The Importance of Balloon-Based Observations in Stratospheric Research

Martyn Chipperfield

Benefits of balloon observations:
- High resolution vertical profiles to ~35 km
- Long-term datasets
- Observations worldwide
- Large, complementary payloads

Examples:
- Polar ozone loss
- Denitrification
- Stratospheric bromine trends
- Climate change and stratospheric circulation?

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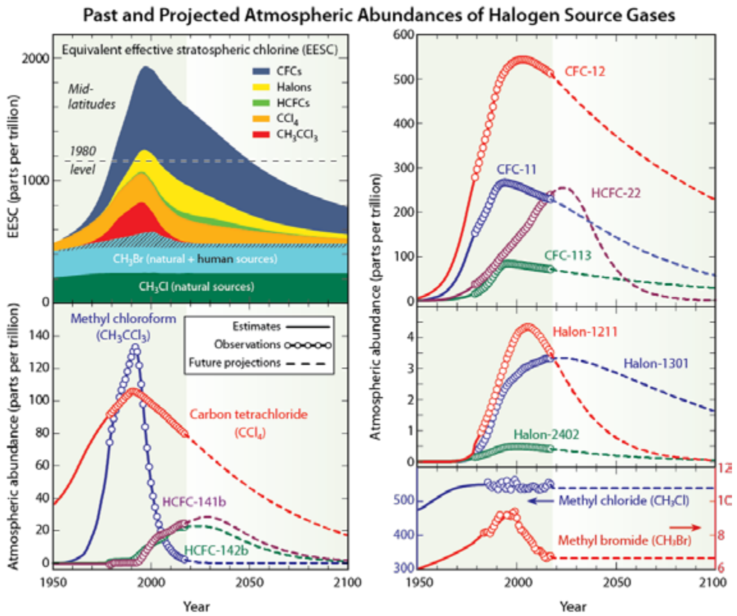
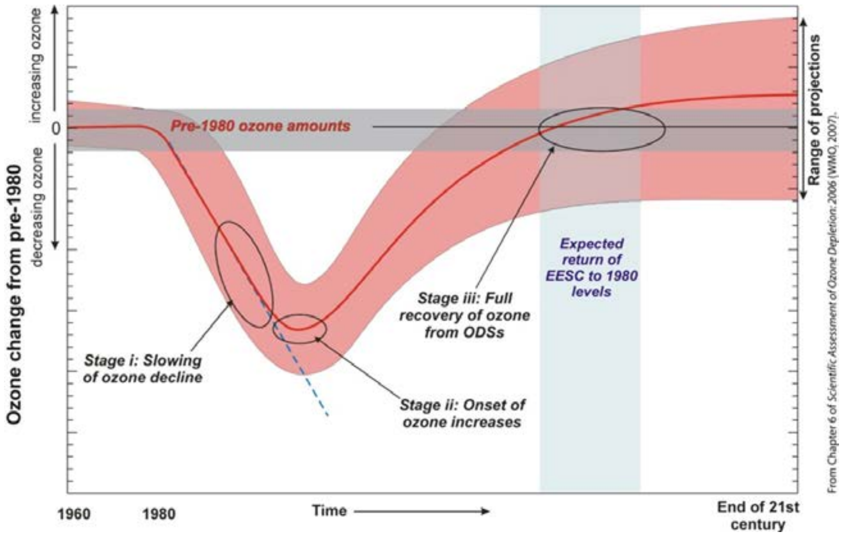
NATURAL ENVIRONMENT RESEARCH COUNCIL

