HALOGEN OCCULTATION

HALOE

O_3, ClO_x, NO_x, HO_x

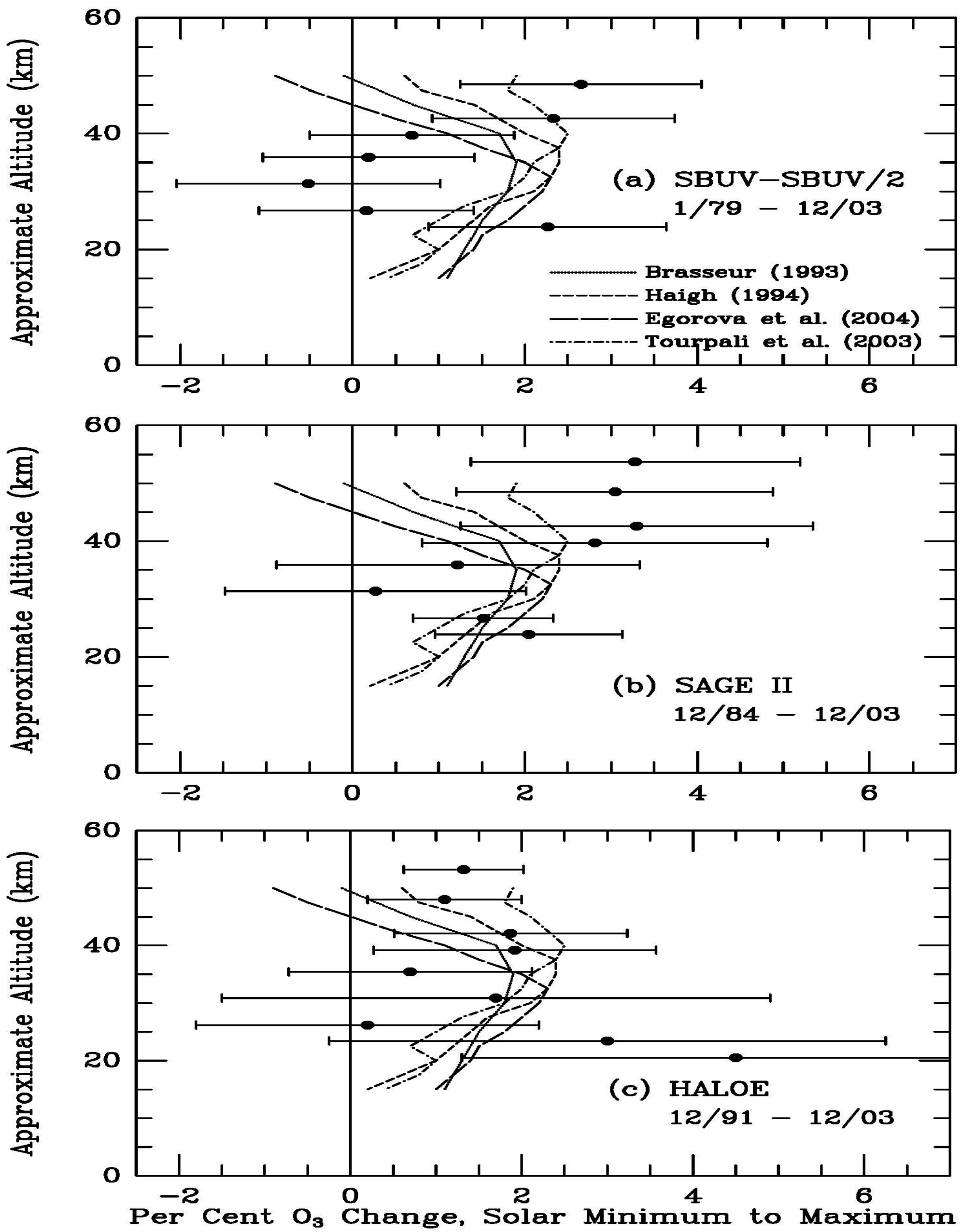
EXPERIMENT

Solar Cycle Effects in the UARS/HALOE Ozone Dataset

Ellis Remsberg
Atmospheric Sciences Directorate
NASA Langley Research Center
Hampton, VA, USA

