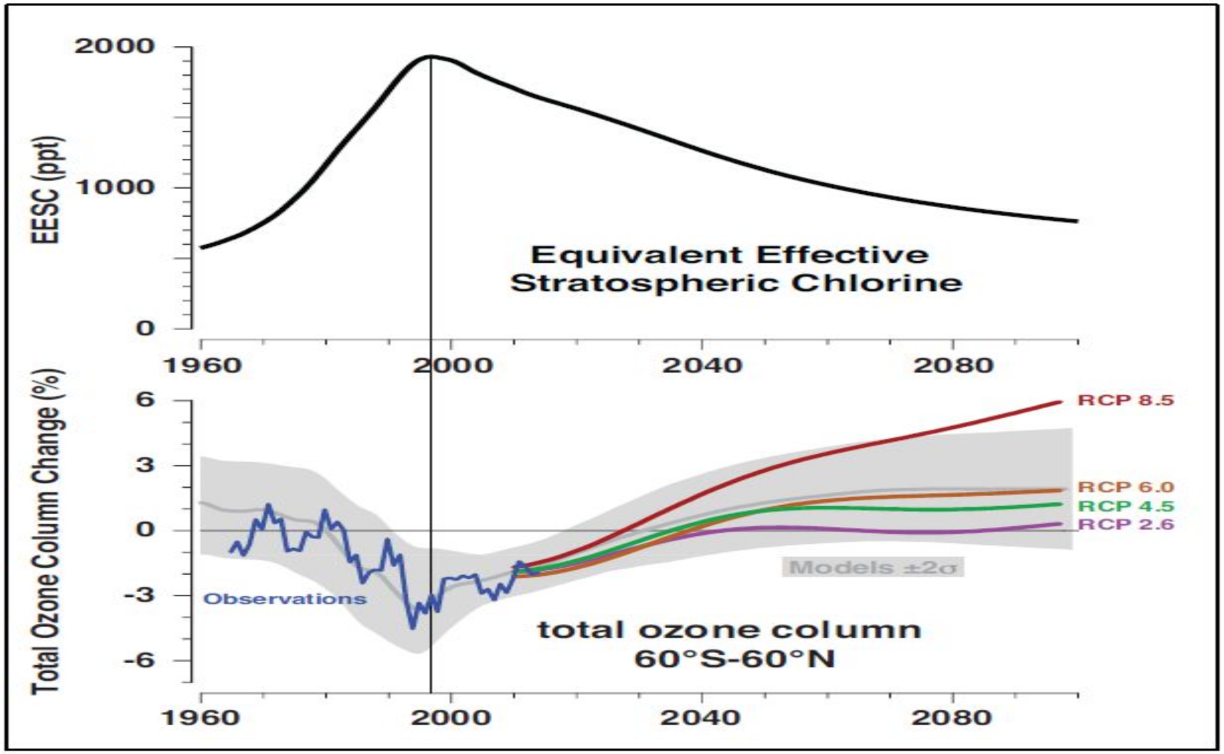
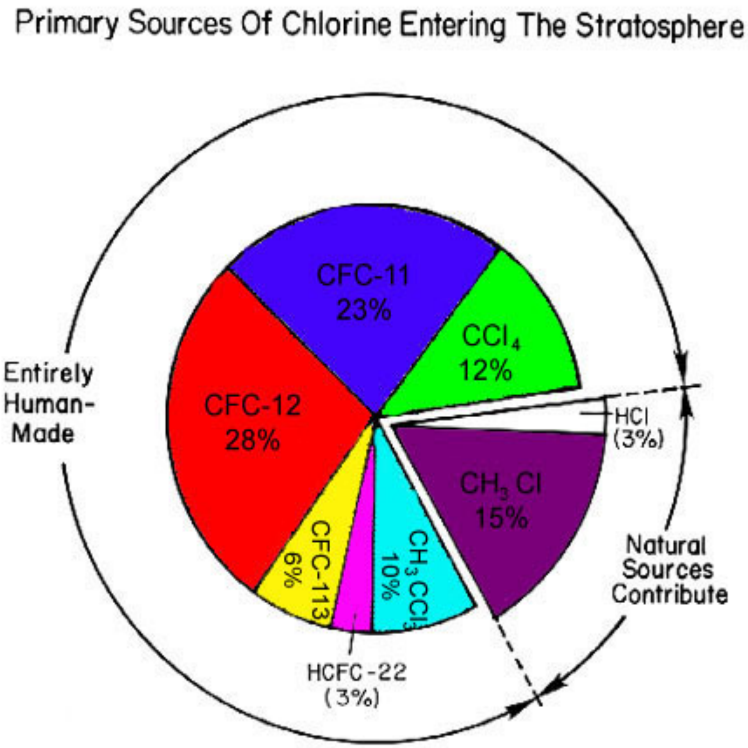


Ozone Recovery?

Michel Van Roozendael, BIRA-IASB

ATC14, 27-31 October, Jülich, Germany

- 1928: start of CFC production
- 1971: 1st observation of CFC in the atmosphere (J. Lovelock)
- 1974: identification of O_3 destruction potential by CFC: Rowland & Molina
- *1995: Nobel prize in chemistry: F. Rowland, M. Molina & P. Crutzen, 1995*



1990: 80% of stratospheric chlorine is of anthropogenic origin

Long term ozone depletion

- Increasing anthropogenic emissions, since industrial revolution, esp. CFCs since 1960

  ↳ increasing concentrations of destructive radicals

  ↳ steady decrease of O_3 on a global scale

- Recurrent spring-time ozone hole at the South pole

- Seasonal ozone depletion in the North pole, strongly modulated by dynamics

JÜLICH FORSCHUNGSZENTRUM

esa

Nature, Vol. 315, 16 May 1985

Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction

J. C. Farman, B. G. Gardiner & J. D. Shanklin

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

Recent attempts[1,2] to consolidate assessments of the effect of human activities on stratospheric ozone (O_3) using one-dimensional models for 30° N have suggested that perturbations of total O_3 will remain small for at least the next decade. Results from such models are often accepted by default as global estimates[3]. The inadequacy of this approach is here made evident by observations that the spring values of total O_3 in Antarctica have now fallen considerably. The circulation in the lower stratosphere is apparently unchanged, and possible chemical causes must be considered. We suggest that the very low temperatures which prevail from midwinter until several weeks after the spring equinox make the Antarctic stratosphere uniquely sensitive to growth of inorganic chlorine, ClX, primarily by the effect of this growth on the NO_2/NO ratio. This, with the height distribution of UV irradiation peculiar to the polar stratosphere, could account for the O_3 losses observed.

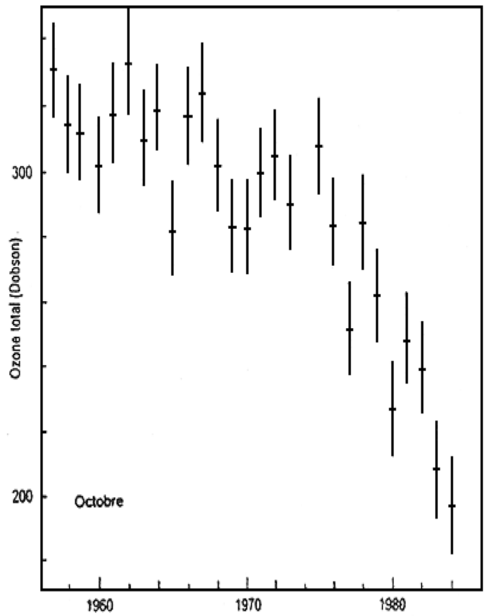
- First alarming signs of O_3 degradation were given in 1982 and 1985 based on Dobson measurements at Syowa and Halley Bay (since 1957)

- Ozone layer thins dramatically in the local spring down to ~ 100 DU

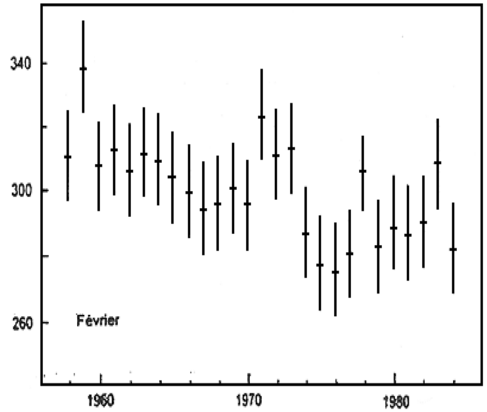
This phenomenon was not expected !

