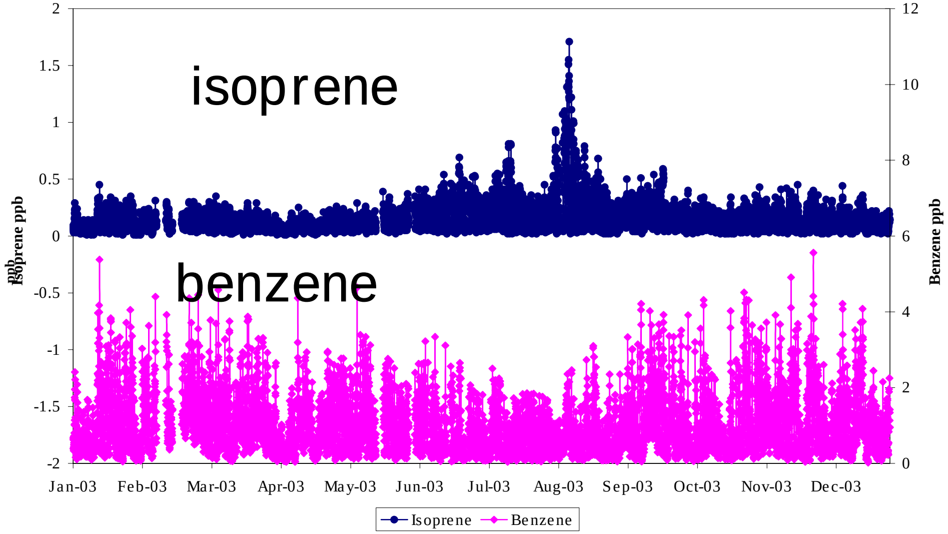
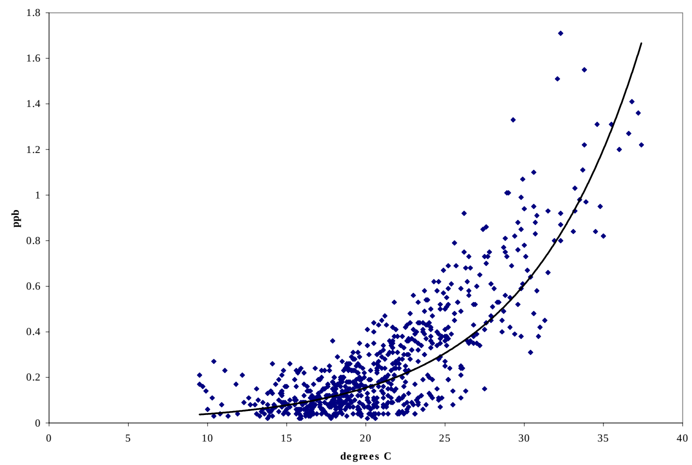
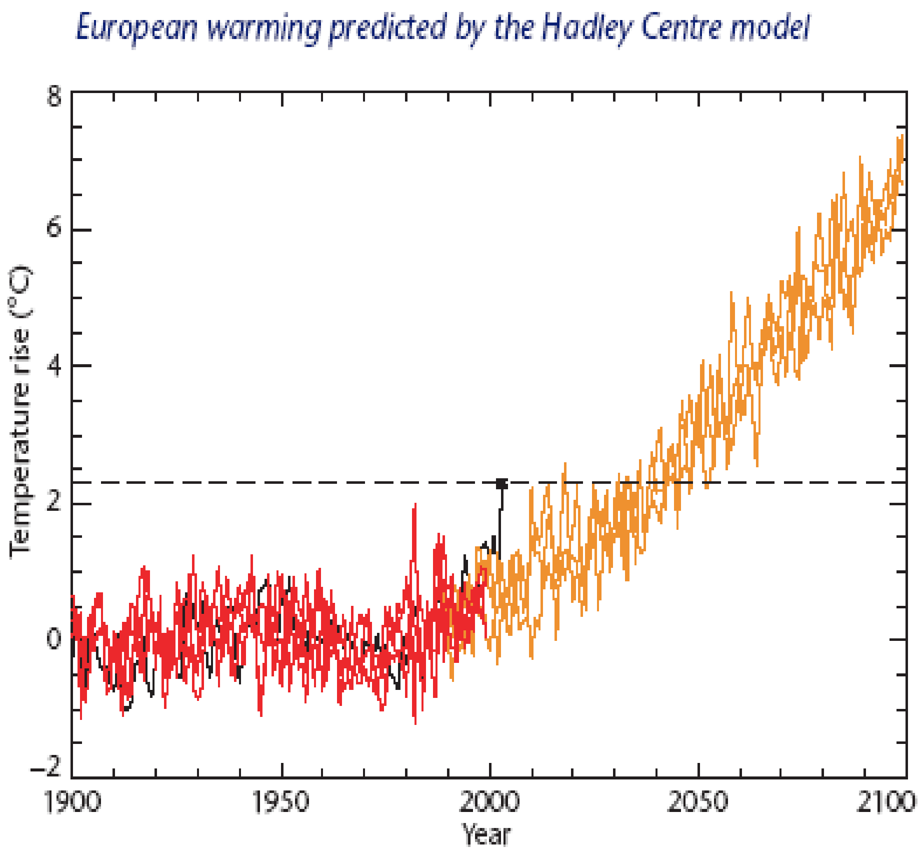