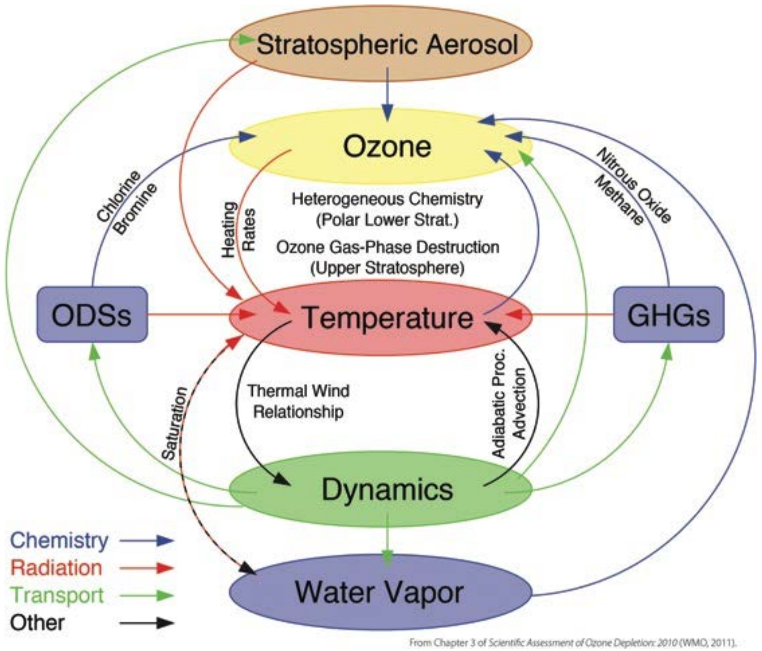
Major Issues in Stratospheric Science



Montreal Protocol has controlled ozone-depleting substances



Ozone is just starting to recover from past depletion



But there are also two-way chemistry-climate interactions

Polar Ozone - Discovery

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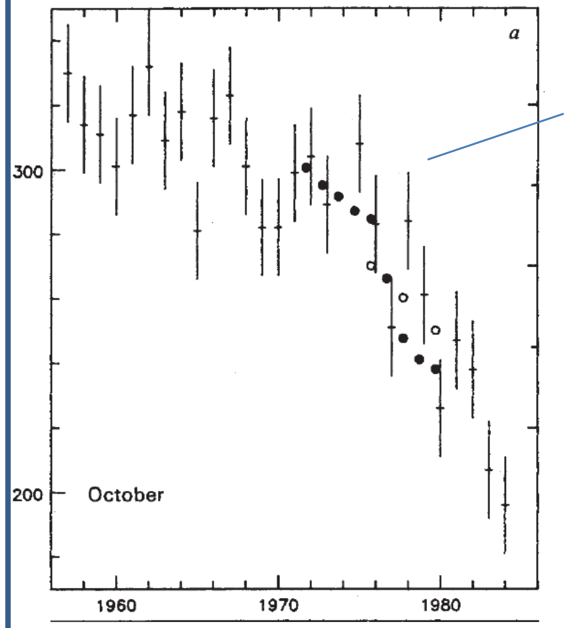
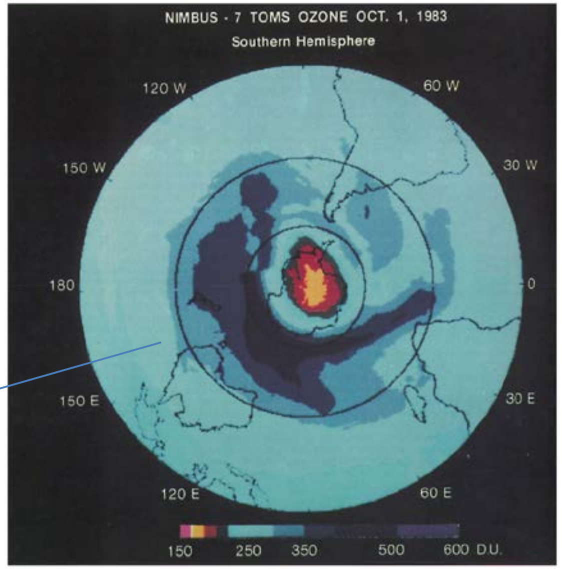
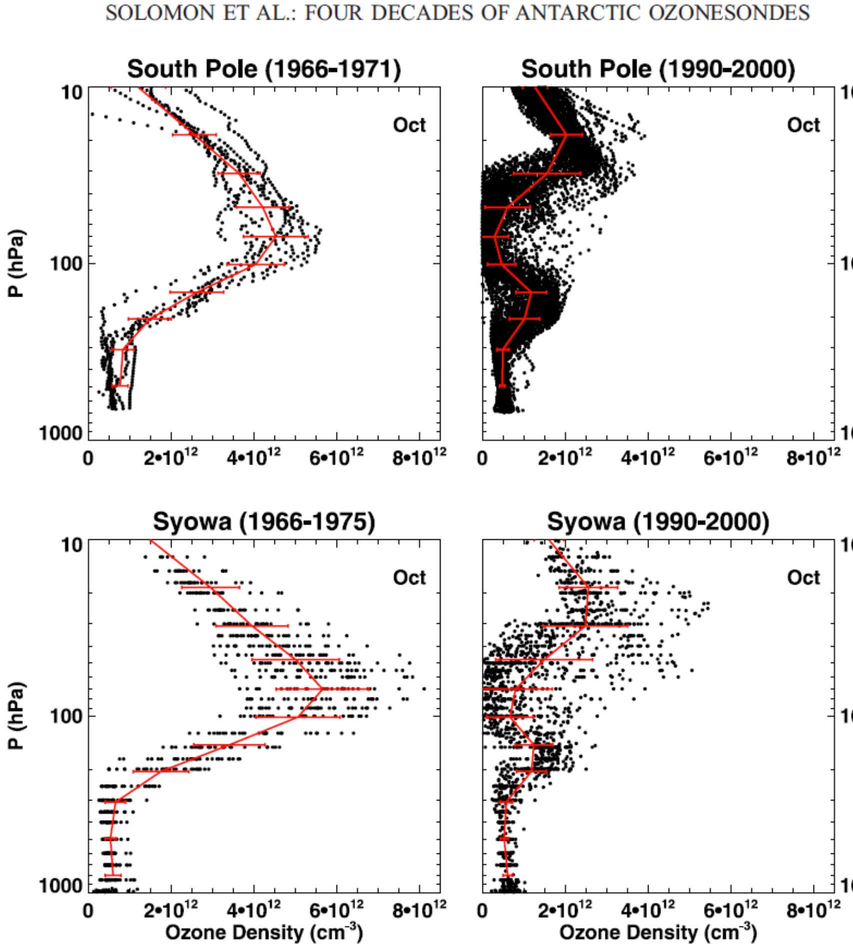
Balloon ozone sondes were essential in revealing the altitude of ozone depletion in campaigns around 1986



Farman et al (1985)
Ozone hole discovered from ground-based column data



Early satellite plots of ozone column



Solomon et al (2005)

Polar Ozone – South Pole Ozone Sondes

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Regular NOAA ozone sondes at South Pole

High vertical resolution

Long timeseries

Polar Ozone - Recovery

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OZONE HOLE

Emergence of healing in the Antarctic ozone layer

Susan Solomon,[1*] Diane J. Ivy,[1] Doug Kinnison,[2] Michael J. Mills,[2] Ryan R. Neely III,[3,4] Anja Schmidt[3]

Sonde data important for confirming 'fingerprint' of decreasing chemical ozone loss in Antarctic