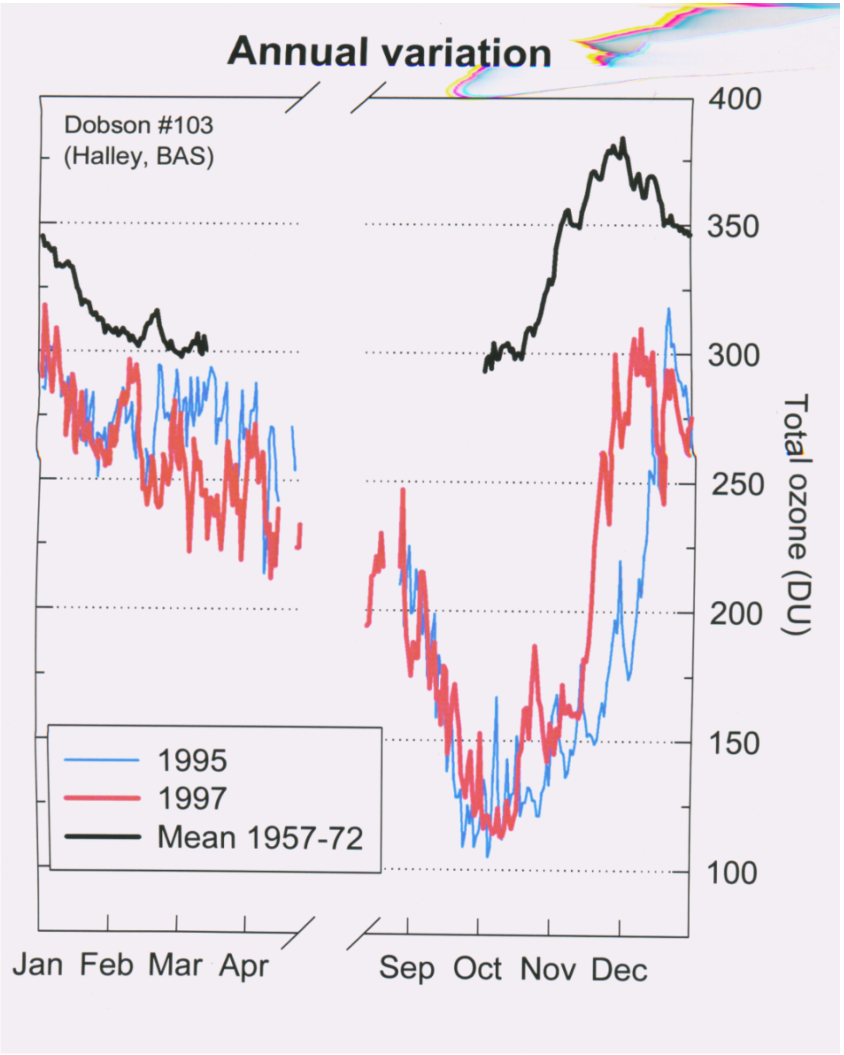
Evolution of average (monthly) O_3 layer thickness between 1956 and 1986