Figure 5 Marylebone Road isoprene hourly average v London Heathrow temperature, August 2003




Isoprene vs T

# Future summer temperatures

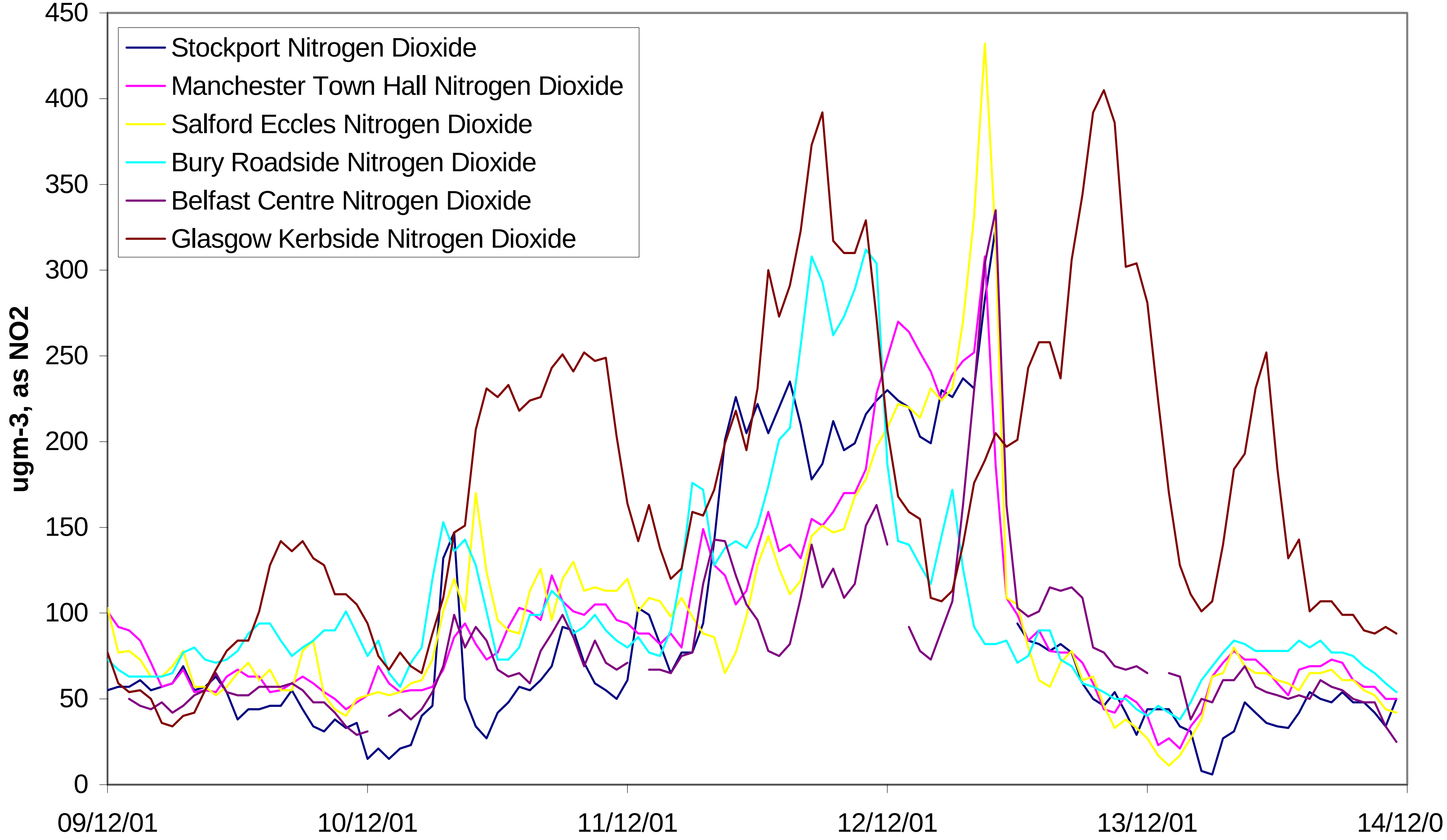



Using a climate model simulation with greenhouse gas emissions that follow an IPCC SRES A2 emissions scenario, Hadley Centre predict that more than half of all European summers are likely to be warmer than that of 2003 by the 2040s, and by the 2060s a 2003-type summer would be unusually cool

Stott et al. Nature, December 2004

2003: hottest on record (1860)
Probably hottest since 1500.
15 000 excess deaths in Europe