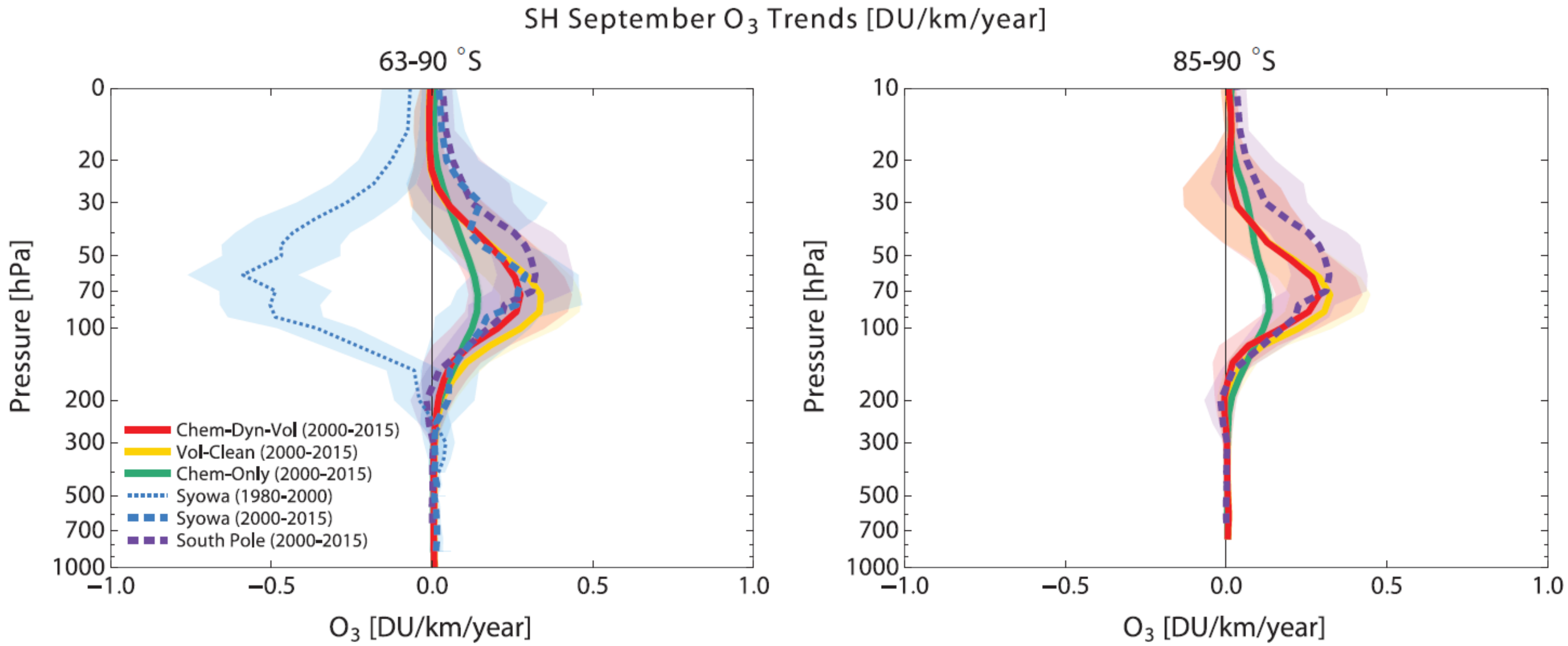

Fig. 2. Trends in Southern Hemisphere (SH) polar cap ozone profiles in September. Ozone data from balloons at the Syowa (69°S, 39.58°E) (**Left**) and South Pole (**Right**) stations, along with model simulations averaged over the polar cap and over 85°S to 90°S, respectively, are shown versus pressure. The shading represents the uncertainties on the trends at the 90% statistical confidence interval.

Solomon et al. (Science, 2016)

Polar Ozone - Denitrification

- MIPAS-B balloon flight – Kiruna (67°N) Feb 11th 1995.
- Limb IR observations of NO_2, HNO_3, $ClONO_2$, N_2O_5, HO_2NO_2, N_2O and CH_4.
- Near complete coverage of stratospheric nitrogen species (NOy).
- Complementary long-lived tracer data essential for dynamics and reference atmosphere.
- Allows determination of '**denitrification**' mechanism – process by which sedimenting polar stratospheric clouds (PSCs) remove condensed HNO_3. Enhances ozone loss.

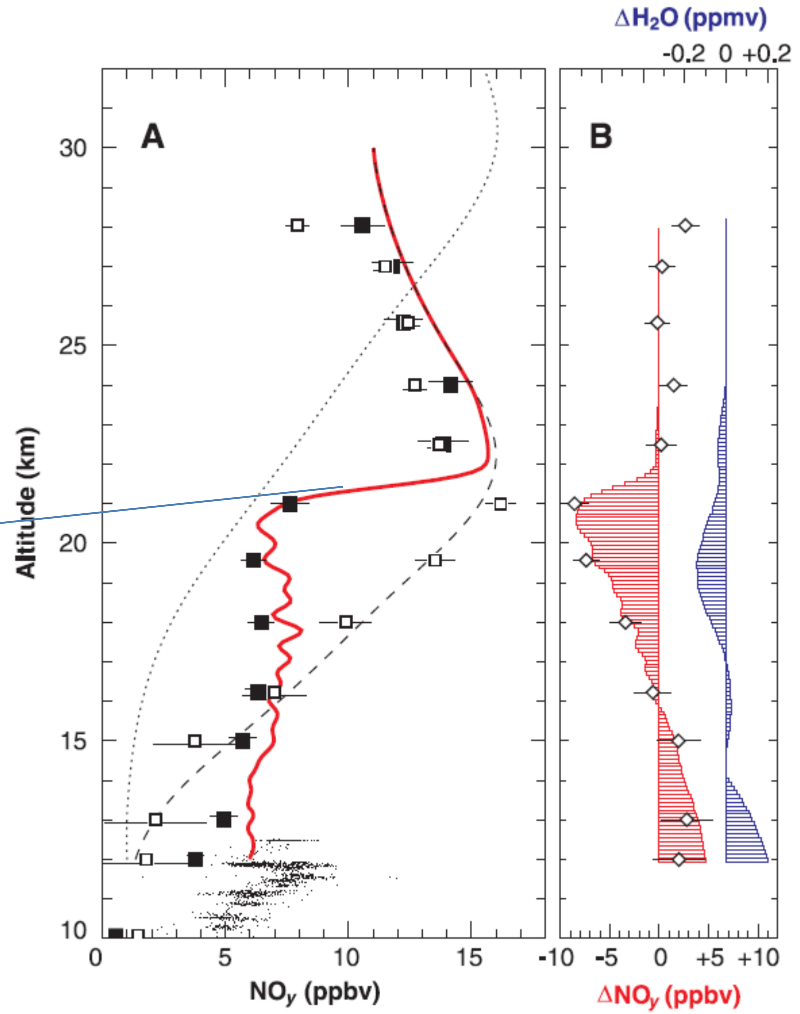

Fig. 1. (**A**) Arctic NO_y profiles in mid-February 1995. Symbols: squares, balloon-borne MIPAS-B observations (*12*); dots, aircraft-borne observations (*16*). Solid symbols are NO_y measurements; open symbols mark NO_y^* deduced from MIPAS N_2O measurements (*13*). NO_y^* represents the unperturbed case (without denitrification). The model calculations are denoted by lines [dotted line, mid-latitude reference NO_y profile (*28*); dashed line, scenario 0 with subsidence of air only (no particle sedimentation); red line, scenario 3 showing the effect of denitrification due to sedimenting ice and NAT particles]. (**B**) Vertical redistribution of NO_y (red) and H_2O (blue). In addition, measured ΔNO_y is shown (◇).