in October

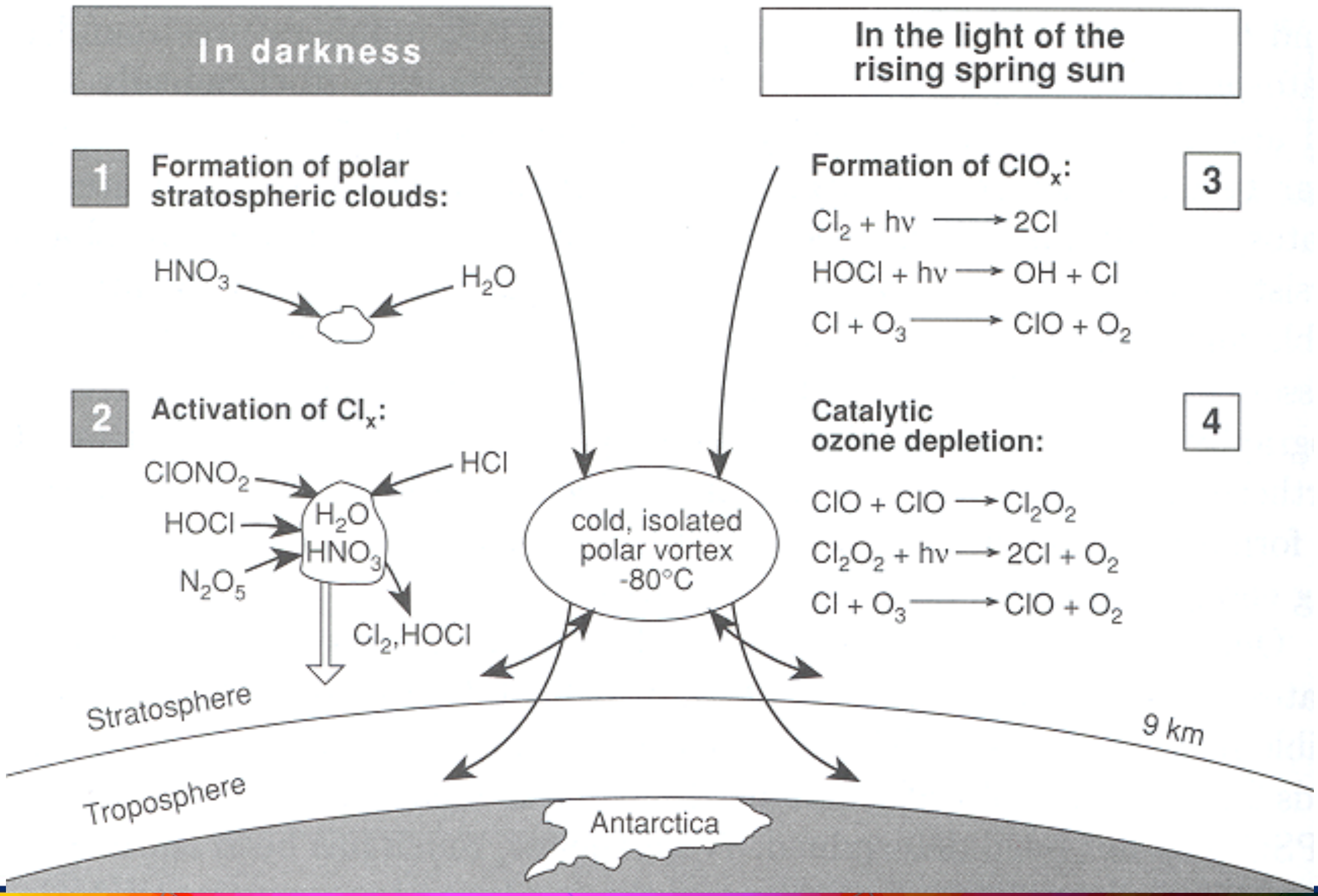


In Februari



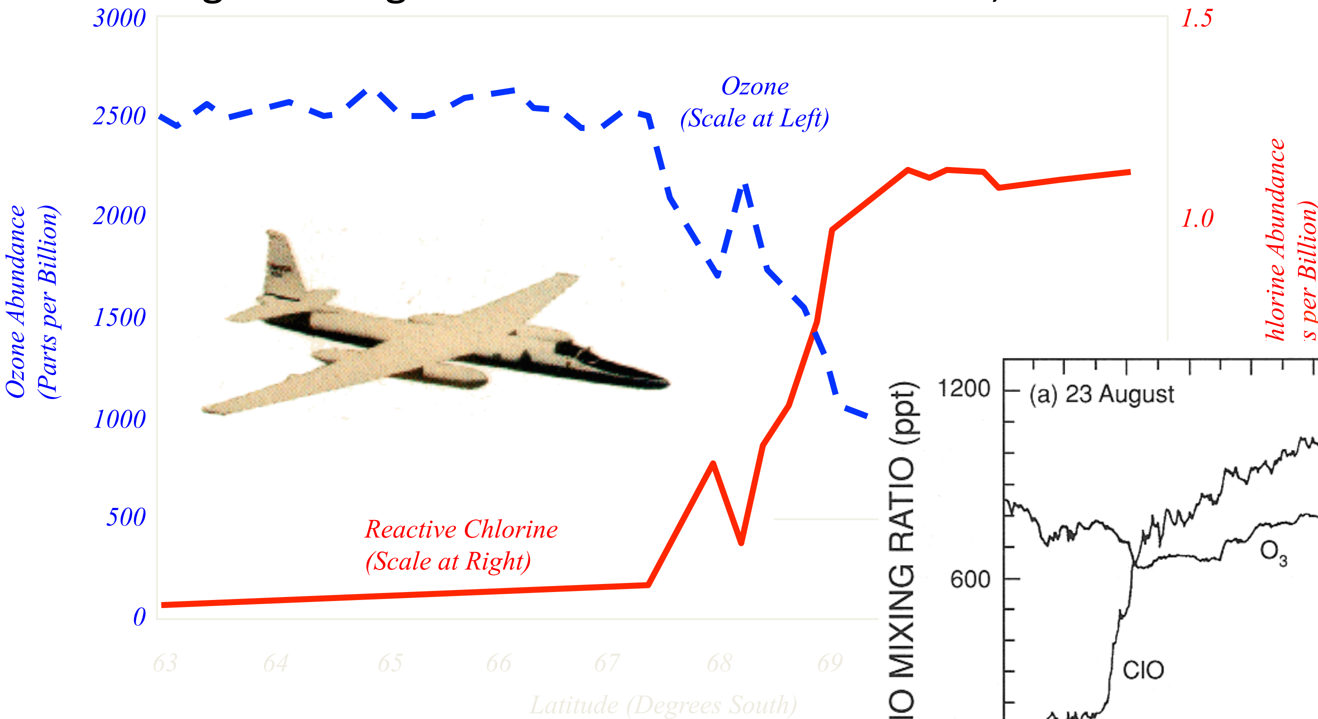


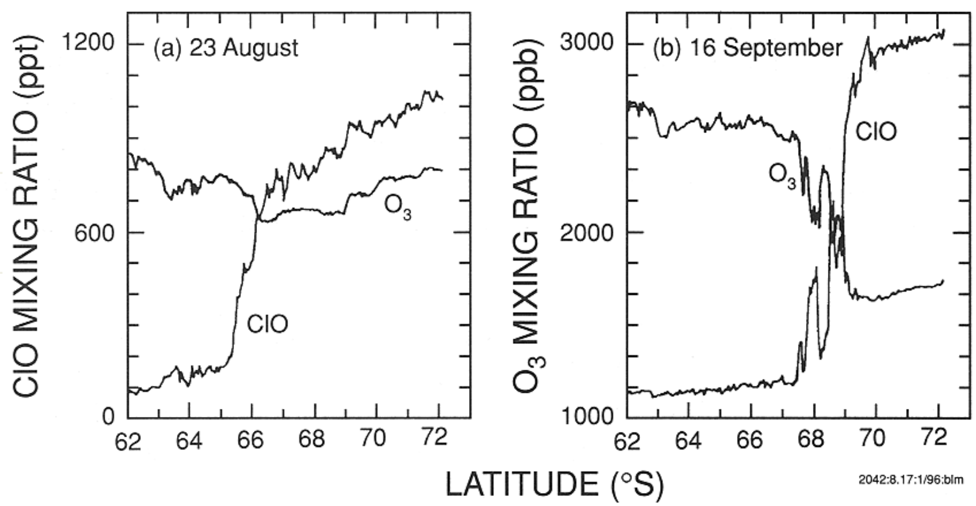
Heterogeneous chemistry on PSCs

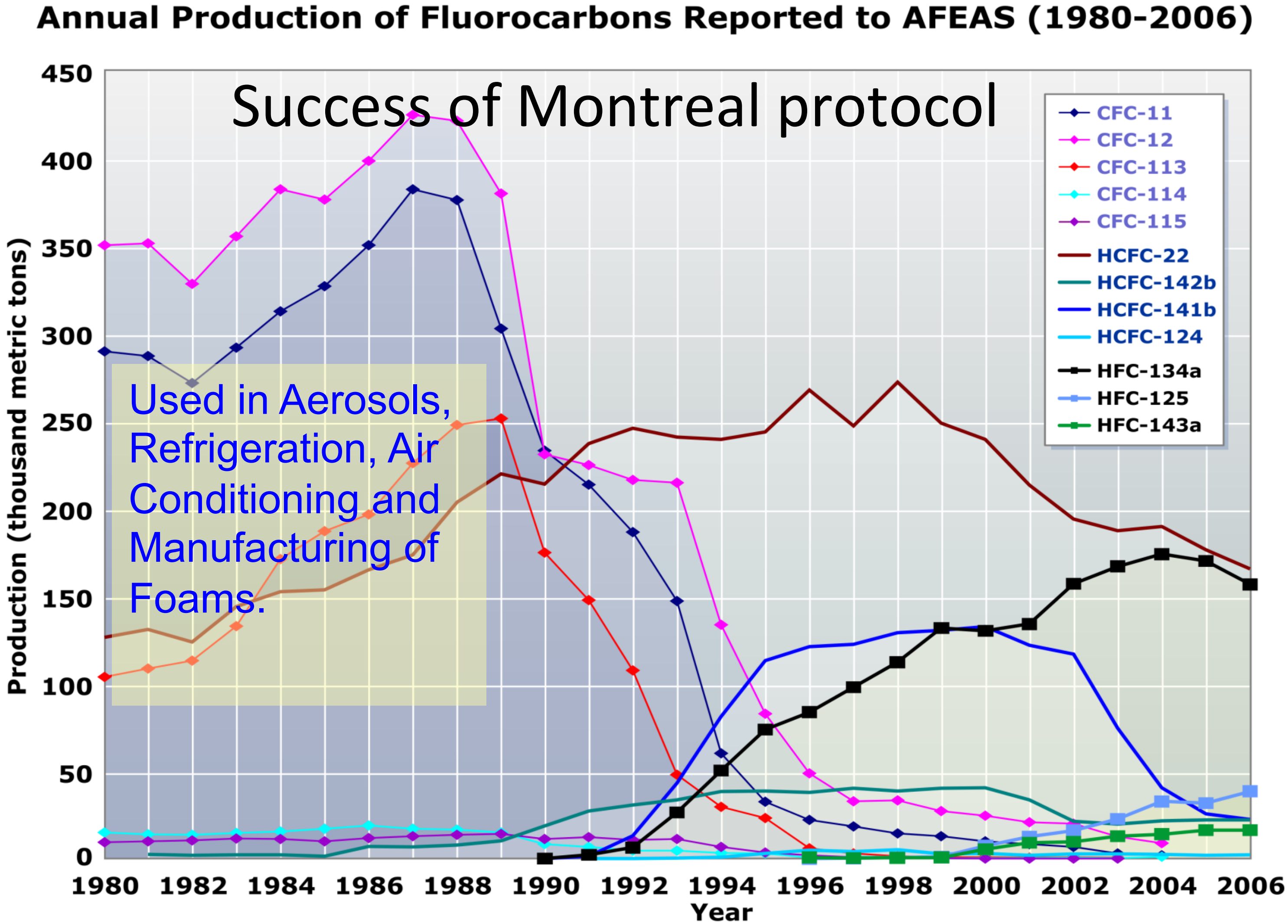


Experimental evidence

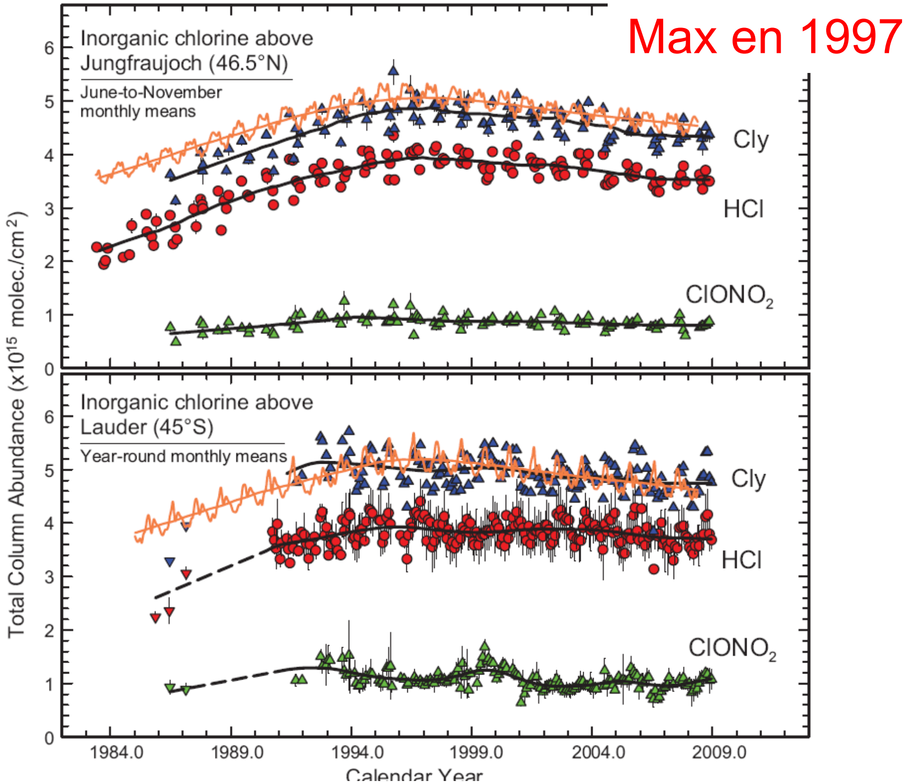
Ozone and reactive chlorine measurements from a flight through the ozone hole in Antarctica, 1987






Annual Production of Fluorocarbons Reported to AFEAS (1980-2006)
Success of Montreal protocol
Used in Aerosols, Refrigeration, Air Conditioning and Manufacturing of Foams.
Production (thousand metric tons)
Year
0
50
100
150
200
250
300
350
400
450
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
CFC-11
CFC-12
CFC-113
CFC-114
CFC-115
HCFC-22
HCFC-142b
HCFC-141b
HCFC-124
HFC-134a
HFC-125
HFC-143a

