Satellite Detection of Global Ozone Trend and Polar Ozone Depletion

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The Critical Importance of Well-Calibrated Long-Term Measurements

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Talk Outline

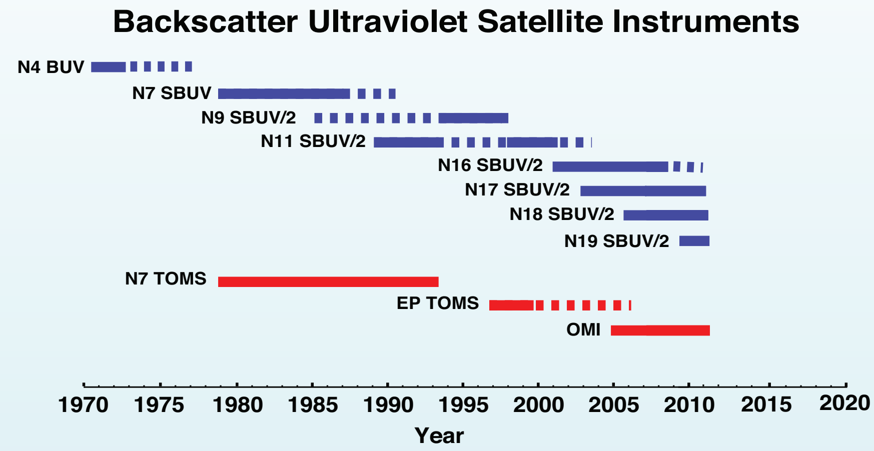
- I will focus on the long-term ozone record from the backscatter ultraviolet series of satellite instruments (TOMS/SBUV)
- Decades of effort by a team of scientists turned this series of measurements into a well-calibrated long-term data set
- The ozone measurement problem is now focused on the search for recovery and its attribution
- Continuing, well-calibrated ozone measurements will be necessary to test the response of stratospheric ozone to the Montreal Protocol

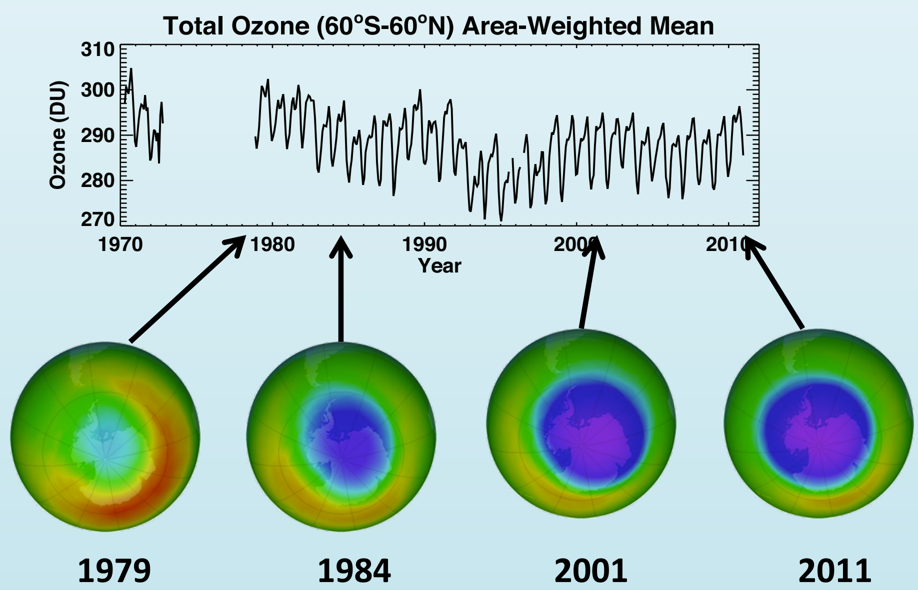
Merged Ozone Data Set Produced from 30+ Years of TOMS and SBUV Measurements

- **Backscatter ultraviolet instruments (TOMS and SBUV) have been measuring the total column amount of ozone continuously since 1978.**

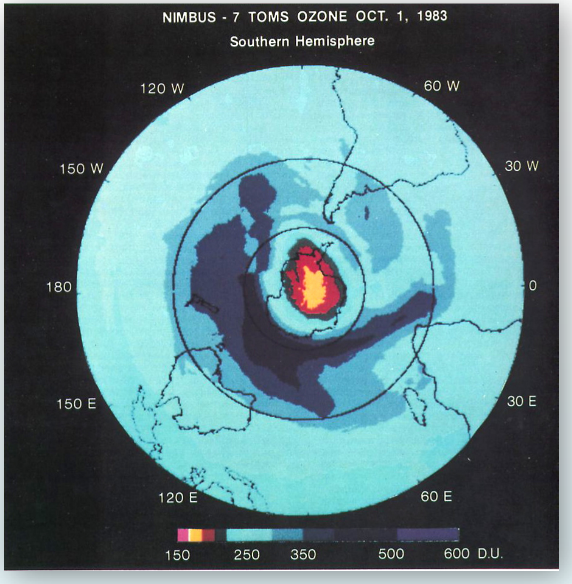
- **Instruments have absolute calibration uncertainties that can be evaluated during measurement overlap periods.**

- **The merged self-consistent data shown have been used in many studies of ozone trends and effects of solar cycle forming an important part of the evaluations by the UNEP/WMO Ozone Assessment.**

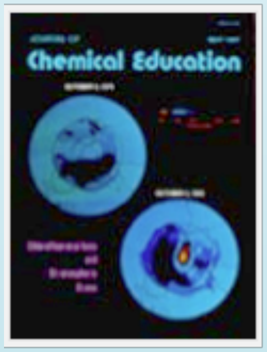




First Presentation of Anomalously low Ozone Concentrations from TOMS Measurements (IAGA, 1985)