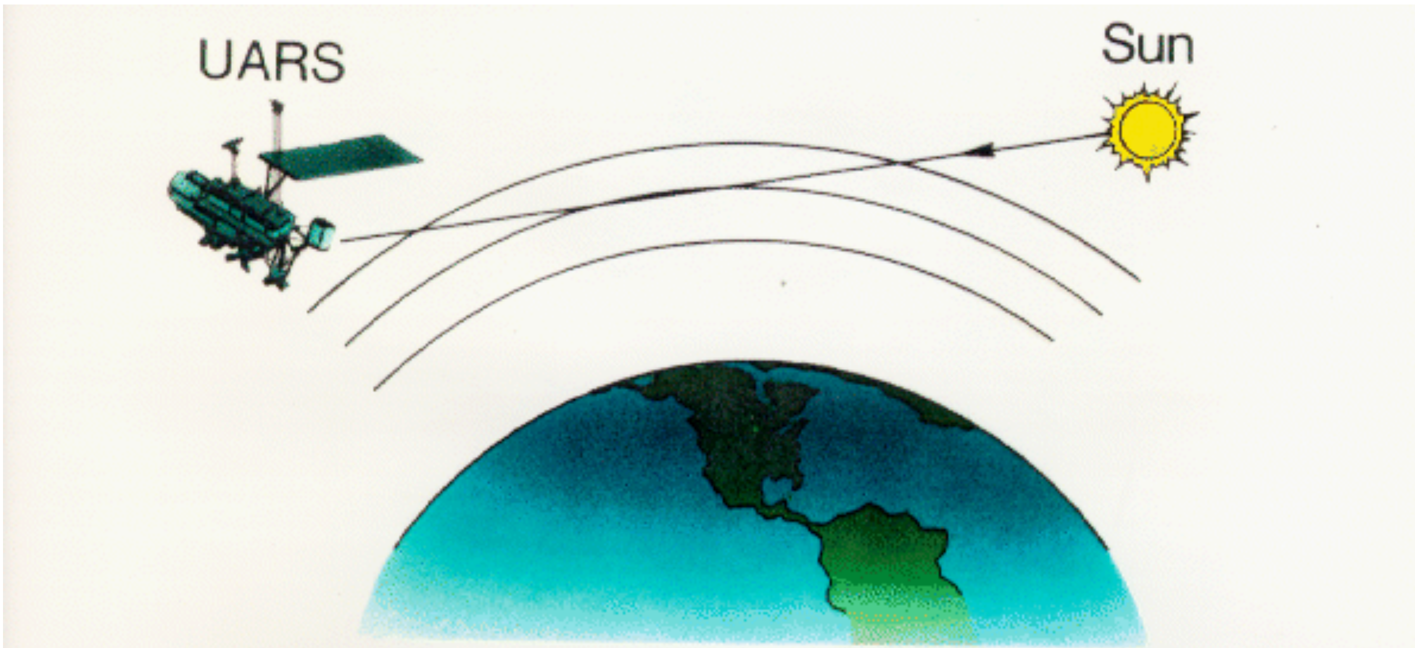
[J. Geophys. Res.-Atmospheres., in press, 2008]

The motivation for this study was the general lack of agreement between the observed and modeled 11-yr solar cycle responses in stratospheric ozone at lower latitudes, as reported in Soukharev and Hood (JGR-Atmospheres, 2006)—see following panel.