Waibel et al. (Science, 1999)

Stratospheric Bromine – Deriving Total Bromine

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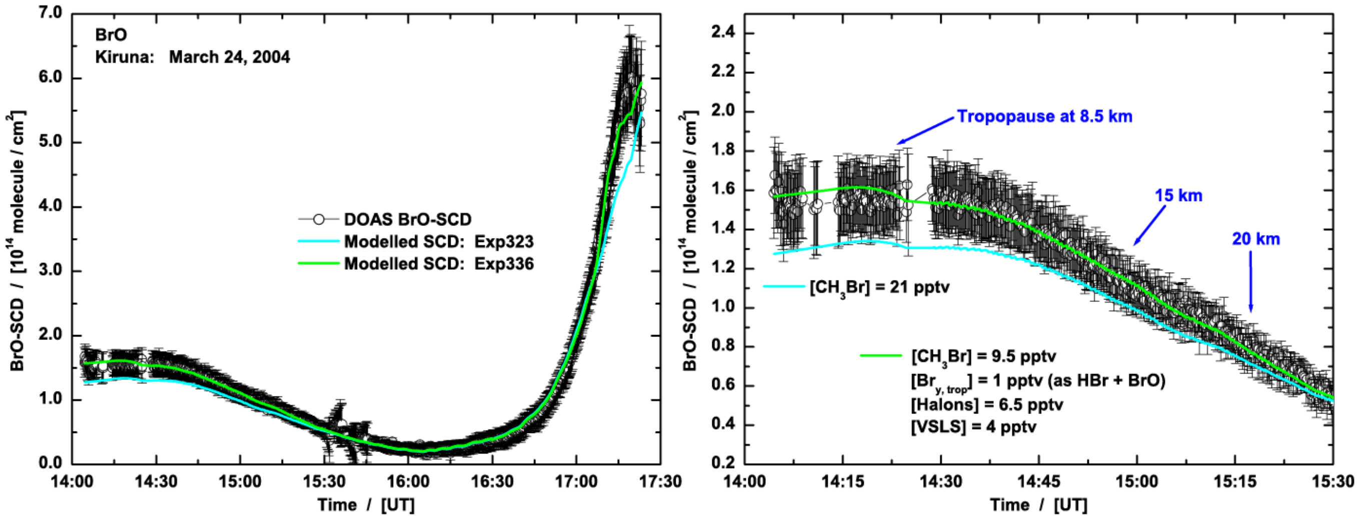
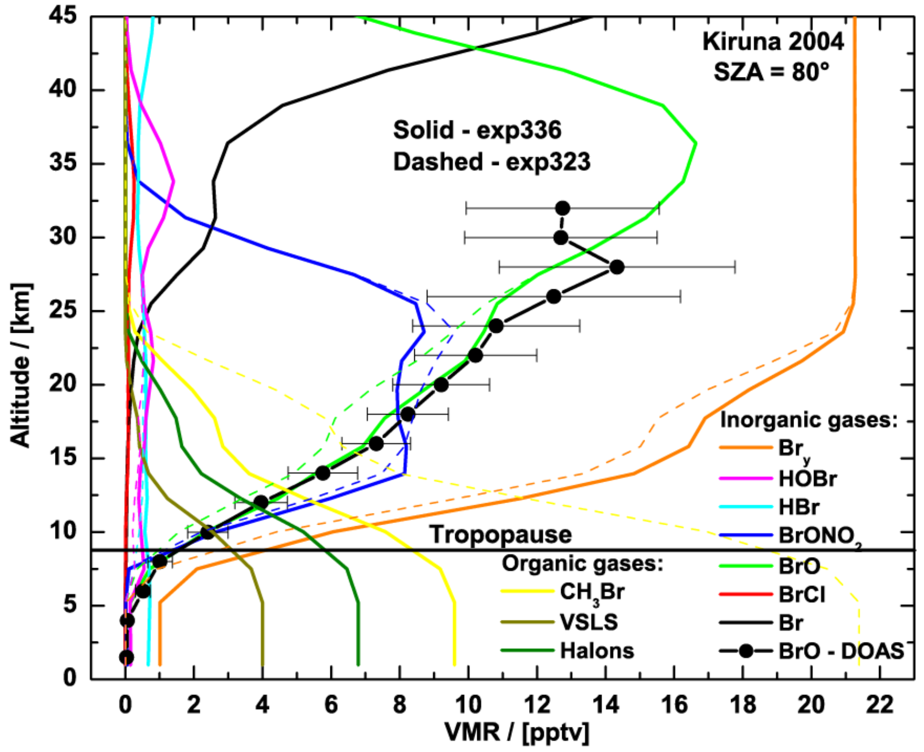
- Bromine, along with chlorine, is one of the most important species for causing ozone depletion.
- Among Bry species, only BrO can be well observed.
- Balloon-borne UV-vis limb BrO observations are an essential data set for allowing us to derive stratospheric bromine trends (and thereby have confidence in the Montreal Protocol and ozone recovery).