Bhartia, P.K., Heath, D.F. & Fleig, A.F. (1985, August); *Observation of anomalously small ozone densities in south polar stratosphere during October 1983 and 1984*. (Paper presented at the Symposium on Dynamics and Remote Sensing of the Middle Atmosphere. 5th Scientific Assembly, Int. Assoc. of Geomagn. and Aeron. (IAGA), Prague Czechoslovakia)



May 1987
Volume 64, Issue 5
Pages 385-472

Similar figure later appeared on the cover of the Journal of Chemical Education (May, 1987)

About the Cover:
Total ozone distribution over the southern hemisphere is illustrated on the cover for October 3, 1979, at the onset of the "ozone hole" phenomenon and on the same date four years later, in 1983; this phenomenon is discussed in the article by Elliot and Rowland which begins on page 387. The images are from the Total Ozone Mapping Spectrometer (TOMS) instrument on board the Nimbus 7 satellite. Color coding spans the range 150-600 Dobsons, or, 0.150-0.600 atm-cm. The Dobson can be converted to more accessible measures of integrated column density, such as molecules/cm2 through the ideal gas law.

Initial Measurement of the Yearly Progression of the Ozone Hole

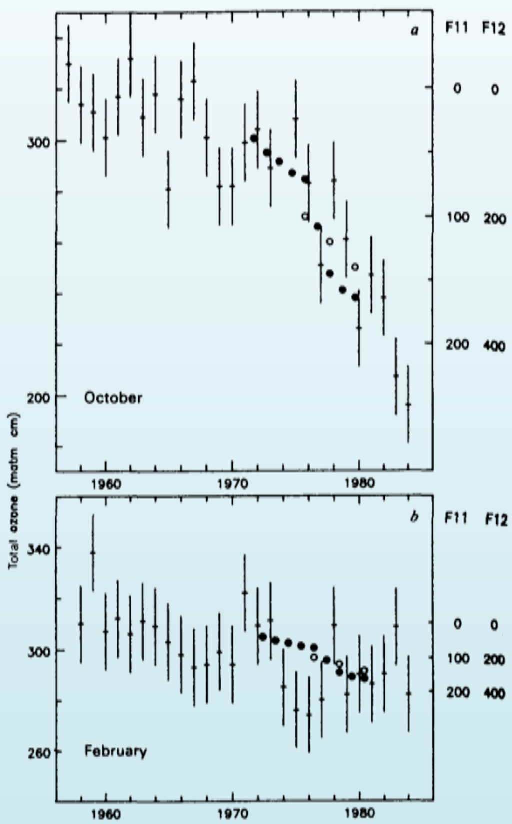
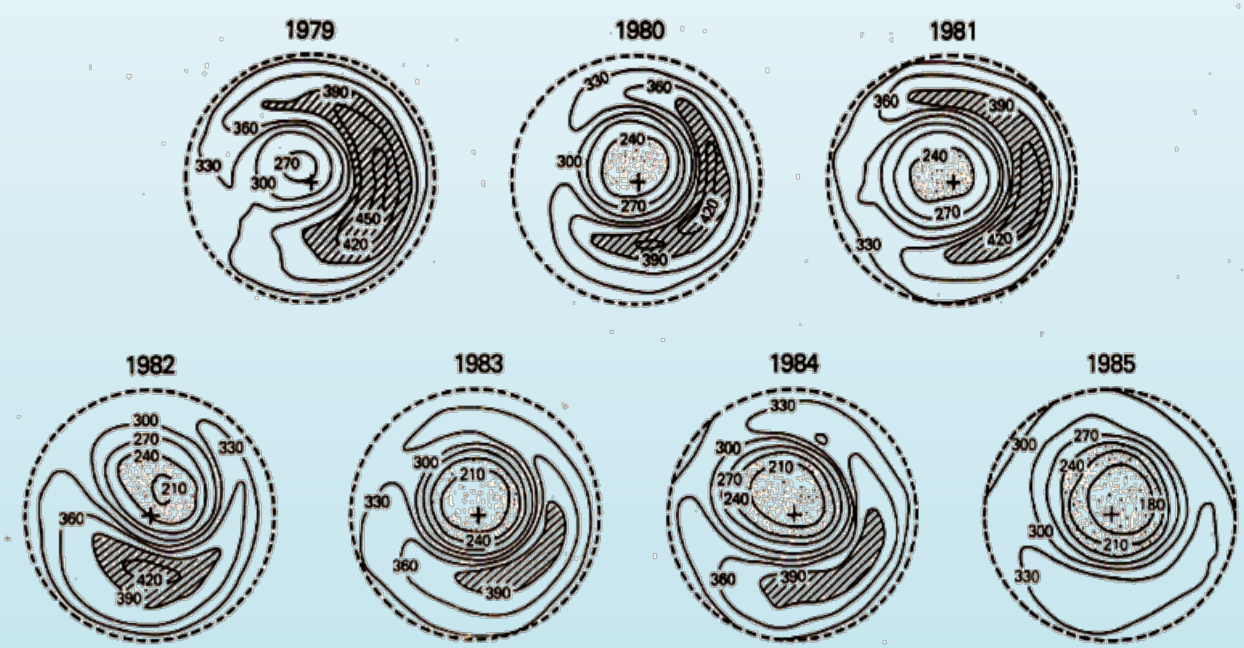
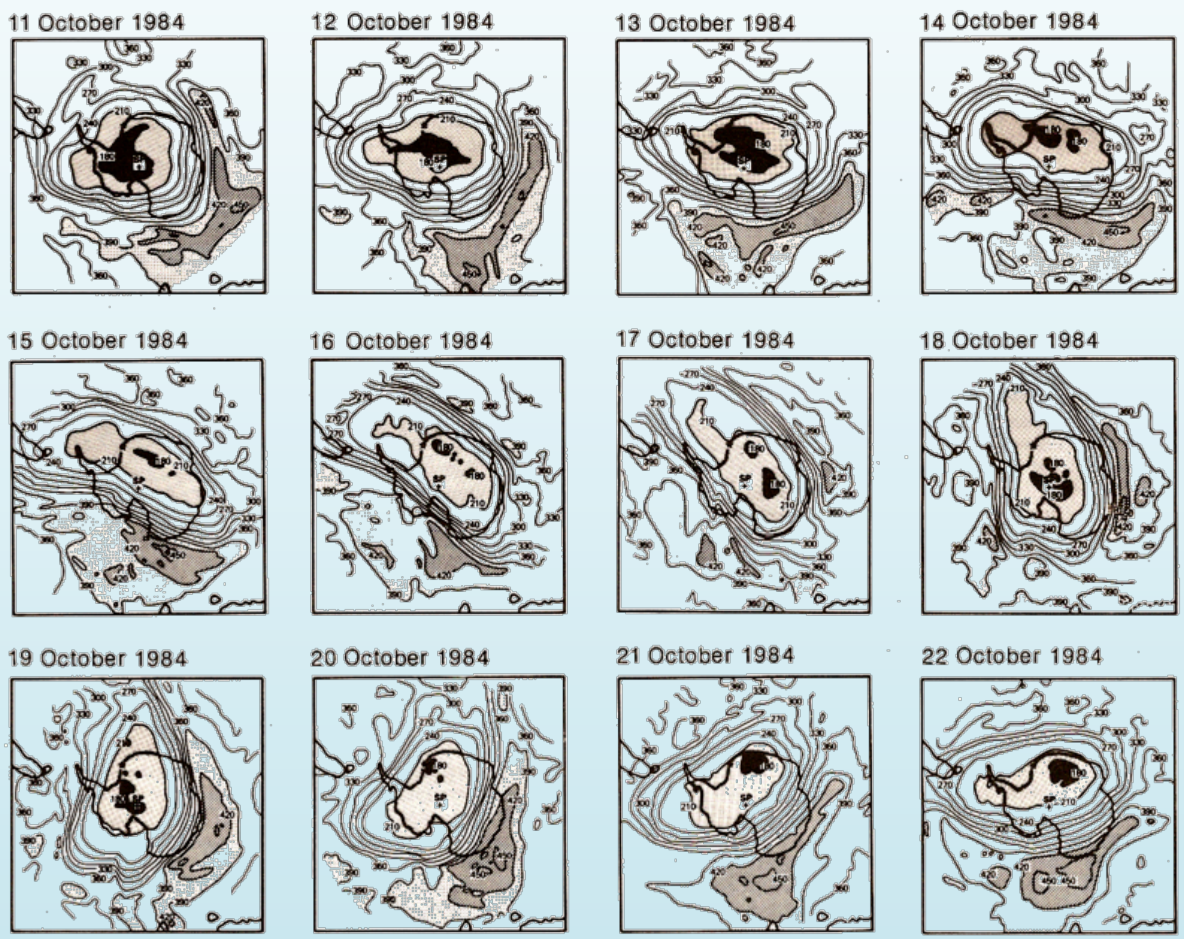