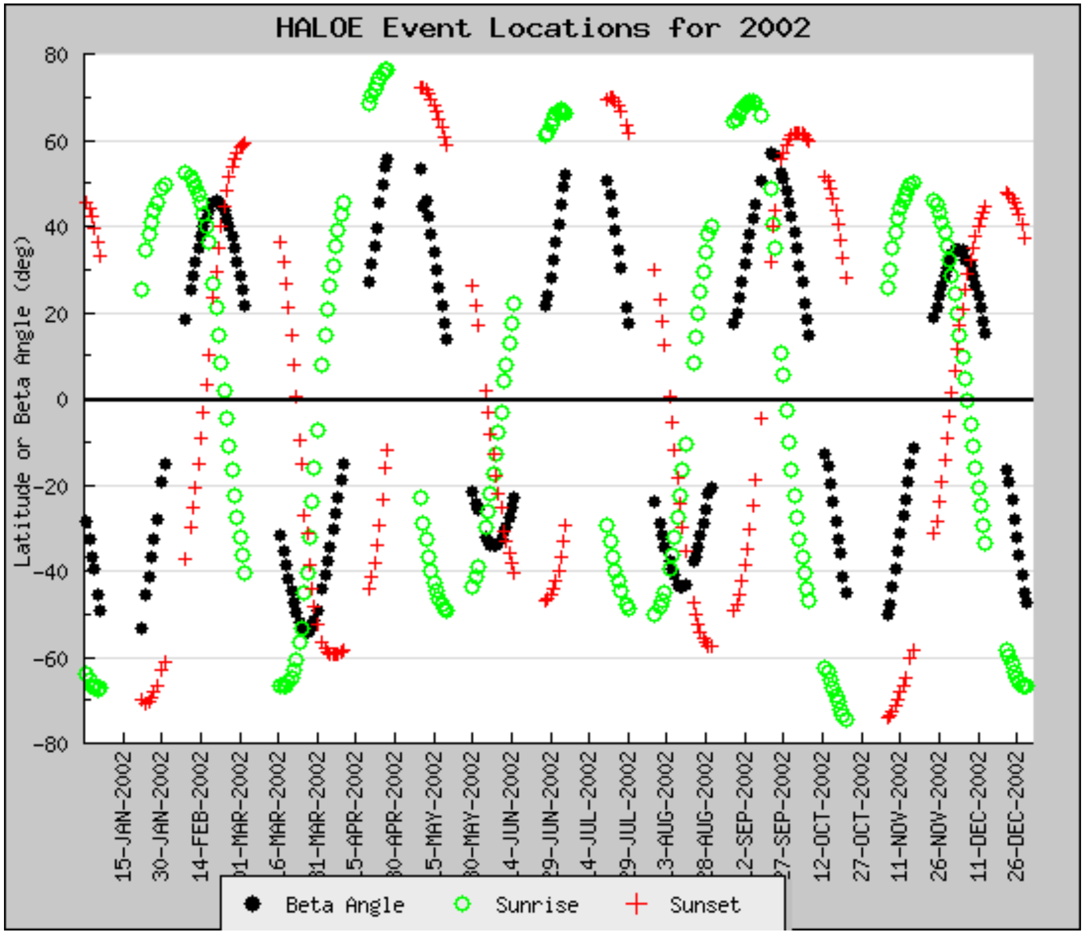
Modeled vs. Observed SC-like Response Profiles (black dots)—averaged for 25S to 25N.

(Soukharev and Hood, JGR, 2006)



OCCULTATION VIEWING GEOMETRY

Location of HALOE SS and SR measurements for 2002. Sampling was adequate from 45S to 45N for the seasonal and longer-period terms.



Characteristics of HALOE Ozone

- Its measured transmission has excellent S/N in the mid and upper stratosphere for sensing a 2% variation in the zonal mean profiles.
- Vertical resolution is about 2.5 km; profiles were integrated into half-Umkehr layers of that thickness to improve data precision. Good vertical resolution is needed to resolve the SC ozone response.
- Calibration to exo-atmospheric Sun look for each SS and SR event.
- The HALOE instrument characteristics were monitored in-orbit and were very stable; there is no evidence of artifacts affecting its trends.
- Averages of SS and SR scans were obtained and combined for ten 20-deg wide latitude bins from 45S to 45N and for 13 half-Umkehr layers from 63 hPa to 0.7 hPa (or about 19 to 53 km).