# Winter $NO_2$ episode, December 2001



# Long range transport of pollution

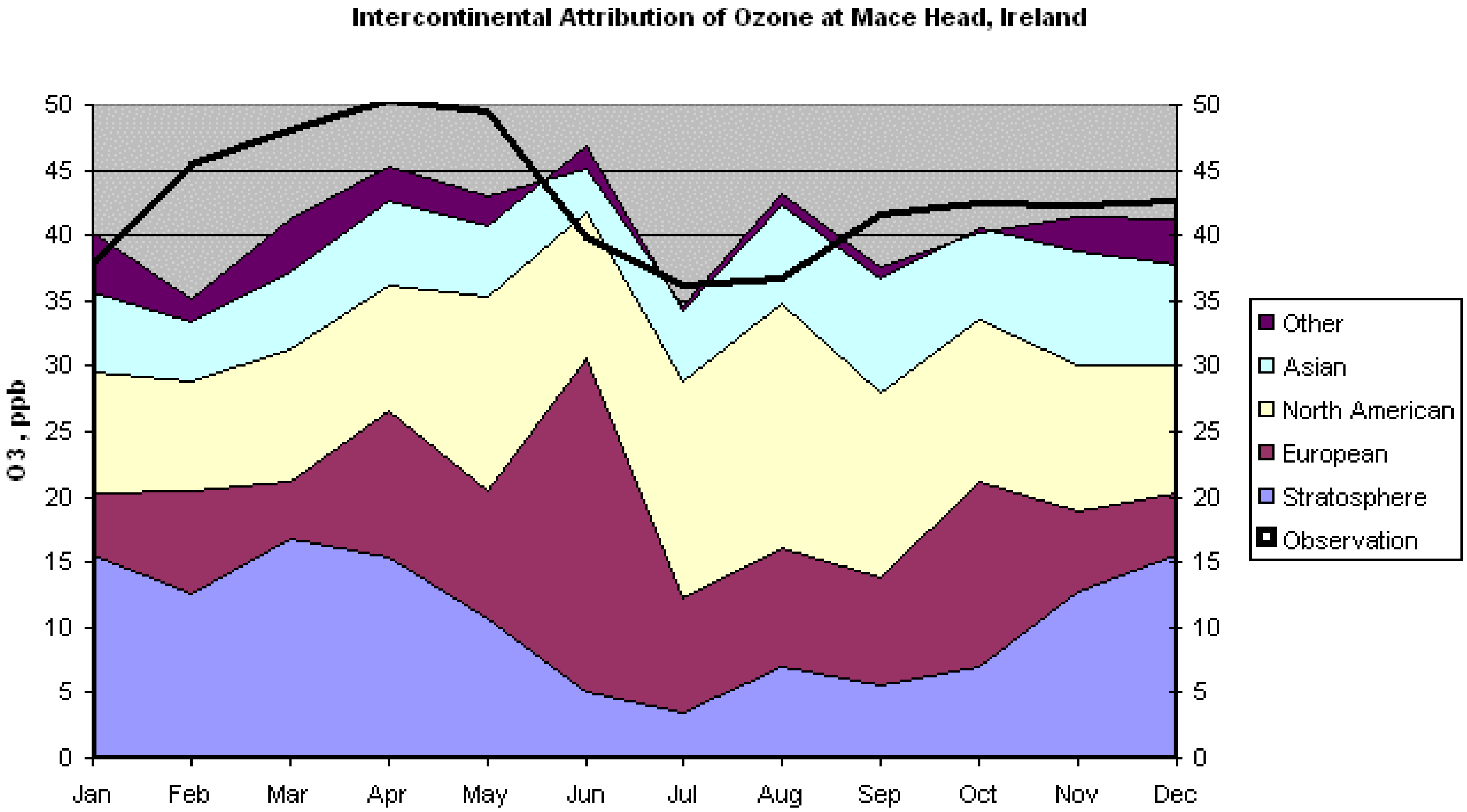
- Ozone is a regional pollutant and concentrations in the UK are influenced by European emissions of ozone precursors. Is longer range transport from other continents significant?

- The AQ objective for ozone is 50 ppb (daily max of 8 h mean, not to be exceeded more than 10 times per year. By 31 Dec 2005).

- Ozone concentrations also influence $NO_2$ through the oxidation of NO.

- What is happening to the hemispheric background ozone concentration?