Fig. 2 Monthly means of total O_3 at Halley Bay, and Southern Hemisphere measurements of F-11 (●, p.p.t.v. (parts per thousand by volume) $CFCl_3$) and F-12 (○, p.p.t.v. CF_2Cl_2). *a*, October, 1957–84. *b*, February, 1958–84. Note that F-11 and F-12 amounts increase down the figure.

- **Discovered in ground-based measurements at Halley Bay, Antarctica [Farman et al. 1985]**
- **Geographical extent determined from TOMS satellite measurements [Stolarski et al. 1986]**



Elongation and Rotation of Ozone Hole As Vortex Responds to Meteorological Variation



TOMS measurements showed rotation of the Antarctic springtime minimum in ozone and that it followed the rotation of the polar vortex

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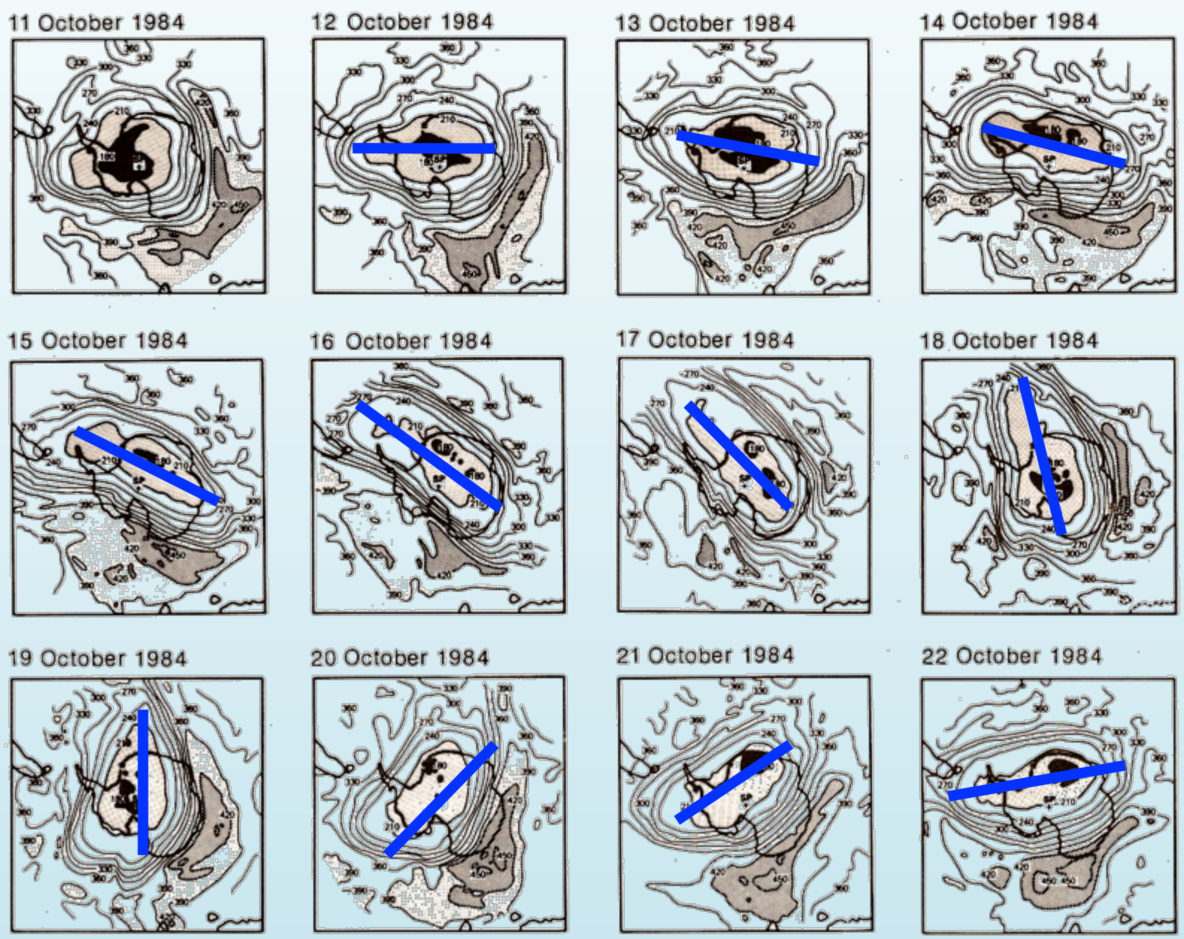

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Global Ozone Trends

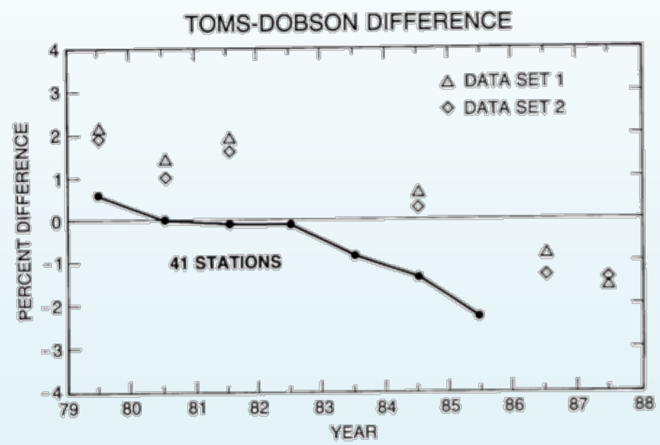
- **The ozone hole is quite obvious and easy to detect**

  once you understand that the unexpected low values of ozone are not an instrumental artifact

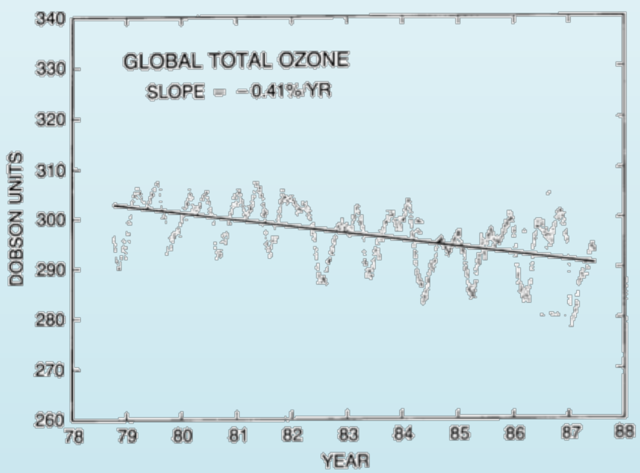
- **Trends around the rest of the globe are smaller and more difficult to detect**

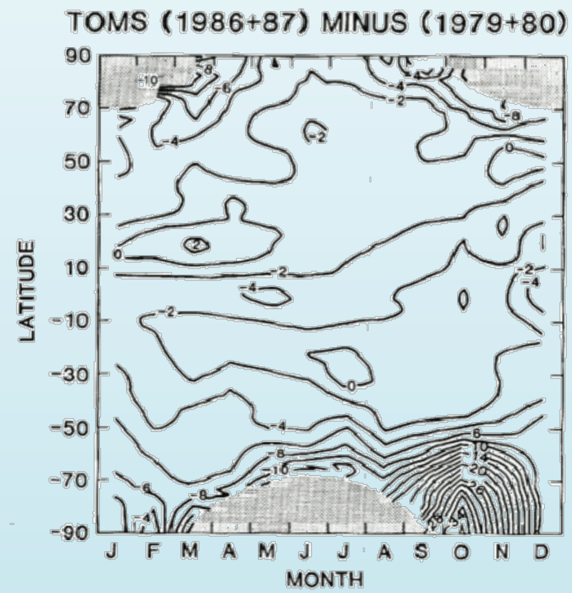
  thus requiring careful attention to calibration