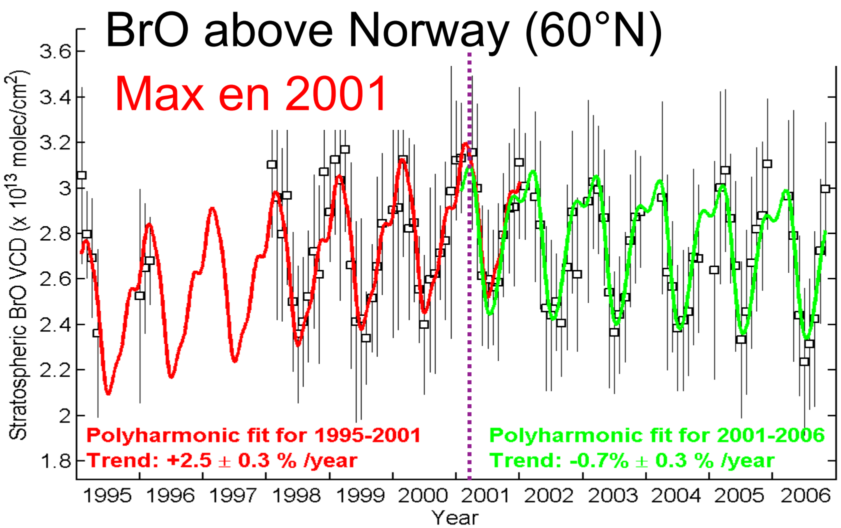
Effect of Montreal Protocol



Courtesy: Univ. Liège

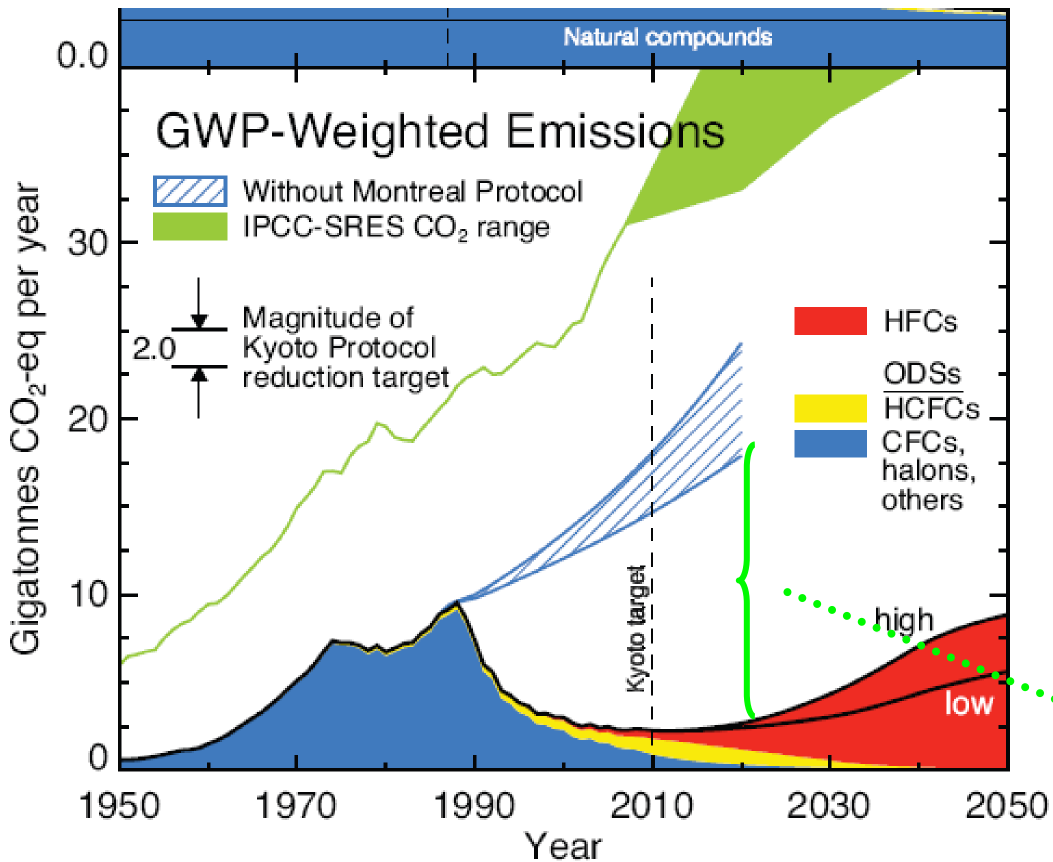
Reduction of chlorine and bromine in the stratosphere follows decrease of concentrations of the surface with a delay of 3 to 5 years

= time to reach from troposphere stratosphere.



Courtesy: F. Hendrick, IASB

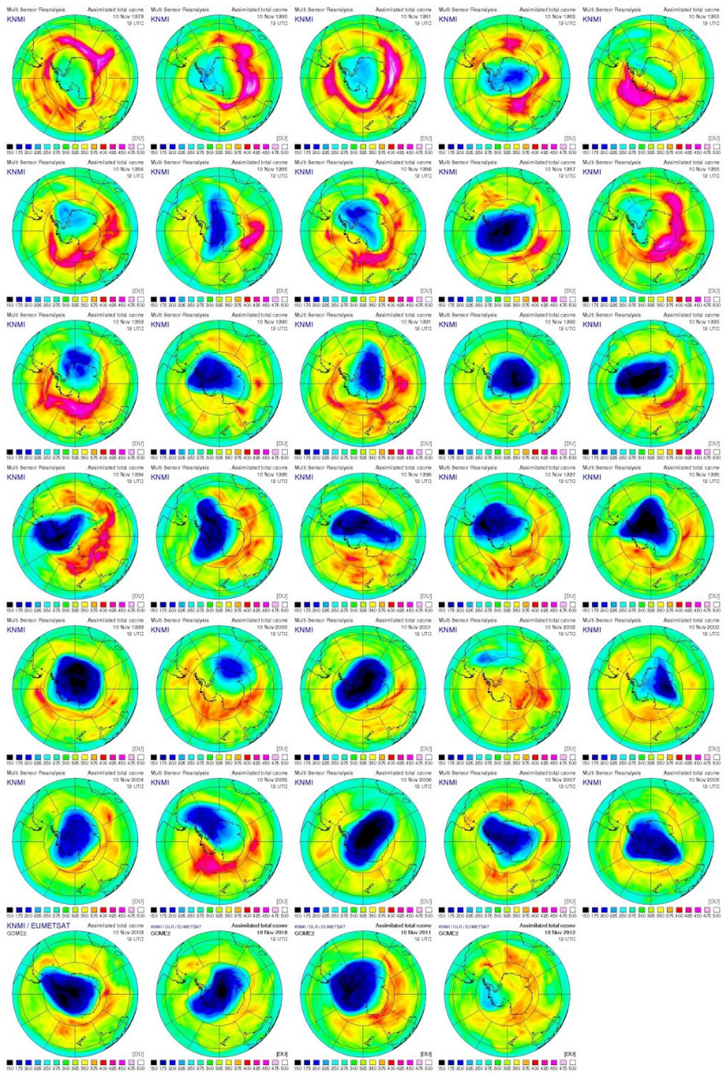
Success of the Montreal Protocol

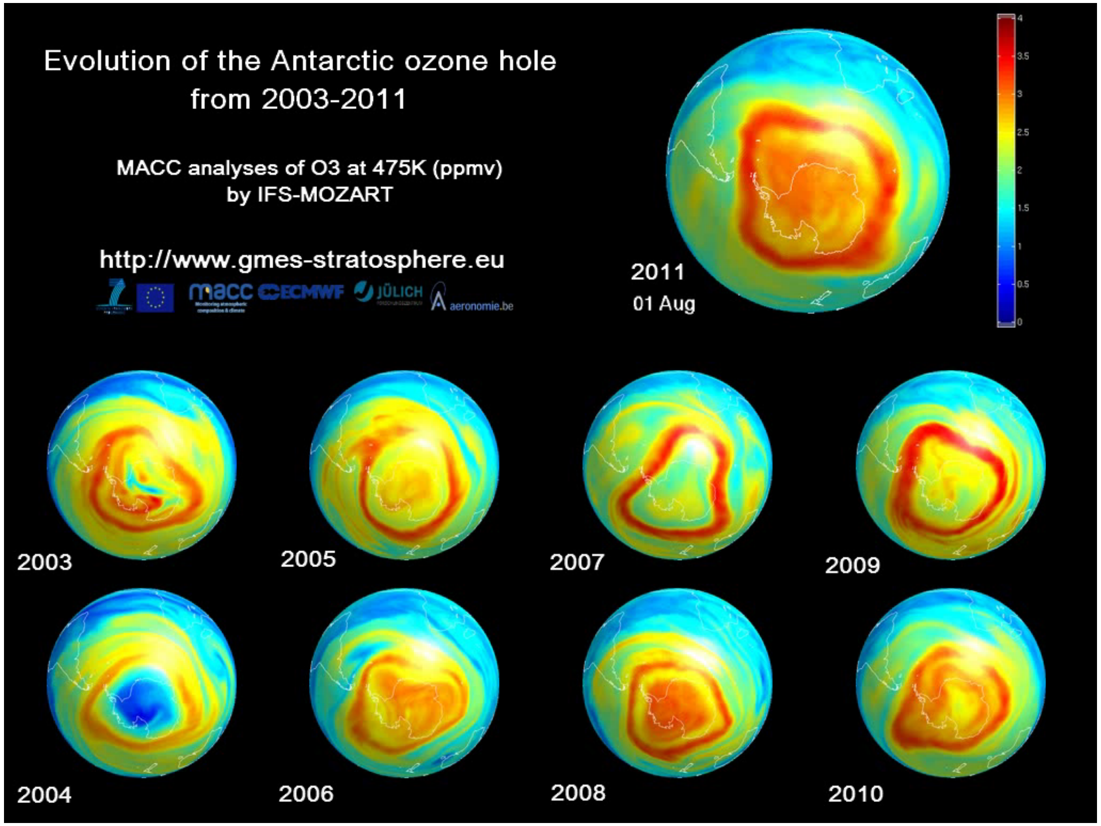


The impact of the Montreal Protocol on climate is of order 5-6 times larger than the objectives of the Kyoto Protocol 2008-2012 !