# Long range transport of pollution (Derwent et al)

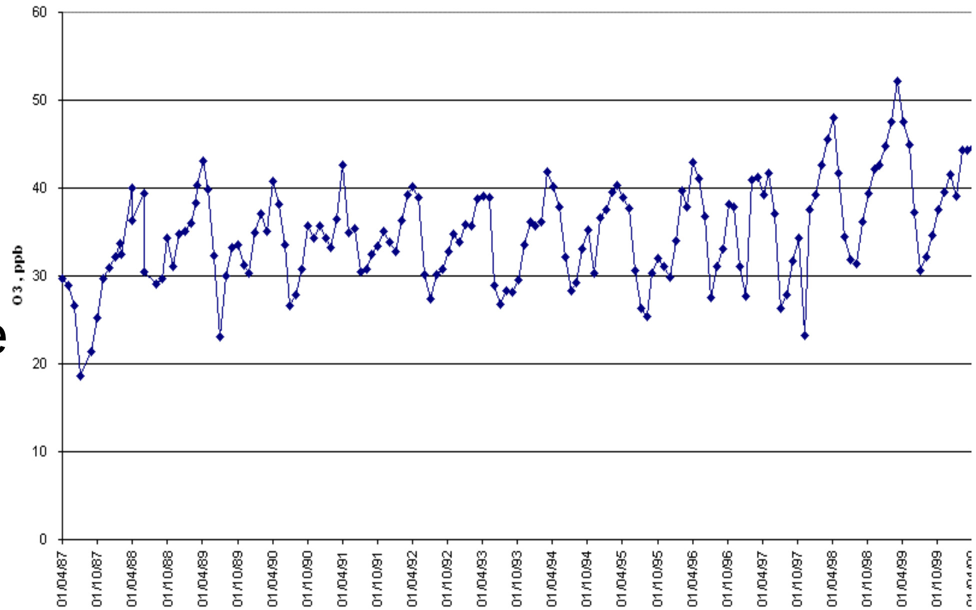



| | |
|---|---|
| Europe label: | $20^oW$ to $60^oE$, $90^oN$ to $23^oN$ |
| Asia label: | $60^oE$ to $140^oW$, $90^oN$ to $23^oN$ |
| N America label: | $140^oW$ to $20^oW$, $90^oN$ to $23^oN$ |
| Rest of globe label: | $23^oN$ to $90^oS$ |

# Ozone

- Background ozone is increasing in the Northern Hemisphere owing to increases in emissions on a global scale. This trend reduces window for regional production. (AQ objective is 50 ppb, 8 hour mean)

Monthly mean ozone concentrations, Mace Head, W Ireland, under westerly (clean) air flows, showing the upward trend in background




Also potential impact on $NO_2$

# Air Quality / Climate Change Interactions1

- Ozone:
  - Health and vegetation impacts
  - Greenhouse gas
  - Concentration and distribution influenced by climate change
  - Affects [OH] and hence lifetime of $CH_4$
- Aerosols / particulate matter
  - Health effects
  - Radiative forcing – complex +(soot), -($NO_3^-$, $SO_4^{2-}$, OC)
  - Reducing PM for air Quality objectives may enhance greenhouse effect

# Air Quality / Climate Change Interactions 2

- Methane
  - Greenhouse gas
  - Contributes to $O_3$ formation globally
  - Affects [OH] and the oxidising capacity of the troposphere
- $NO_x$ / VOCs
  - Affect health via $O_3$, $NO_2$, PM
  - Affect oxidising capacity of atmosphere
- $SO_2$
  - AQS objective
  - Affects PM via $SO_4^{2-}$
  - Sulphate aerosol is reflective - affects radiative forcing

- Effects are non-linear