Ozone Trends Panel Report: 1988

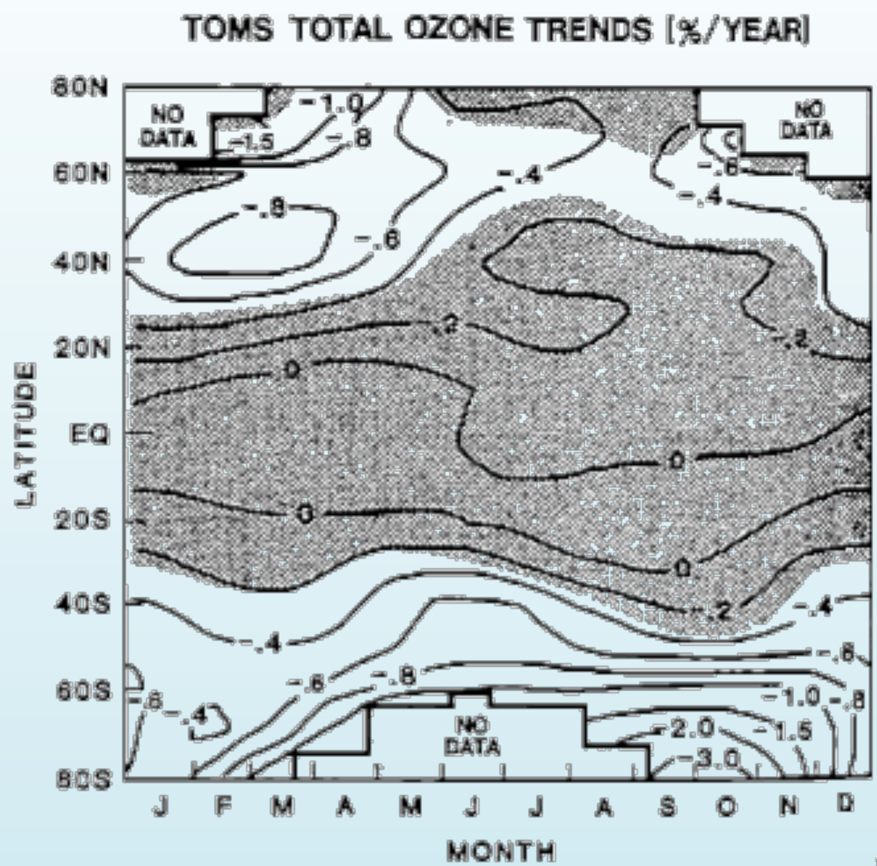


TOMS Ozone Measurements Normalized to Ground-Based Measurements





Trends derived from TOMS data



- Drift corrected using "pair-justification" method (Herman, et al., JGR, 1991)
- Statistically-significant trends in Antarctic/ Southern mid-latitudes
- Also significant trends in northern mid-latitudes in winter/spring
- Using data through 1990

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. D4, PAGES 7531–7545, APRIL 20, 1991

A New Self-Calibration Method Applied to TOMS and SBUV Backscattered Ultraviolet Data to Determine Long-Term Global Ozone Change

J. R. Herman, R. Hudson, R. McPeters, and R. Stolarski

Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland

Z. Ahmad, X.-Y. Gu, S. Taylor, and C. Wellemeyer

ST Systems Corporation, Lanham, Maryland

from Stolarski et al., GRL, 1991

V6 Data

We Now Use SBUV Rather Than TOMS for Trend Detection

- SBUV incorporates 6 more wavelengths than TOMS
  → allowance for profile shape dependence of total ozone determination
- SBUV algorithm uses time-independent a priori
  → No aliasing into trend, more noise in individual profiles

$$O_3(\text{meas}) = \alpha\, O_3(\text{actual}) + (1-\alpha)\, O_3(\text{a priori})$$

$$dO_3/dt\,(\text{meas}) = \alpha\, dO_3/dt(\text{actual}) + (1-\alpha)\, dO_3/dt(\text{a priori})$$

(P.K. Bhartia, presentation at EGU/AGU, Nice, France, 2003)

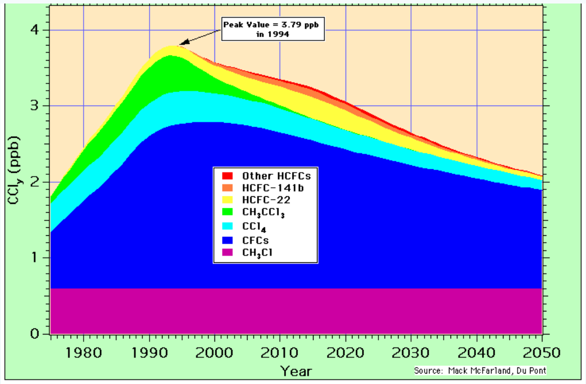
- TOMS uses complex, time-dependent a priori
  → less individual profile noise, better daily mapping
  → less appropriate for long-term trends

What determines the requirements for calibration maintenance?