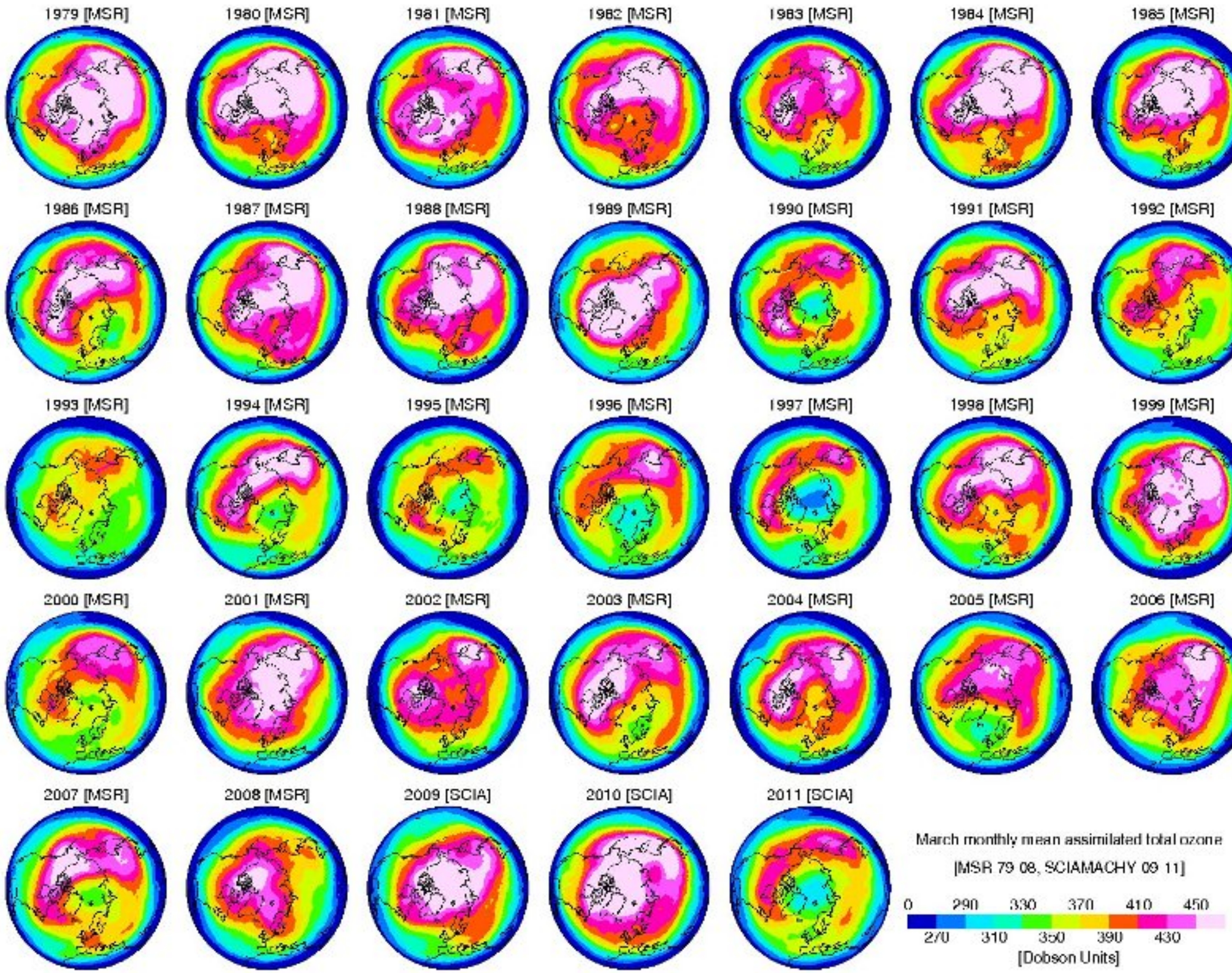
Reduction by Montreal Protocol of ~12 $GtCO_2$-eq/yr