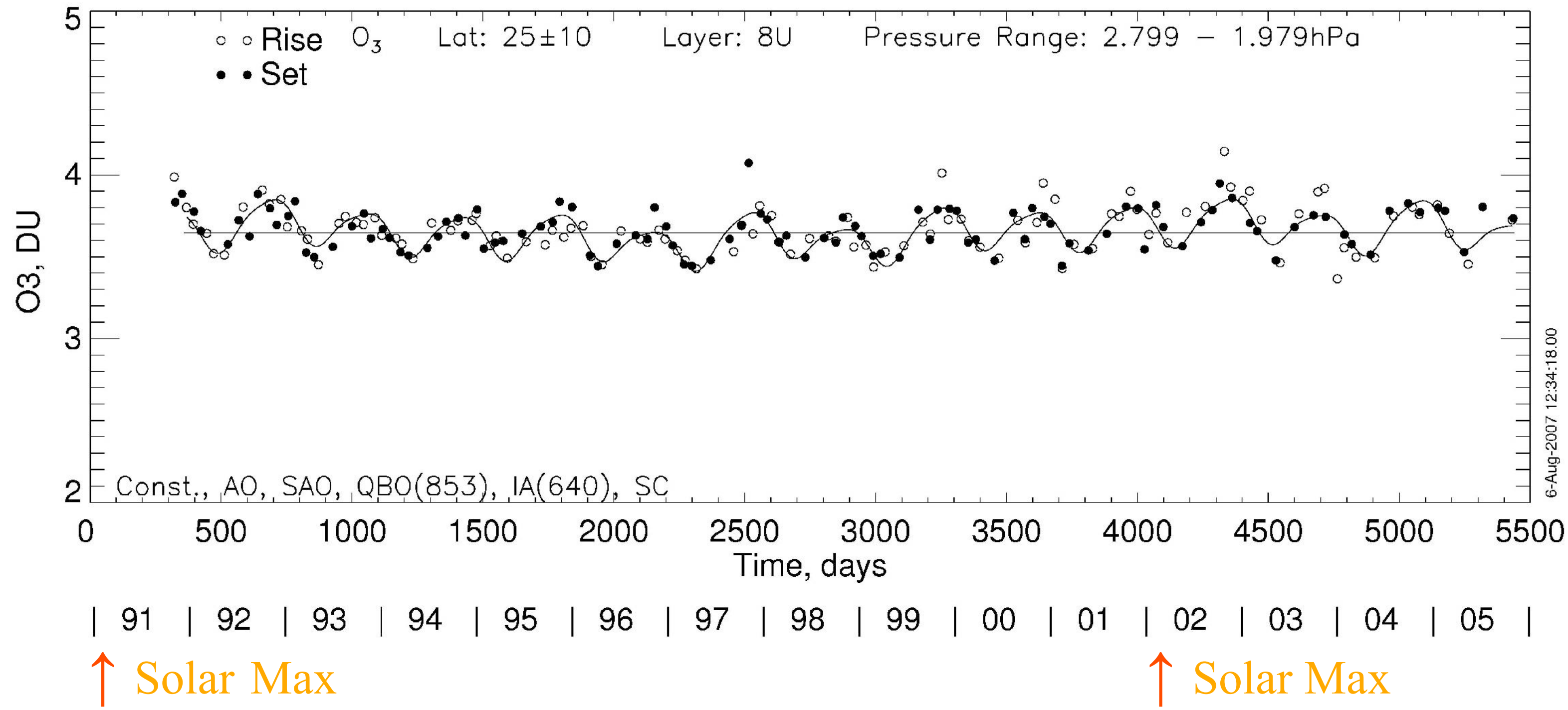
Objectives of Ozone Time Series Analysis

- This study was an exploratory search for the response of HALOE ozone to an 11-yr and/or a solar cycle (SC-like) uv-forcing term.