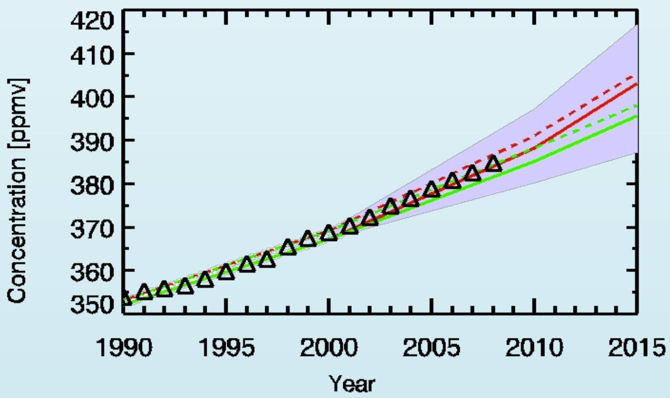
- **Initial issue was detecting trend consistent with CFC/chlorine changes**
- **This was followed by search for slow-down and leveling off of trend**
- **Now looking for statistically-significant increase**
- **Attribution is a more difficult problem**

What is the attribution problem?

- EESC (measure of ODSs) projected to decrease at about 1/3 the rate of increase during 1980s leading to recovery (increase) of ozone



- GHGs cool stratosphere, slowing down rates of ozone loss reactions (thus increasing ozone)

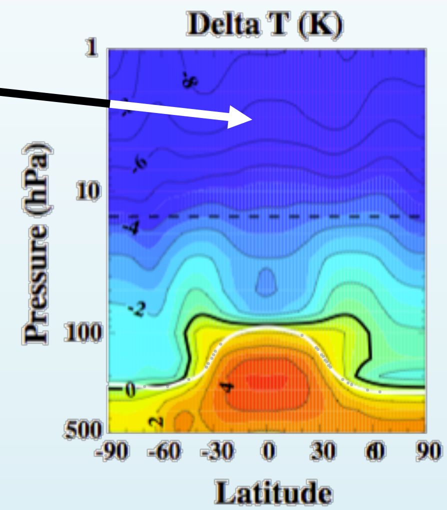


- Both lead to more-or-less linear increase in ozone predictions, thus difficult to separate

The Post-CFC Ozone Layer

What will the stratospheric ozone layer look like after CFCs have been removed?

- **Greenhouse gases cool the stratosphere**



Results from GEOS CCM
2065-1980
F. Li et al. ACP (2009)

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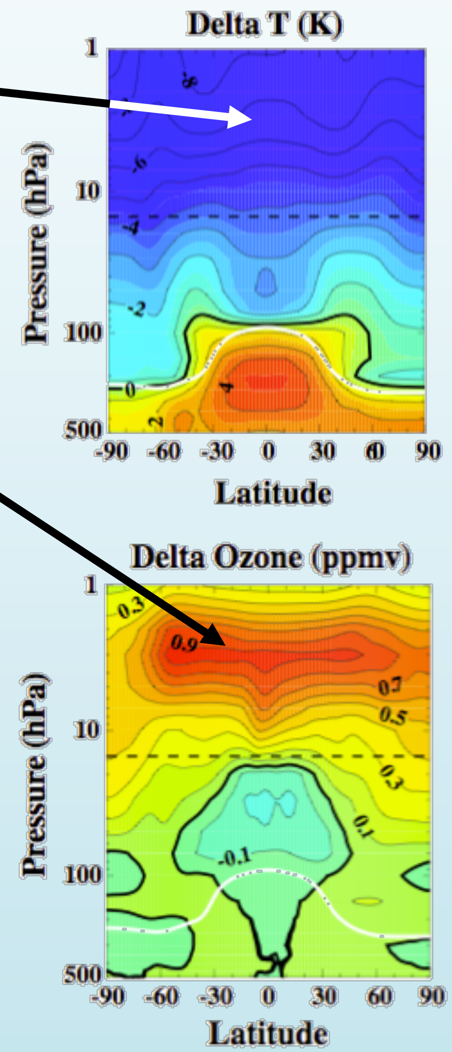

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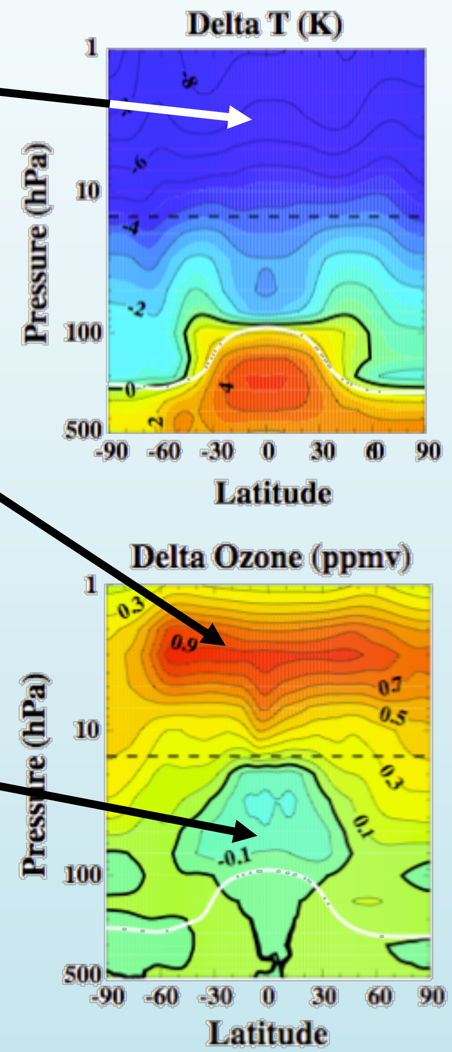