Monitoring of the ozone hole using satellites and models



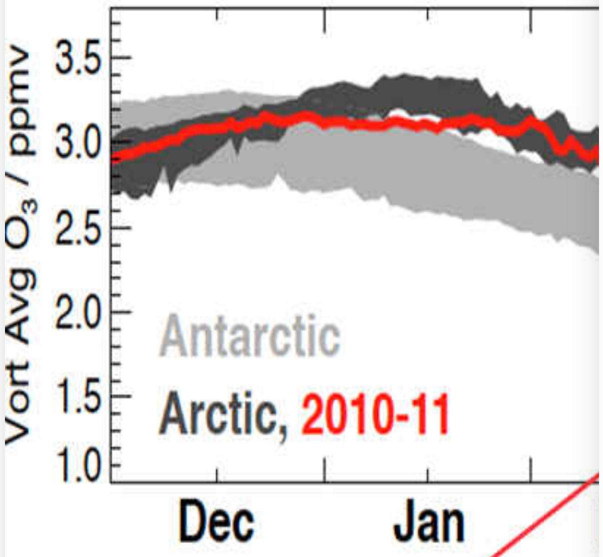


Evolution of the Spring polar ozone over the North Pole from 1979 until 2011



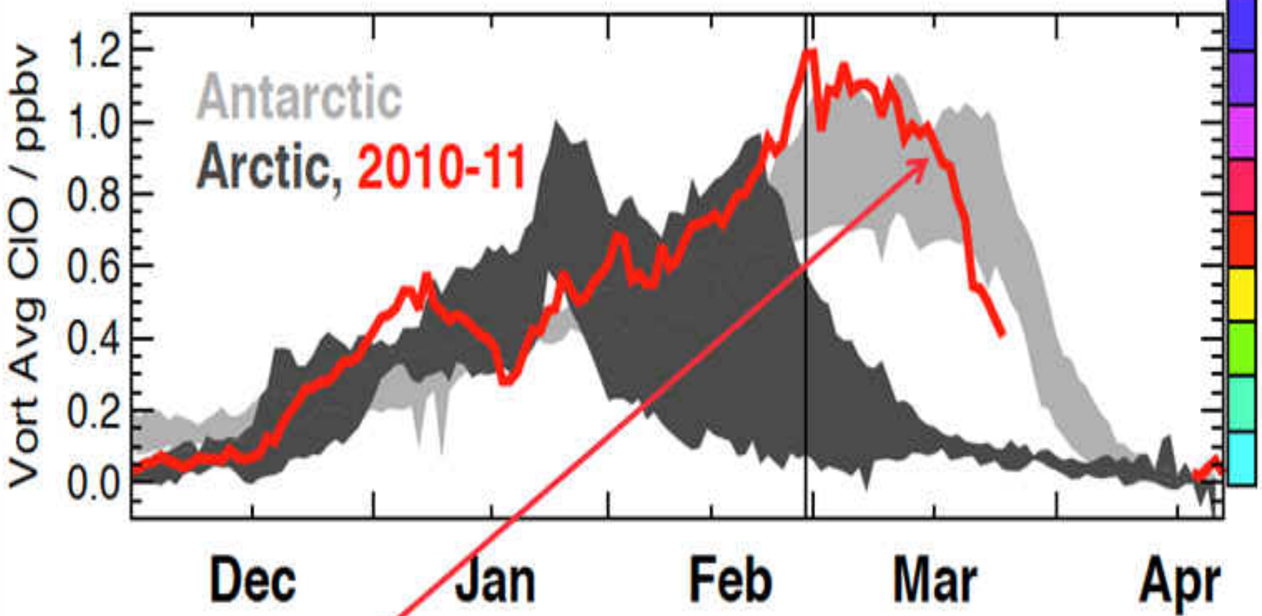
MACC/MSR, KNMI

Ozone



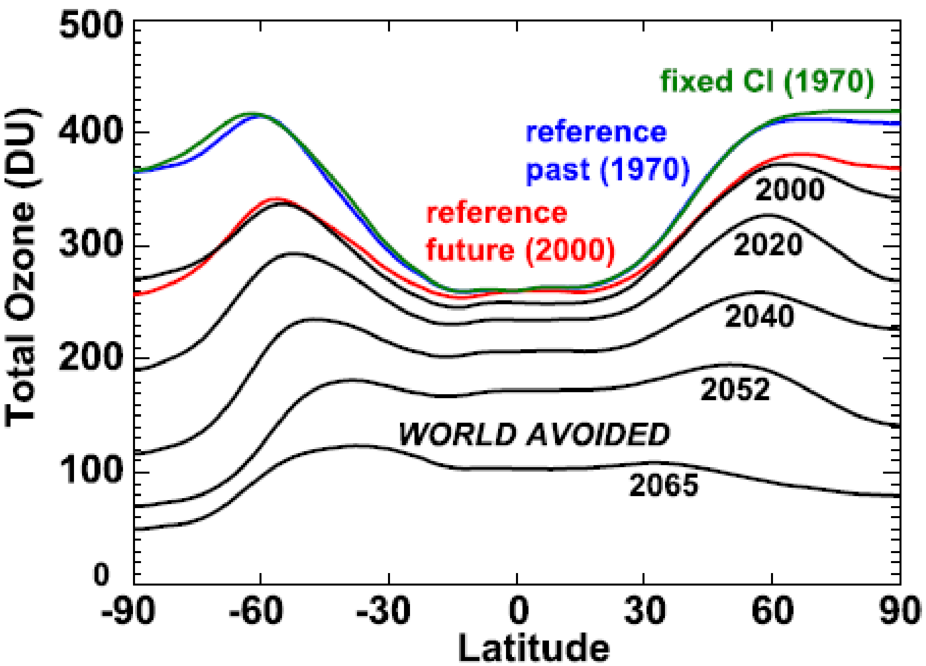
Arctic Ozone in 2011 was
2005-2010 winter observ
as Antarctic ozone.

MLS Chlorine Monoxide

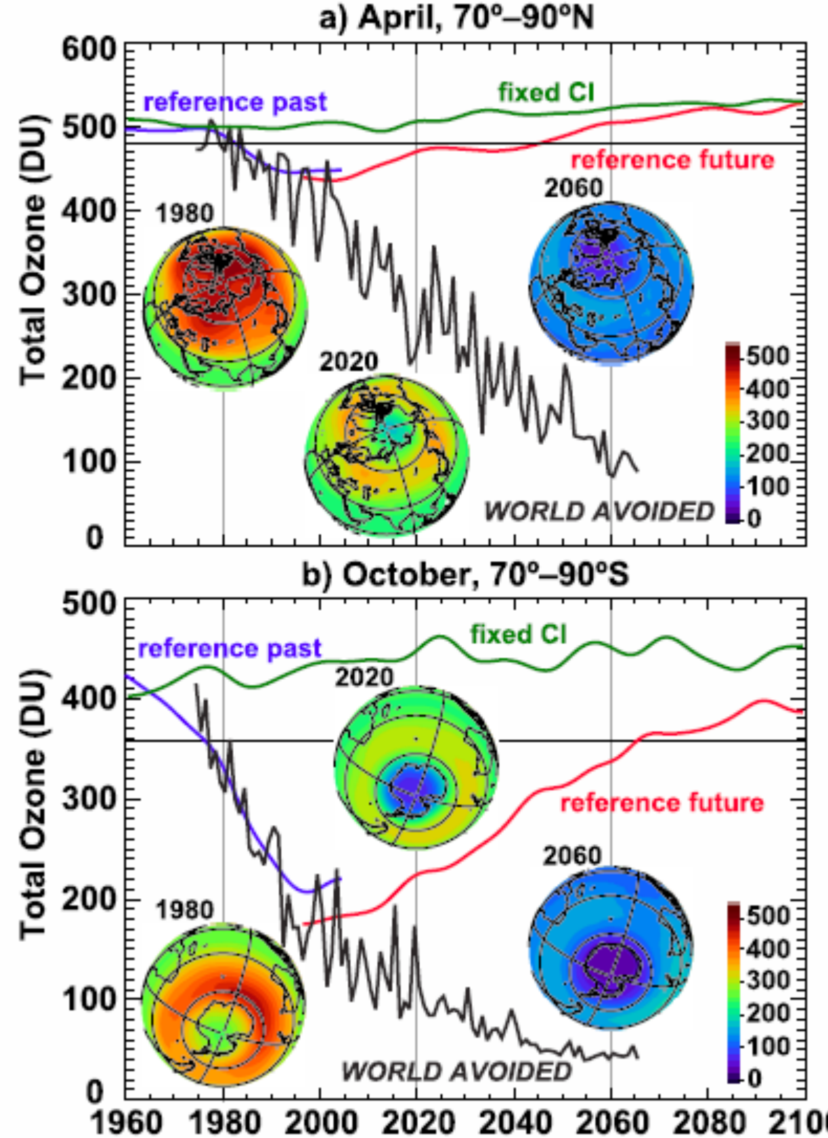


Arctic ClO in 2011 was outside the range of the 2005-2010 winter observations, and comparable to Antarctic ClO.

What would have happene chlorofluorocarbons (CFCs) h



Newman et al., ACP, 2009



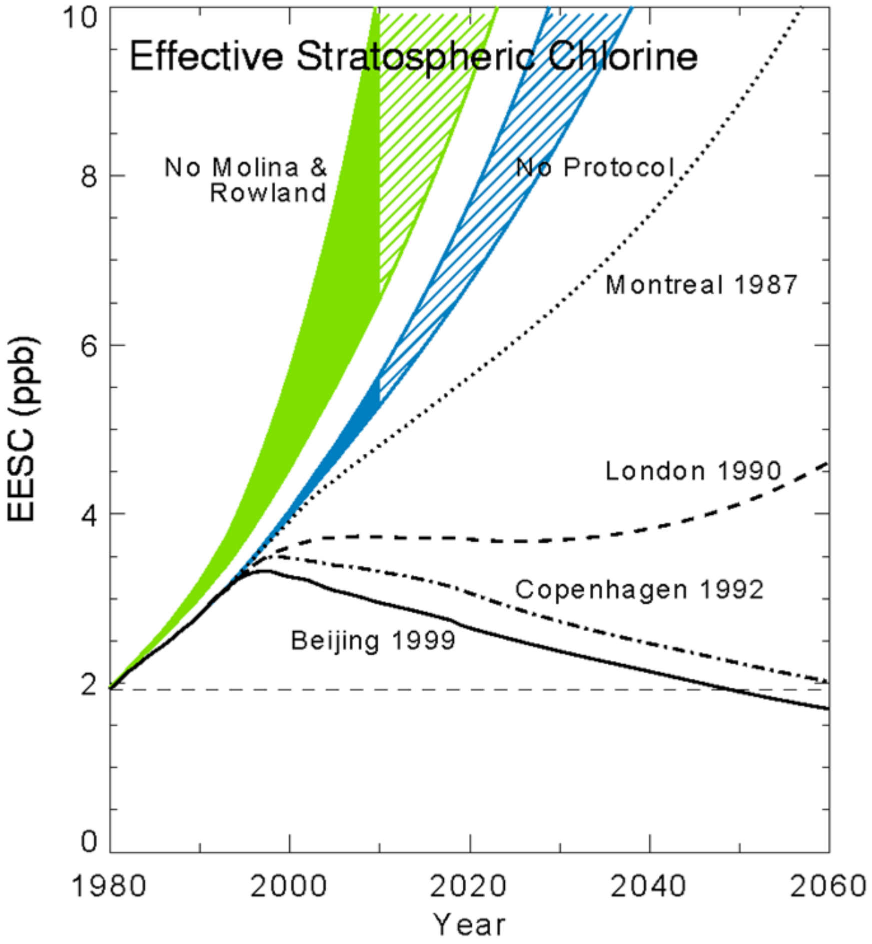
Current situation

- O_3 in the middle latitude:
  - 6% (3.5%) lower than average in 1964-1980 SH (NH)
  - UV has not increased since the late 1990s
- O_3 hole at the poles is still as in early 1990 (subject variability) i.e. in Antarctica in October, 40% lower than in 1980
- UV on Antarctic is higher by 55 to 85% than in 1963-1980
- Evidences for changes in SH tropospheric summertime circulation due to Antarctic ozone hole
- The stratosphere has cooled a few K between 1980 and 1995 due to ozone depletion; the cooling reinforced by increasing GHG esp. in recent years