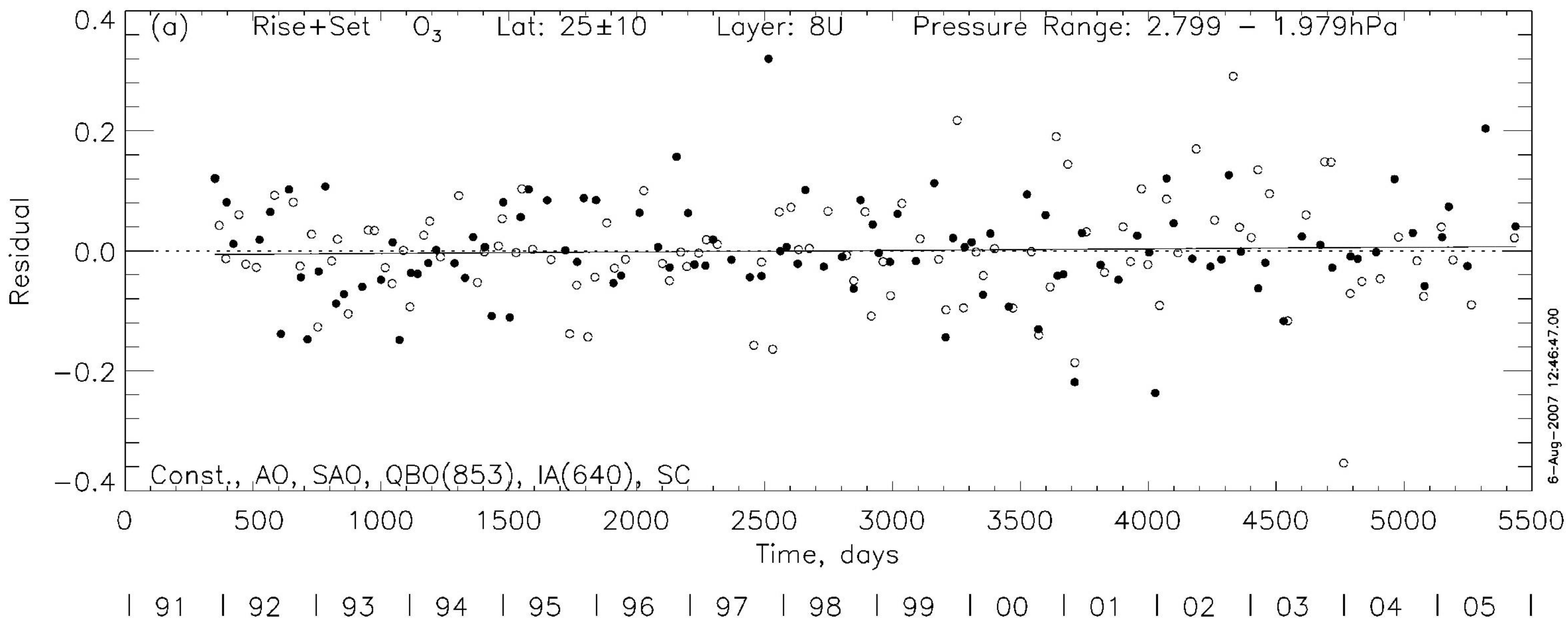
- Multiple linear regression (MLR) techniques were used to fit the 130 separate, 14-yr time series of bin-averaged HALOE ozone points.

- The goal was to determine the significant periodic structure in the ozone time series before fitting them for decadal-scale and trend terms. This approach aims to examine the unique periodic structure of each separate time series and account for it, rather than regressing against assumed, proxy terms for every series.