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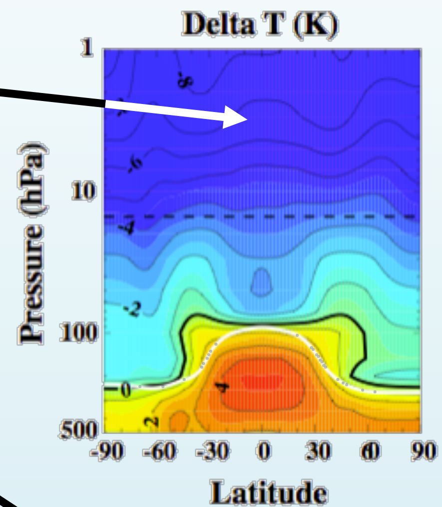
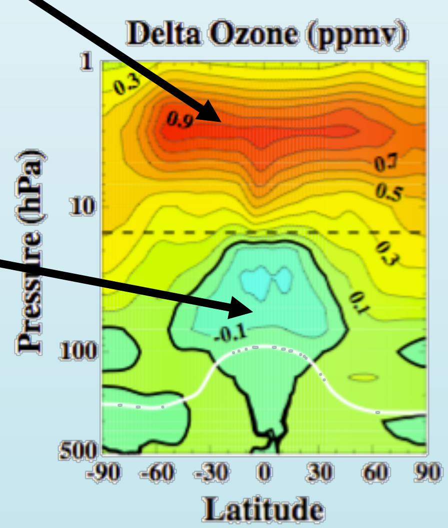
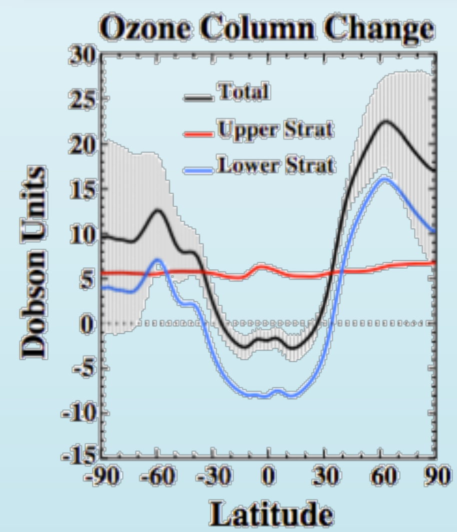
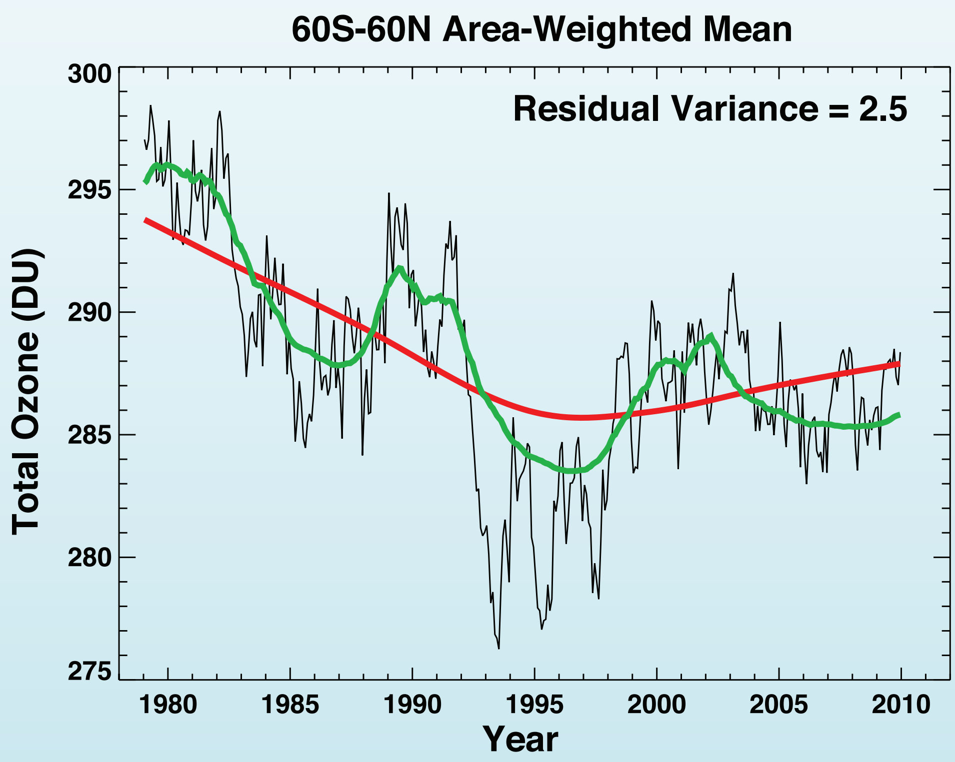