Coupling between ozone and climate

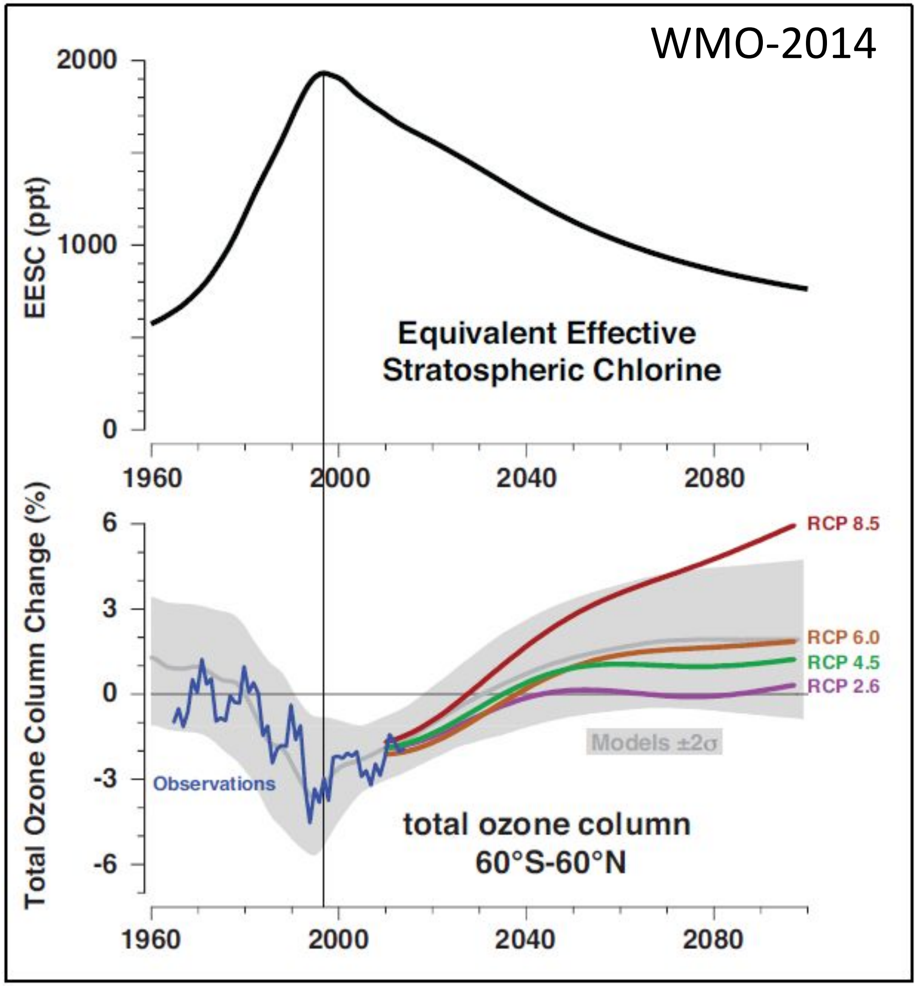
- Concentrations of greenhouse gases (CO_2, CH_4, N_2O,...) rise
- T°rises at the surface; but decreases in the stratosphere
- Atmospheric transport changes, rate of chemical reactions changes
- Frequency of formation of clouds, aerosols and PSC change
- Radiation balance changes
- Ozone formation / degradation is influenced, in turn ozone affects UV, T°stratosphere ....

Future evolution of ODS



- EESC back to 1980 levels:
  - in ~2050
  - in ~2065 at the poles (older air)

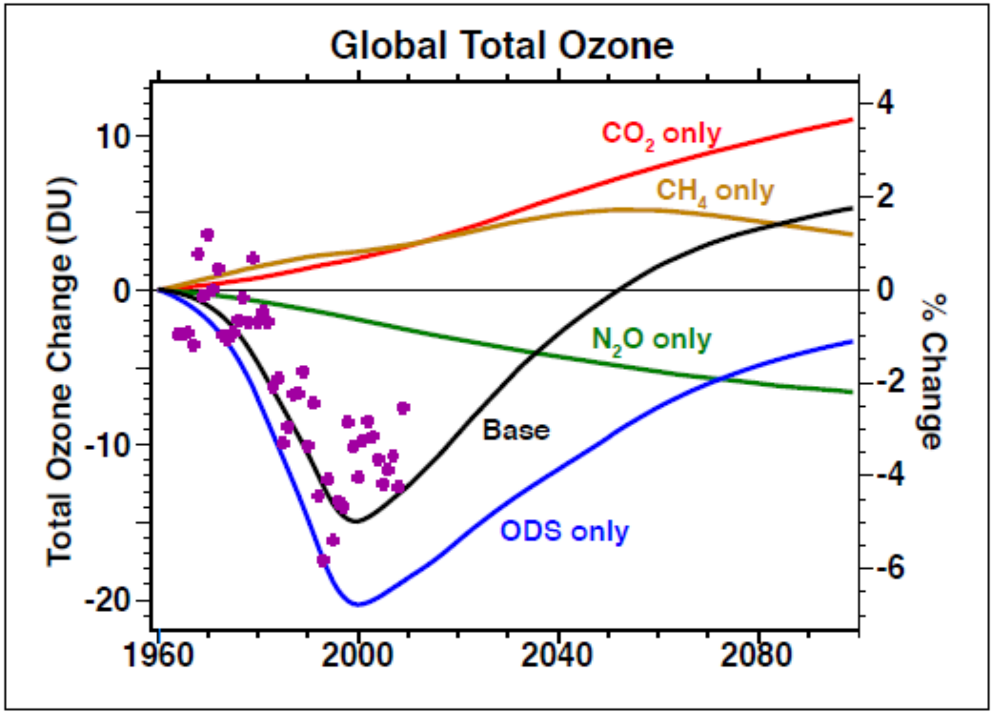
Future evolution of mid-latitude ozone



Average total column ozone changes over the same period, from multiple model simulations compared with observations between 1965 and 2013.

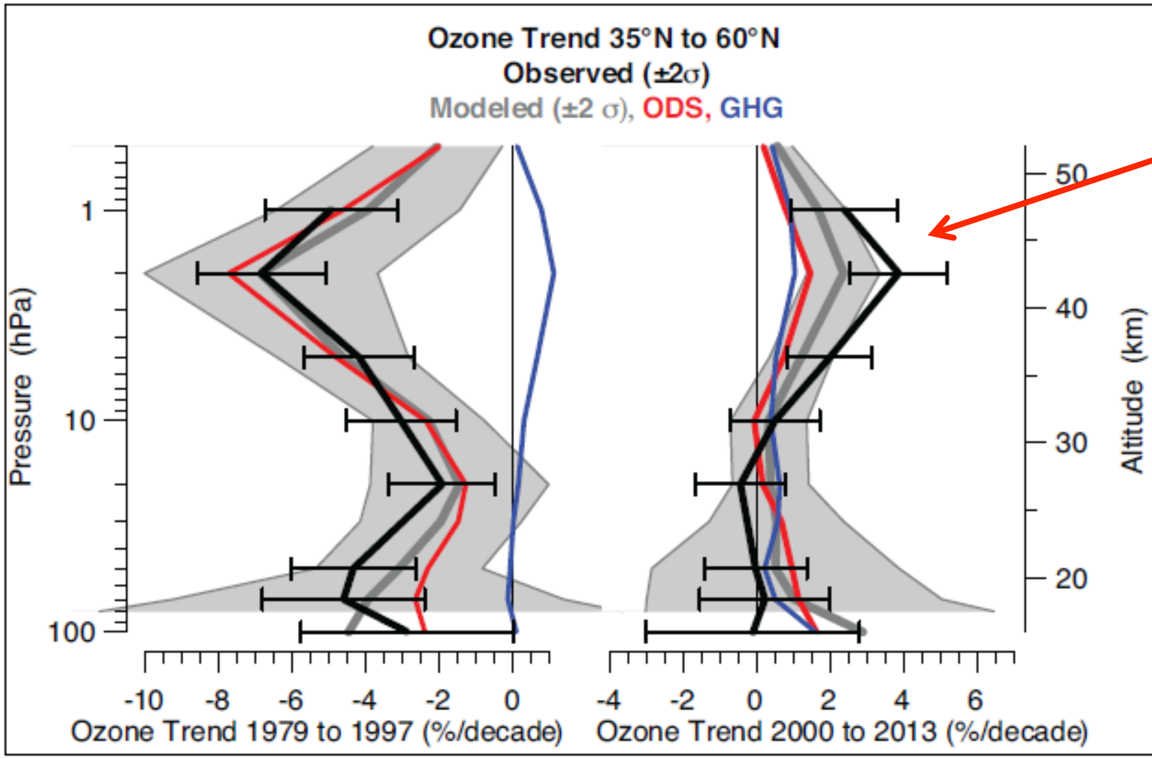
Four possible greenhouse gas (CO_2, CH_4, and N_2O) futures are shown. The four scenarios correspond to +2.6 (**purple**), +4.5 (**green**), +6.0 (**brown**), and +8.5 (**red**) W m^{-2} of global radiative forcing