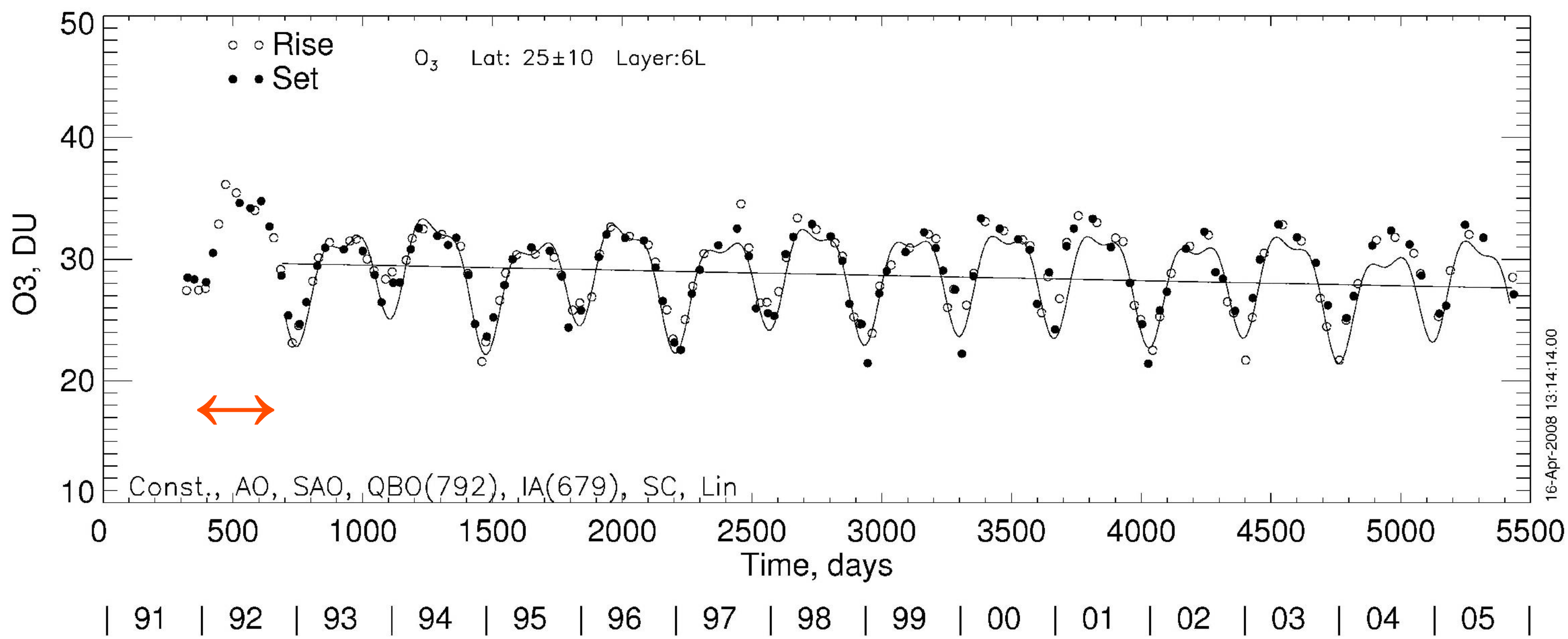
- After accounting for the seasonal terms, interannual (QBO/28 mo. and sub-biennial/21 mo.) cycles were found consistently in the time series residuals of the upper stratosphere; the dominant QBO periods varied from 26 to 30 months in the lower stratosphere. Subbiennial terms arise from the interaction of the annual cycle and the QBO. A modulation of the QBO and sub-biennial terms can also