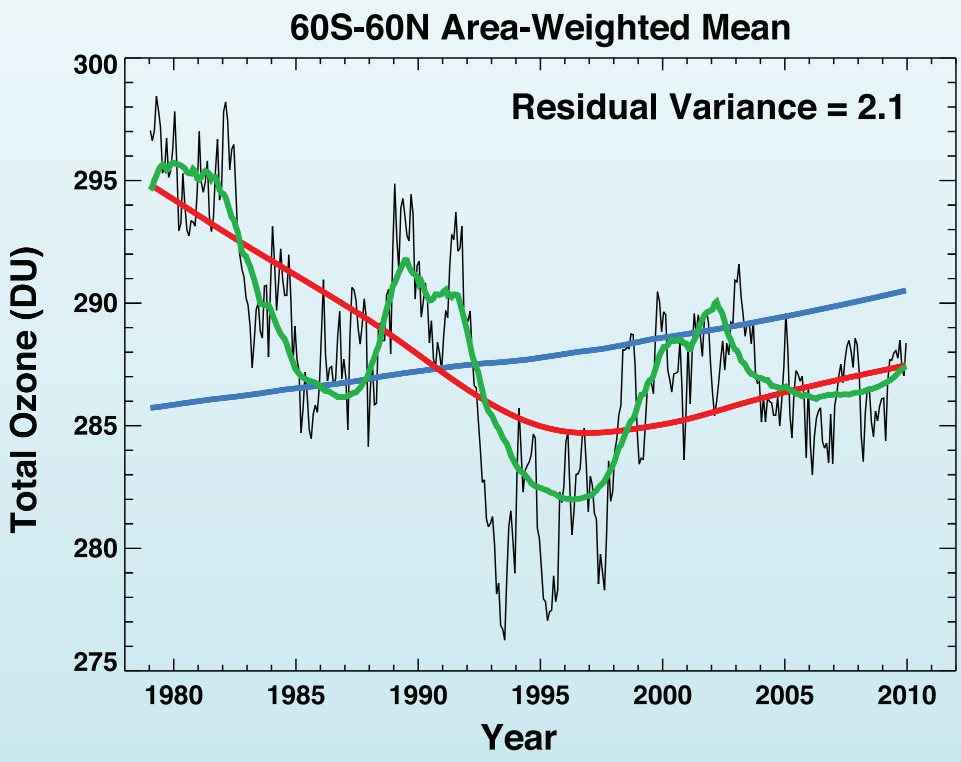
Net result is a column ozone increase at mid to high latitudes and almost no change near the equator



Fit to deseasonalized ozone time series
EESC + Solar



Fit to deseasonalized ozone time series EESC + CO_2 + solar



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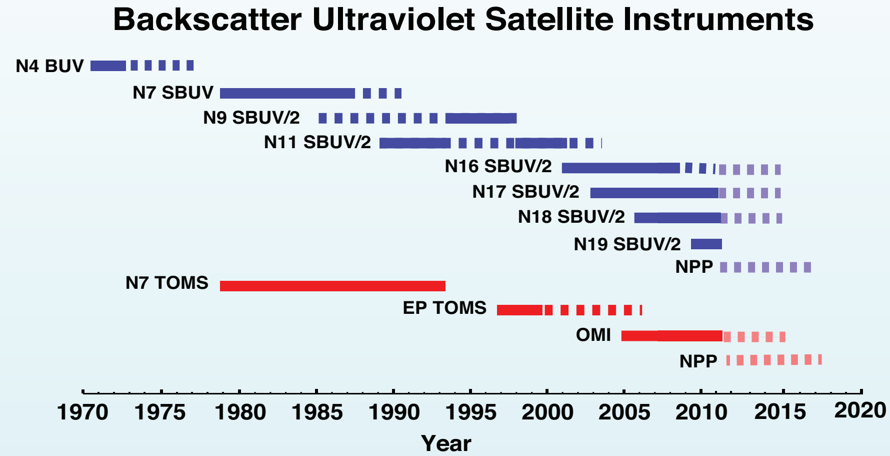

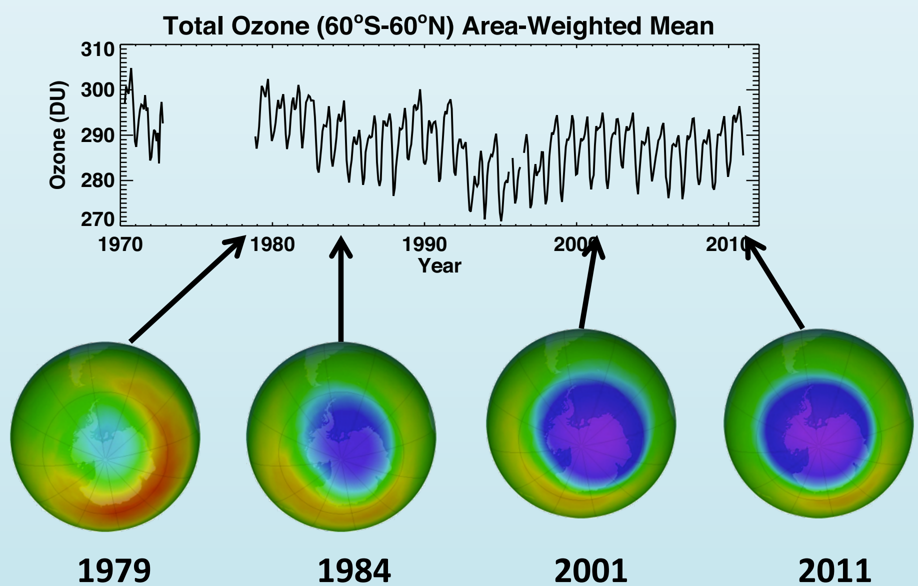

What I have not discussed

- Importance of process studies driven by measurements of the variety of other molecules important to determining the sensitivity of ozone to ODSs (e.g. ClO, NO, NO_2, $ClONO_2$, HCl, OH and many more)
- The important role of ground-based data that can be calibrated on demand
- The role of high vertical resolution satellite measurements of the ozone profile

Conclusions

- **Measurement of future ozone change is the ultimate test of our predictions**
- **Patterns are important, but changes are small: need precise measurements with well-maintained calibration history**
  - **Multi-decadal effort on the part of measurement teams**
- **Independent measurement systems provide critical corroboration of results**
- **Measurement of other constituents demonstrate mechanisms and test processes and how they are incorporated into global models**