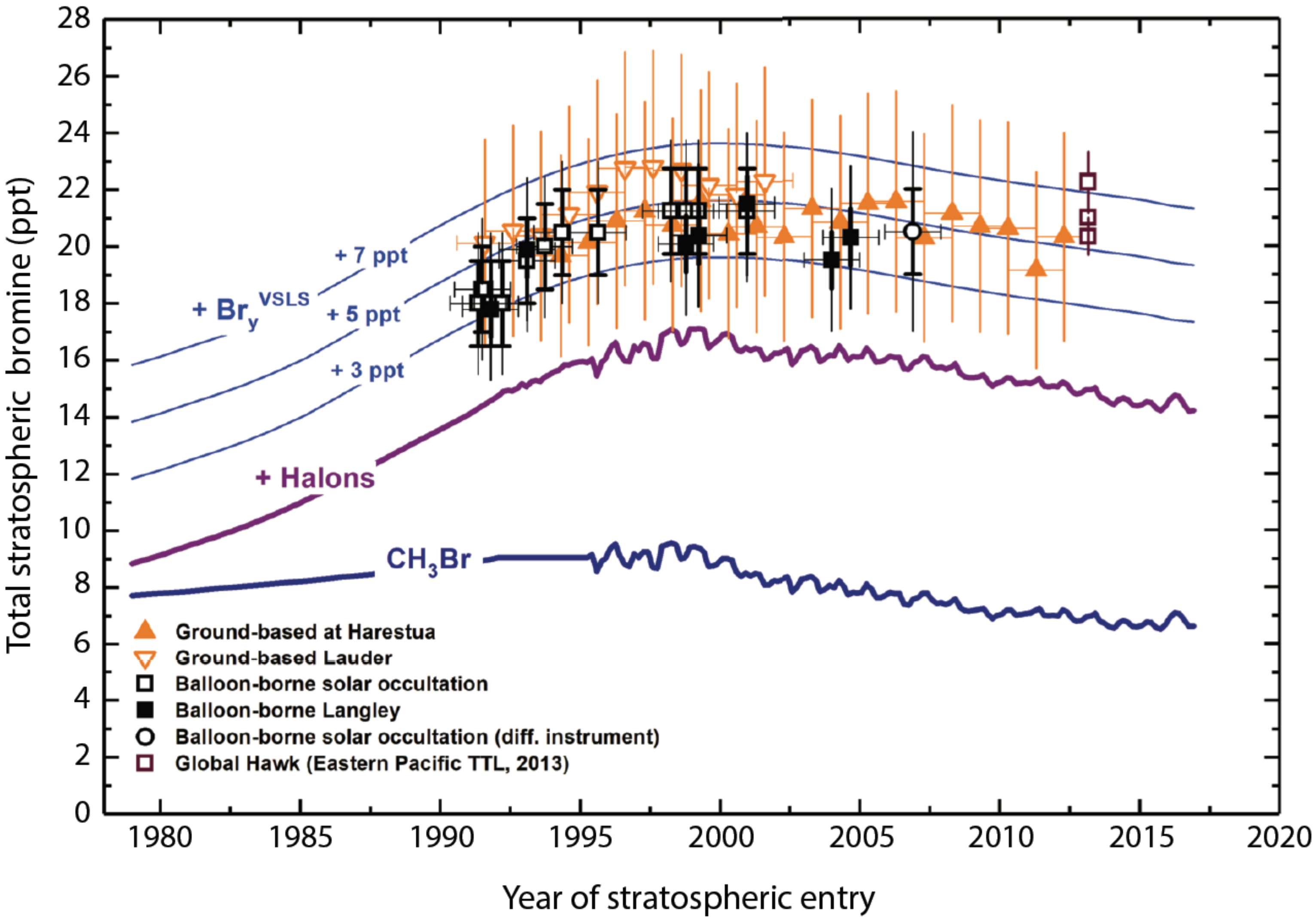




Detailed photochemical modelling to convert BrO to Bry

Dorf et al., GRL, doi:10.1029/2006GL027714, 2006.

Stratospheric Bromine – Long-Term Variation



Update of Dorf et al. (2006)

Evidence that stratospheric bromine is decreasing, but important to continue to monitor (e.g. as large contribution from natural very short-lived species (VSLS), which may change…)

WMO/UNEP (2018)

Balloons as Dynamical Tracers - Vorcore

- Long duration superpressure balloons
- 27 flights in Antarctic vortex in spring 2005
- Reveal Lagrangian dynamics of polar vortex

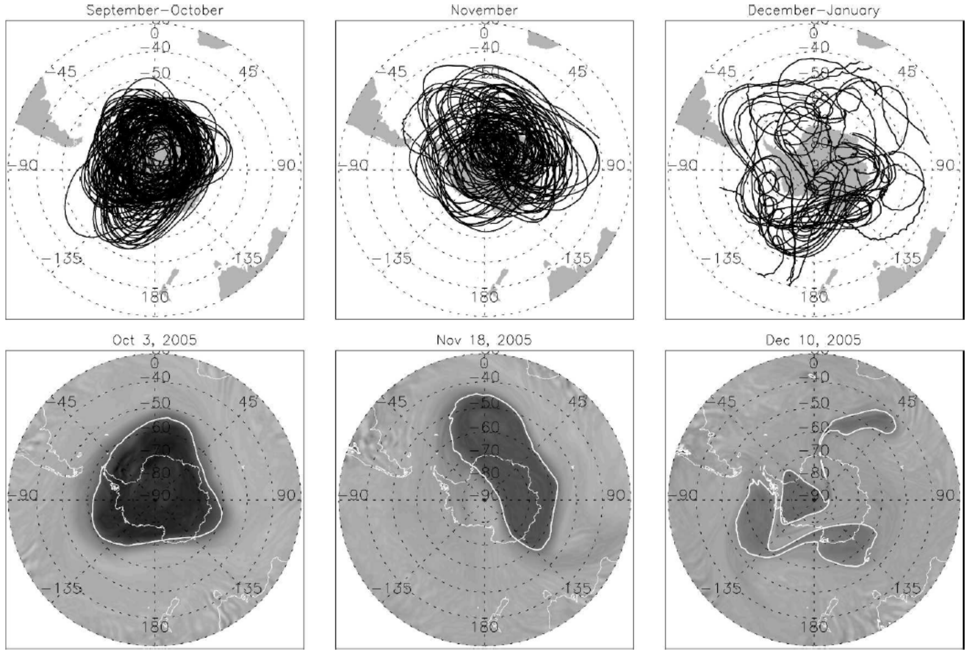


FIG. 8. (top) Geographical distribution of Vorcore balloon observations in (left) September–October, (middle) November, and (right) December–January. (bottom) Potential vorticity analyzed by ECMWF on the 475-K isentrope on days representative of the three phases of the stratospheric flow during Vorcore: (left) centered vortex, (middle) vortex displaced off the South Pole but still well defined, and (right) vortex broken up in several pieces. The thick white line represents the vortex edge as defined by the Nash et al. (1996) algorithm. The PV color code is the same on the three panels.

Stratéole/Vorcore—Long-duration, Superpressure Balloons to Study the Antarctic Lower Stratosphere during the 2005 Winter

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Hertzog et al (2007)

Changing Brewer-Dobson Circulation?

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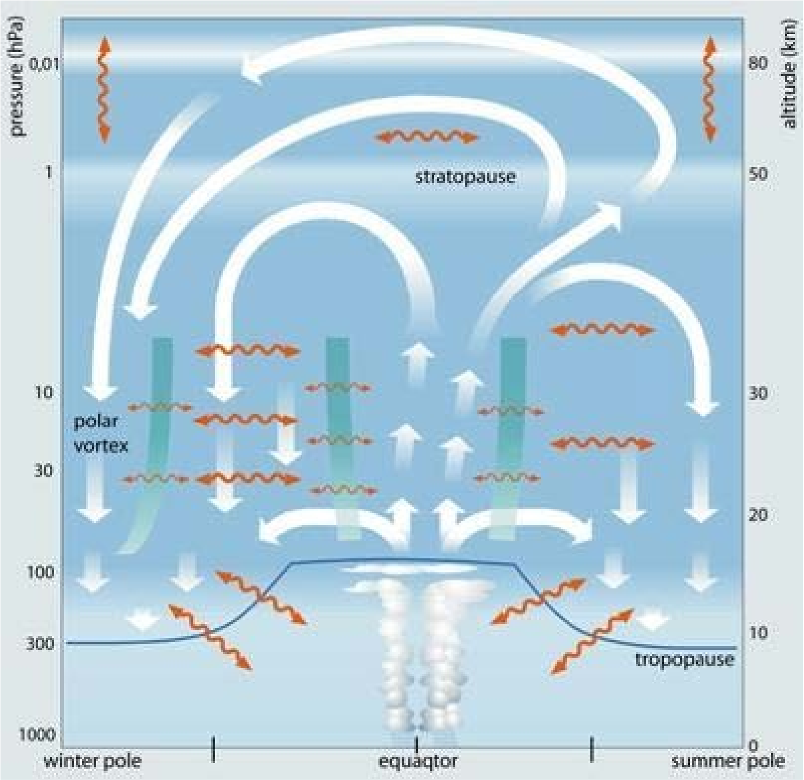