lead to a decadal-scale term that may or may not be in-phase with the SC.



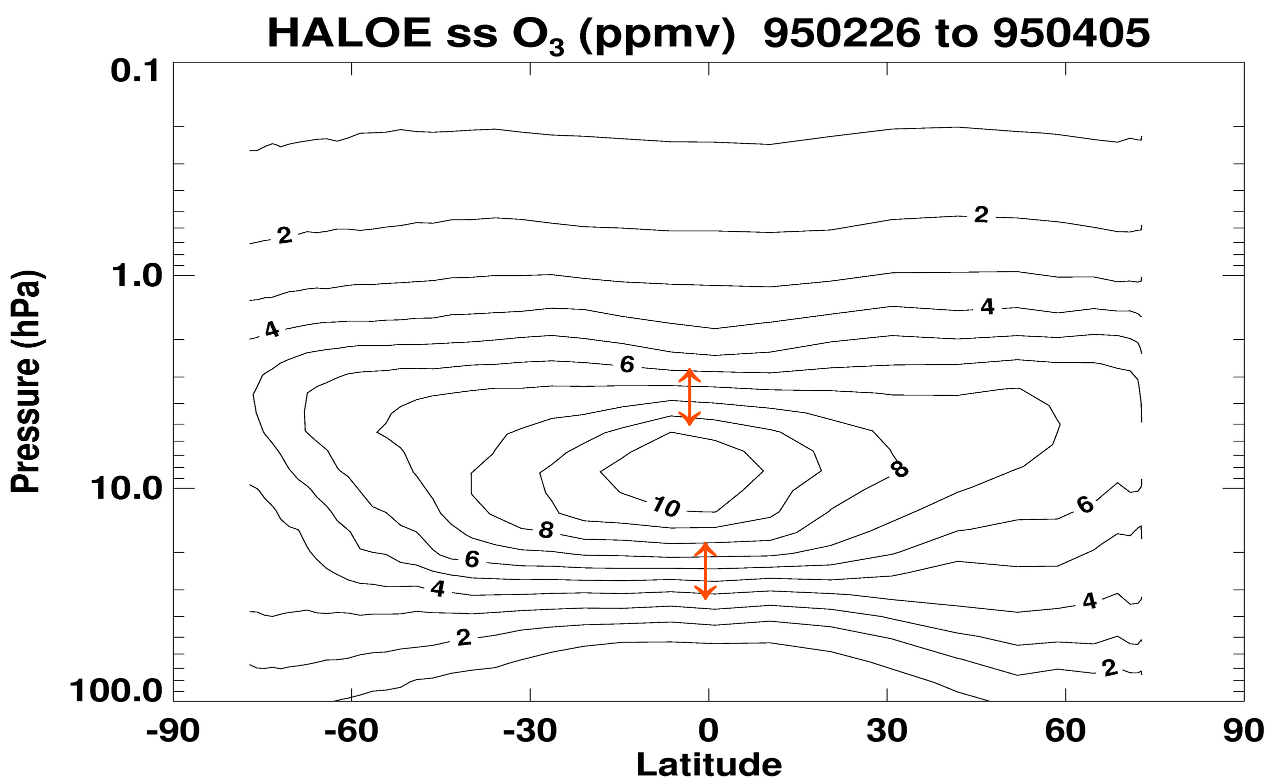
Time series of HALOE bin-averaged SR and SS ozone at 25N and near 2.4 hPa (42 km). MLR model terms include AO, SAO, 28 month (QBO-like), 21 month (sub-biennial), and 11-yr (or SC-like) terms. The 11-yr term is closely in-phase with that of a solar uv-flux proxy; its phase-adjusted, max minus min value is 2.7%.