Impact of projected changes in GHGs on ozone



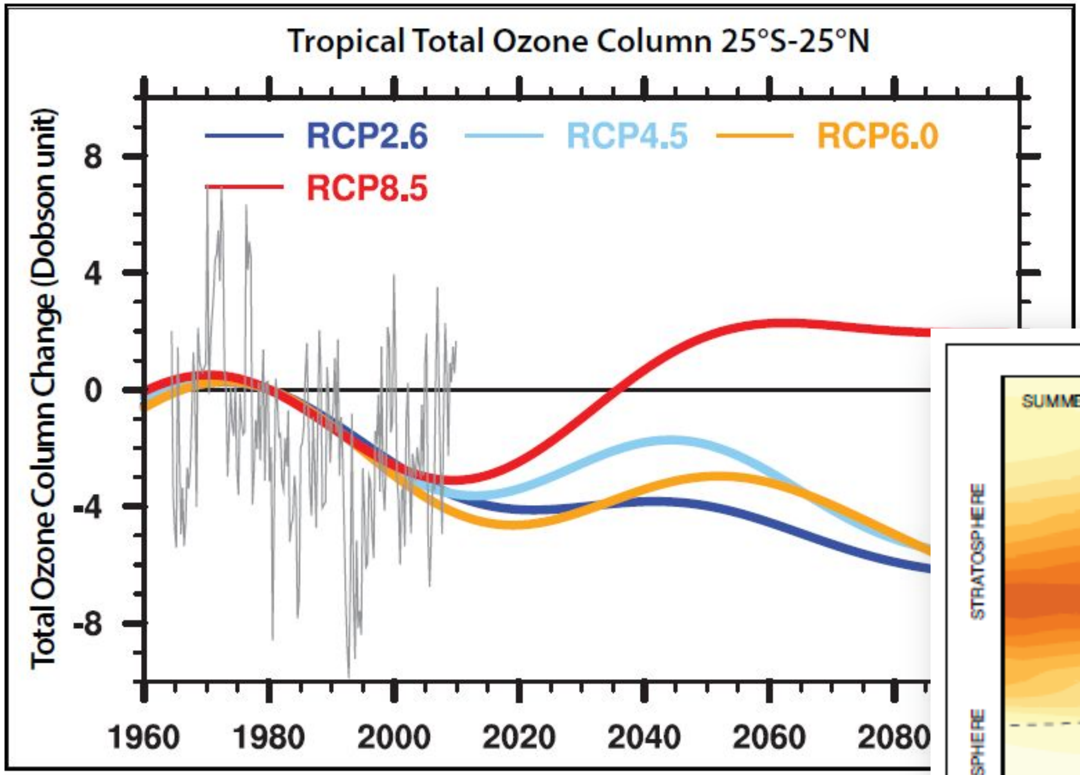
- Increased CO_2, CH_4 and N_2O cools the stratosphere, which tends to increase O_3 because of temperature-dependent chemistry (reduced efficiency of loss)
- Increased CH_4 and N_2O also have further chemical impact on O_3
  - CH_4 increases O_3 by mitigating the effect of halogen-driven O_3 destruction catalytic cycles
  - N_2O decreases O_3 through enhancing the efficiency of the NOx-driven catalytic cycles

Evidence for O_3 recovery in upper stratosphere

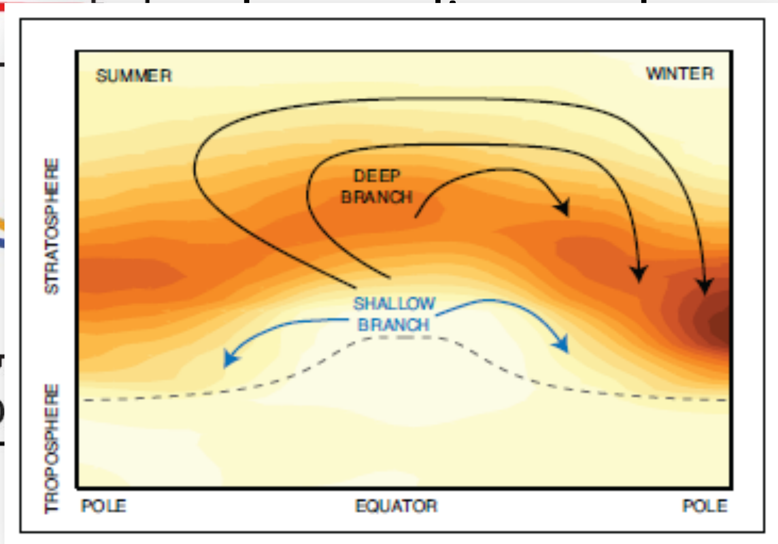


O_3 recovery at 45 km altitude is due to combination of reduction in ODS (Montreal protocol) reinforced by cooling due to GHG increase

Predicted reduction of the tropical ozone layer

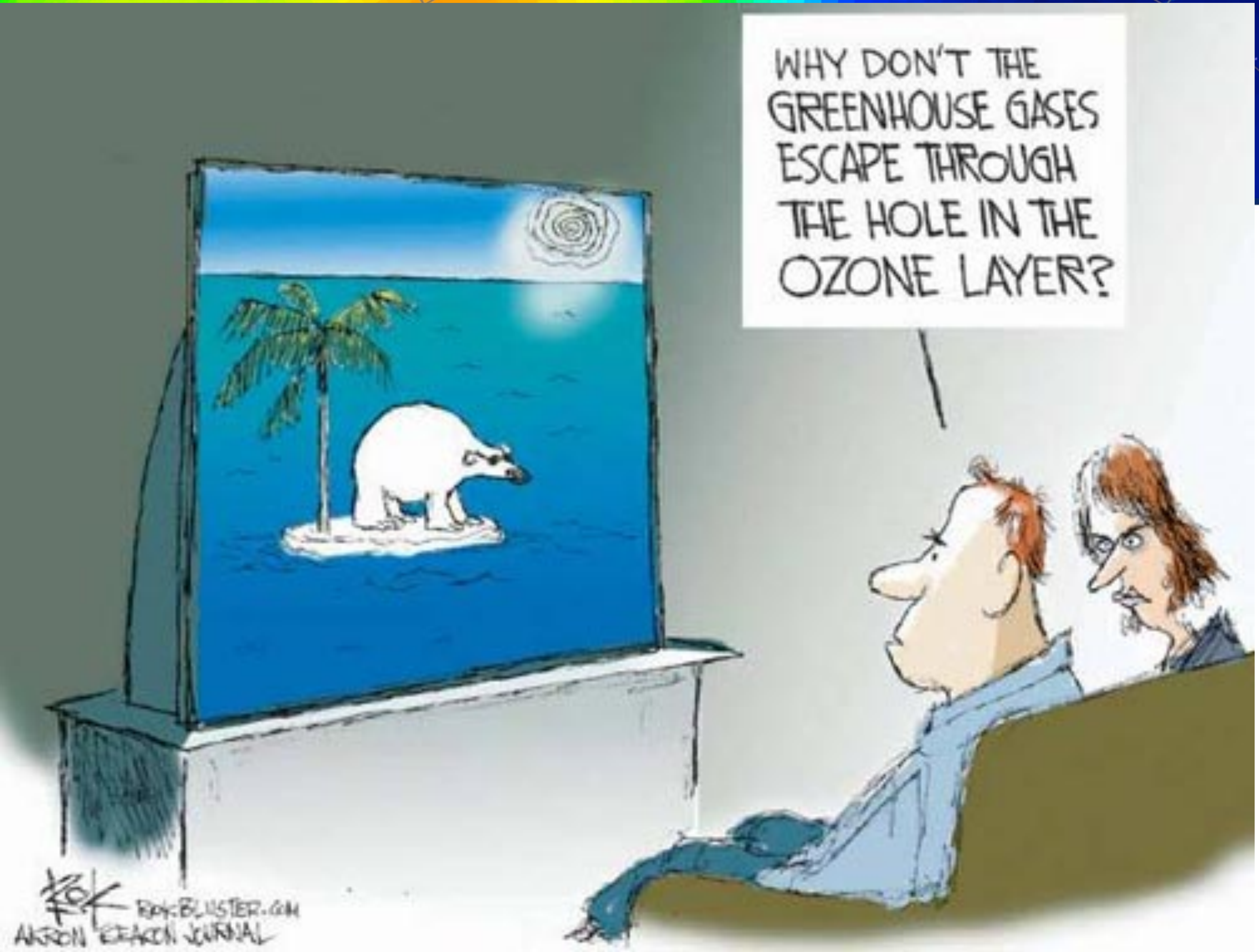


Recent evidence for changes in tropical upwelling and higher latitudes downwelling



Summary

- O_3 on a global scale will return to state from 1980 by 2050, i.e. faster than ODS, namely:
  - Around 2030-2040 in middle latitudes of both hemispheres
  - Around 2045-2060 in Antarctica
  - The increase of ozone will be accelerated in a colder stratosphere under the impact of GHGs
- As result, at the end of the 21st century the stratospheric ozone concentration will be higher than in 1980
- Tropical ozone is expected to decrease due to climate-change induced changes in the Dobson-Brewer circulation
- The climate benefits of the Montreal Protocol could be significantly offset by projected emissions of HFCs used to replace ODSs
- Large uncertainties in future emission scenarios and resulting impacts



There are links between the stratospheric ozone evolution and climate change, and air pollution and atmospheric transport, and …
These effects make the scientific questions much more complicated, and make it very difficult to design the best mitigation policies.