Meridional Brewer-Dobson Circulation

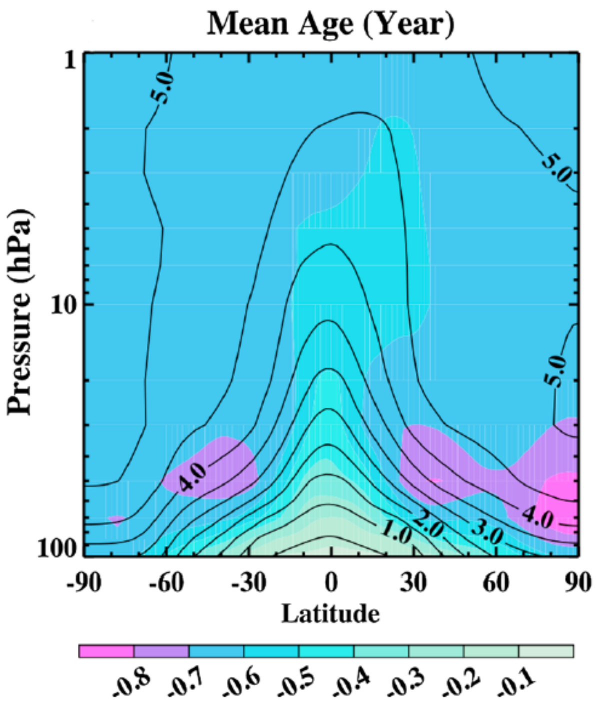

Figure 3. Annual mean age of air in years simulated by a CCM for the year 2000 (contours) and the simulated change in age from 2000 to 2080 (colors). Figure 2a from *Li et al.* [2012]. ©American Geophysical Union. Used

Stratospheric age of air (AoA)

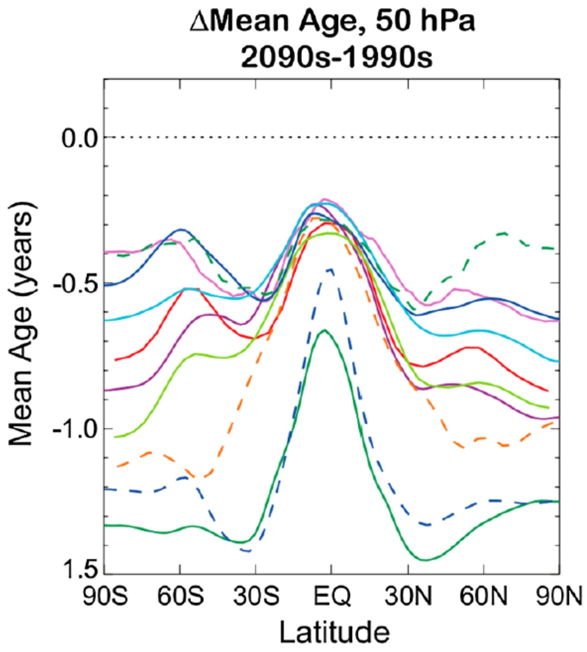

Figure 10. Mean age changes at 50 hPa during 21st century simulations from ten of the CCMs described in *Morgenstern et al.* [2011]. The mean age difference is the difference between an average of the last 10 years of the simulations (usually, 2090–2099), and an average over 1990–1999. All of the CCMs predict younger age at all latitudes at the end of the 21st century. Figure 5.18 (left panel) from *Neu et al.* [2010].

Models predict circulation will speed up – i.e. younger AoA

Changing Brewer-Dobson Circulation?

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LETTERS
PUBLISHED ONLINE: 14 DECEMBER 2008 | DOI: 10.1038/NGEO388
nature geoscience

Age of stratospheric air unchanged within uncertainties over the past 30 years

A. Engel[1]*, T. Möbius[1], H. Bönisch[1], U. Schmidt[1], R. Heinz[2], I. Levin[2], E. Atlas[3], S. Aoki[4], T. Nakazawa[4], S. Sugawara[5], F. Moore[6†], D. Hurst[6†], J. Elkins[6], S. Schauffler[7], A. Andrews[6] and K. Boering[8]

- Balloon observations of long-lived tracers (SF_6, CO_2)
- 27 flights 1975-2005; 32°N-51°N
- Data (up to then) did NOT show significant trend
- Need to continue data series…