# Impacts of trace gases (EEA report)

| | $SO_2$ | $NO_x$ | $NH_3$ | VOC | CO | $1^0$PM | $CH_4$ | $CO_2$ |
|---|---|---|---|---|---|---|---|---|
| Ecosystems | | | | | | | | |
| Acidification | X | X | X | | | | | |
| Eutrophication | | X | X | | | | | |
| $O_3$ | | X | | X | X | | X | |
| Health | | | | | | | | |
| Direct | X | X | | X | X | X | | |
| Via $O_3$, PM | | X | X | X | X | | X | |
| Radiative forcing | | | | | | | | |
| Direct | | X | | | | | X | X |
| *Via* aerosols | X | X | X | X | | X | | |
| *Via* OH | | X | | X | X | | X | |

# Linkages in emissions and control options

- Synergies and trade-offs in technical control measures
  - Increased use of natural gas has favourable impacts on AQ and CC – SYNERGY
  - FGD improves AQ and reduces acid deposition, but may increase $CO_2$ and reduce reflective aerosol – TRADE-OFF
- Impact of climate change on fuel usage
- Need integrated assessment across sectors and across effects
- Implementation of climate change policies (e.g. Kyoto) may reduce costs of meeting AQ objectives

# Changes needed in approaches to policy

- Opportunities for synergies and accommodation of trade-offs not integrated into AQ policies or policy negotiations (e.g. EAP, CAFÉ) or into climate negotiations (UNFCCC)
- Increasingly recognised in e.g. IPCC, UNECE need to take into account at the activity level (e.g. fossil fuel combustion) rather than at the individual pollutant level.
- Full understanding of economic costs only appreciated if treat AQ and CC together.
- Holistic approach also needed for full appreciation of environmental impact.
- Need operational framework for design of complementary policies