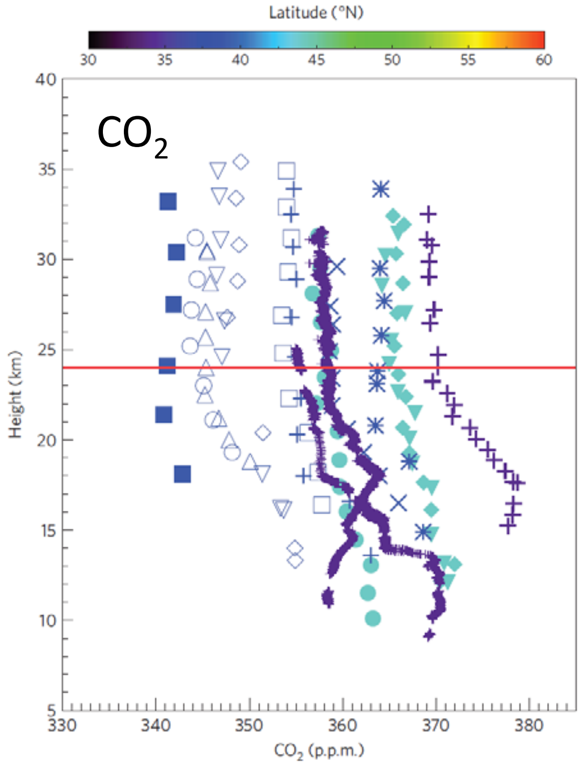

Figure 1 | Vertical profiles of CO_2 in the mid-latitude stratosphere. Data

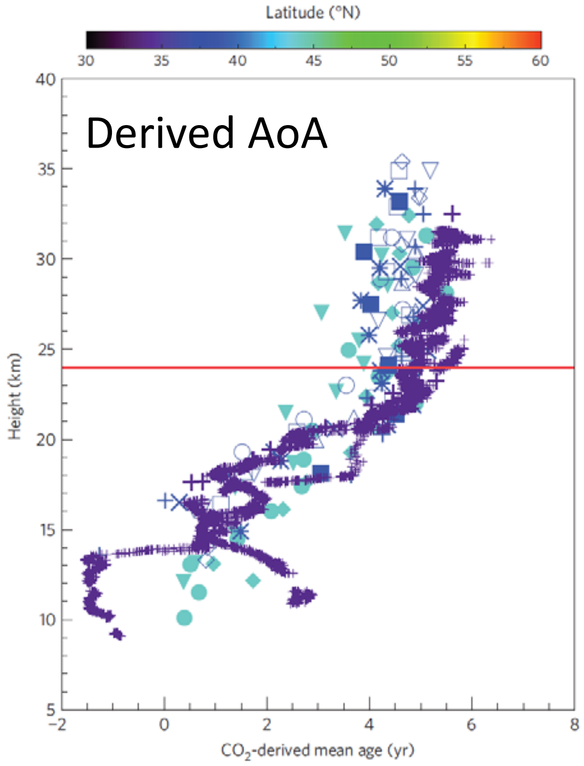

Figure 2 | Vertical profiles of mean age derived from the CO_2 data shown

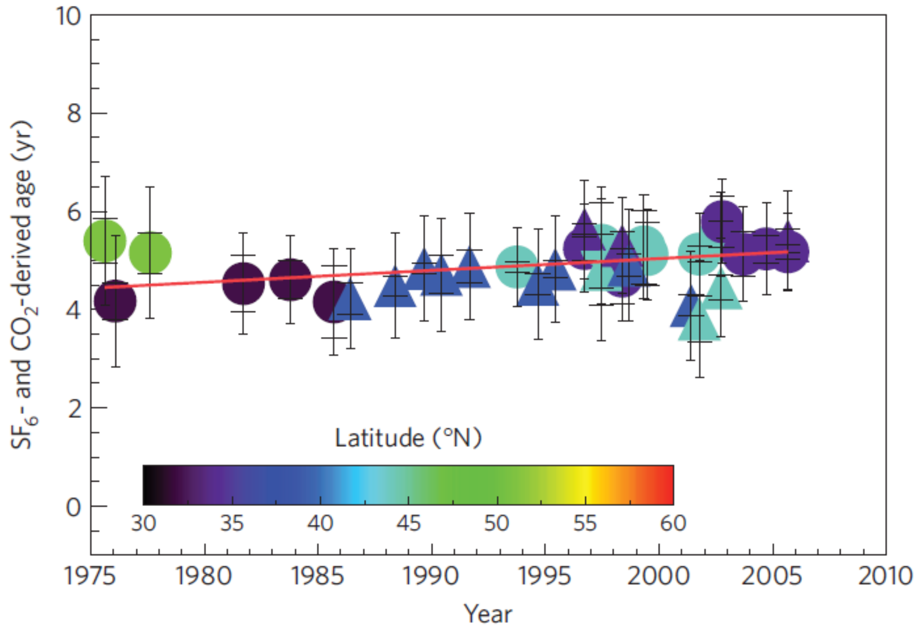

Figure 3 | Long-term evolution of mean age above 24 km altitude.

Engel et al. (2008)

Summary

- Balloons offer some important and unique advantages as a platform for stratospheric observations (vertical resolution, altitude range, …). Complementary with ground-based/aircraft/satellite platforms.
- Balloon-borne observations have made important contributions to our understanding of stratospheric composition during the past ~50 'ozone depletion' years (e.g. characterising O_3 depletion, chemical and microphysical mechanisms, trace gas trends, …).
- Balloons will continue to help probe changing composition of the stratosphere related to ozone recovery and changing climate.

Montreal Protocol (1987)

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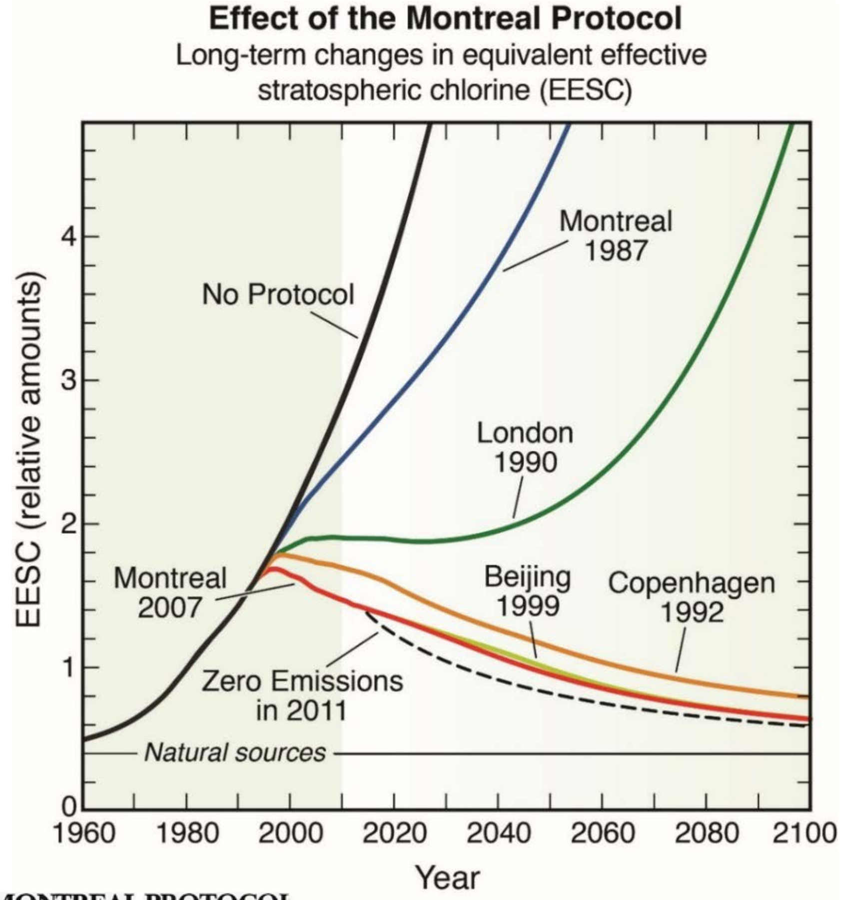
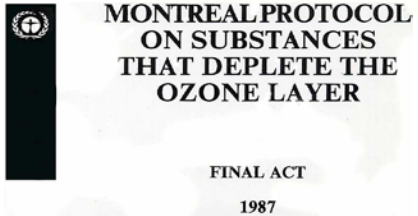
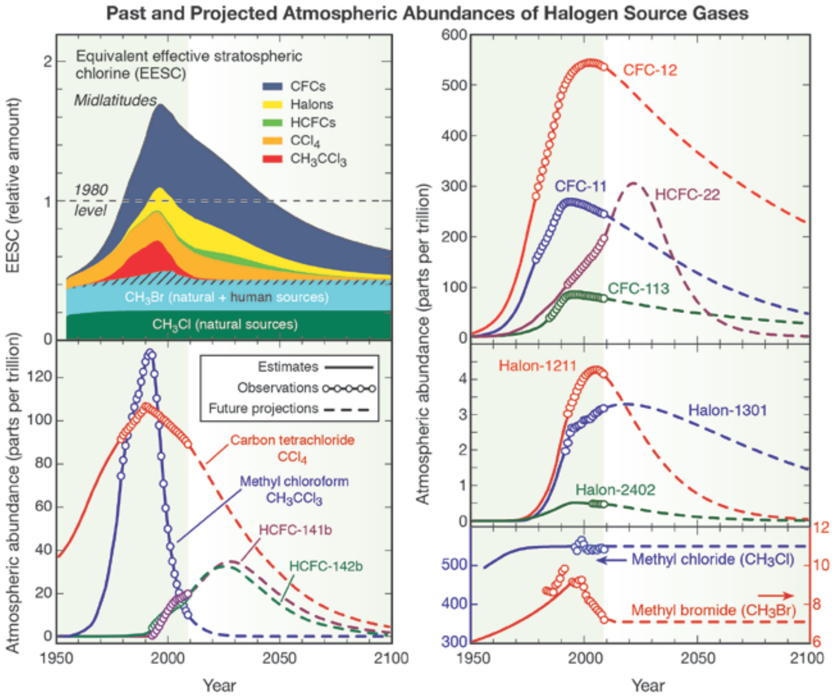




MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

FINAL ACT

1987



Tropospheric loading of long-lived ozone depleting substances now largely decreasing.

Subsequent decrease in stratospheric chlorine (Cly) and bromine (Bry).

Ozone Depletion and Recovery

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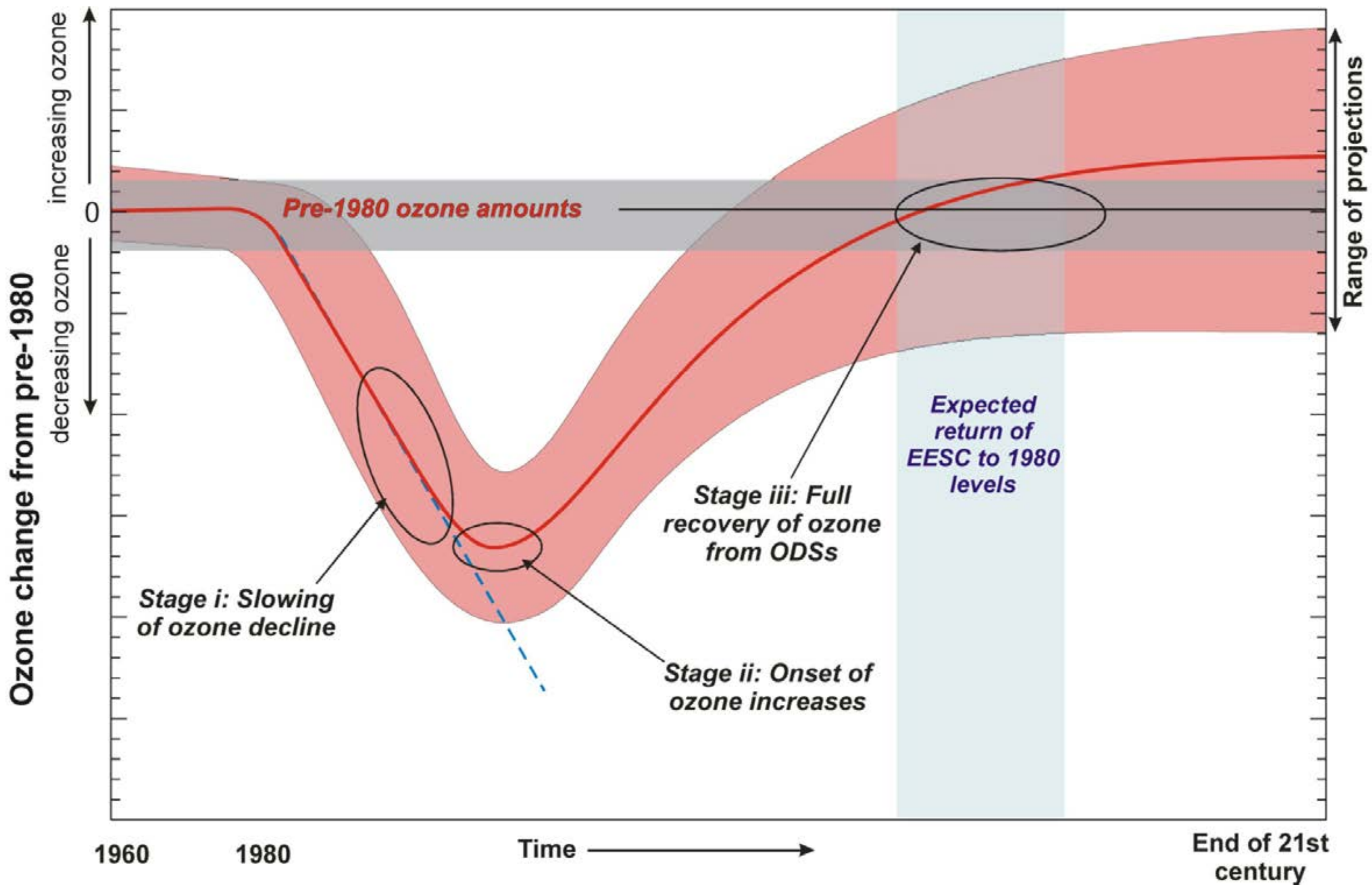
1980 used as reference baseline, but ozone depletion from chlorine and bromine did occur before this time.



From Chapter 6 of *Scientific Assessment of Ozone Depletion: 2006* (WMO, 2007).