Ozone residual in Dobson units (DU) for the MLR model at 25N and near 2.4 hPa. The solid line is the linear fit to the residual. Its trend is essentially zero.

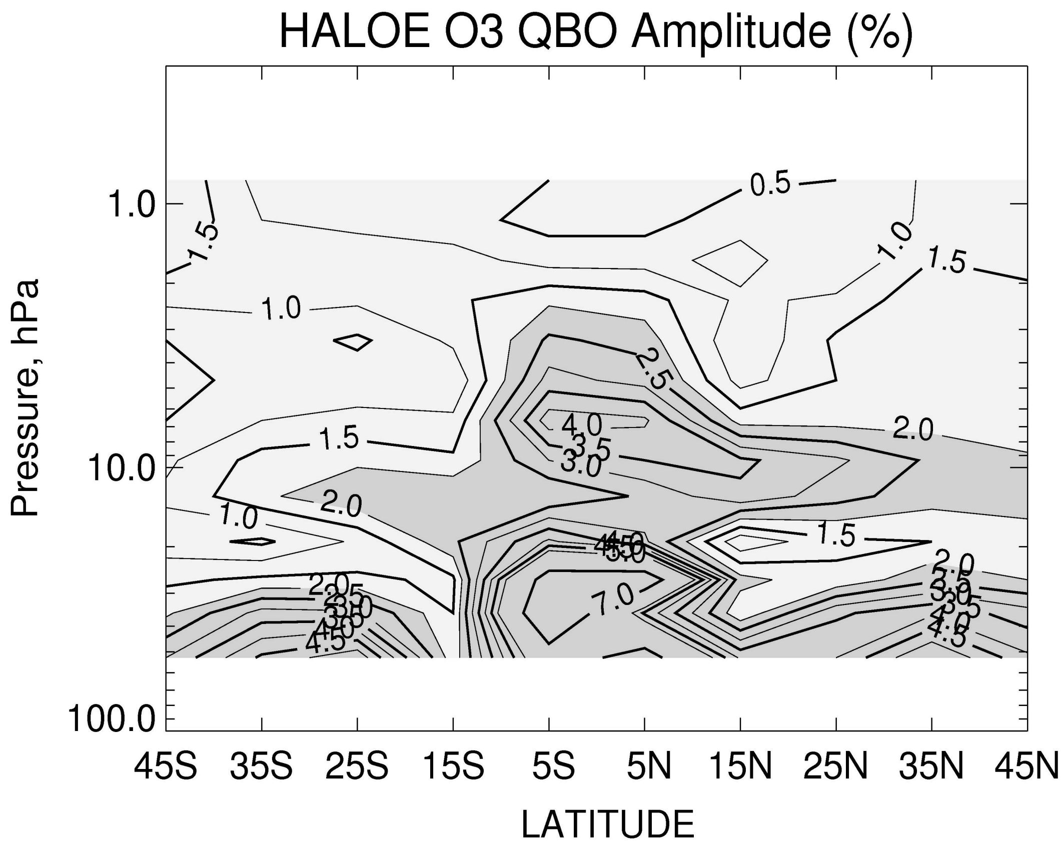


Time series of ozone for layer 6L (near 13 hPa) at 25N. Both QBO and sub-biennial terms are apparent, along with a weak negative linear trend. Because of the anomalous, excess O3 of 6L, 25N in its first year, the MLR analysis was begun at September 1992. That excess O3 may be a result of the repartitioning of the odd nitrogen (NOy) toward nitric acid, rather than NOx, in the presence of the volcanic aerosol layer from the eruption of Mt. Pinatubo.

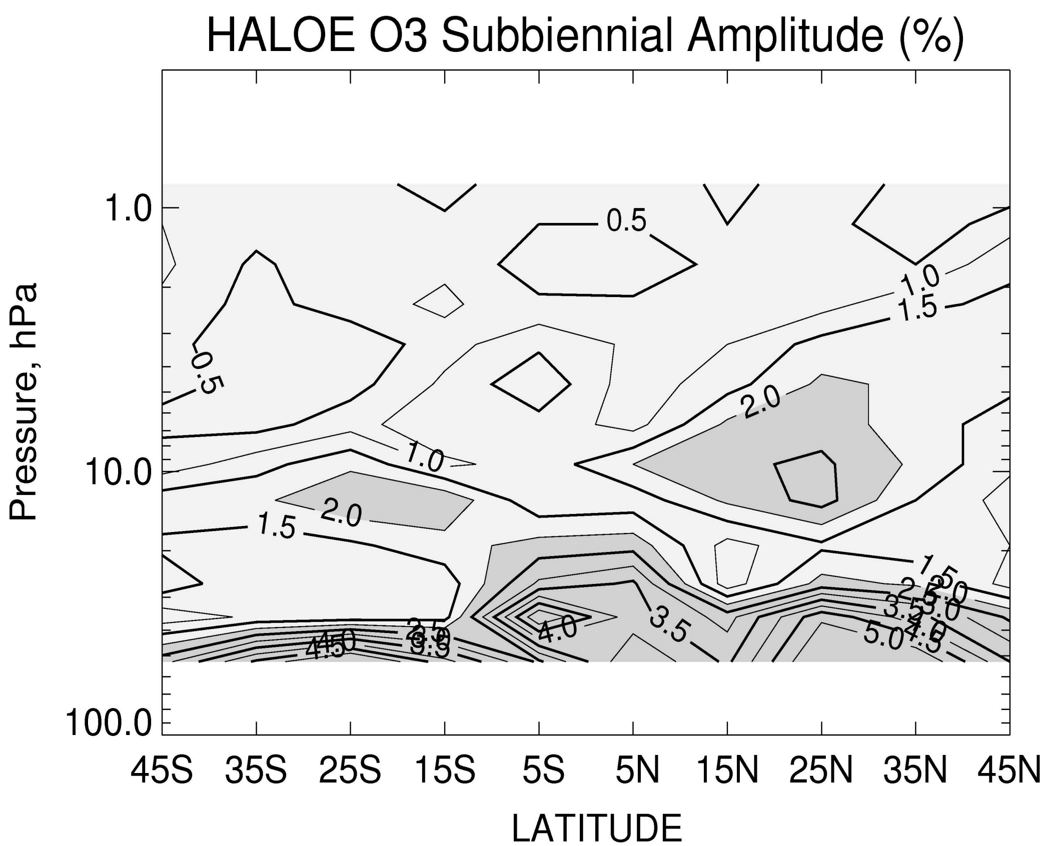


A representative zonal mean cross section of HALOE ozone. Its vertical gradients are largest in the tropics at 5 and 30 hPa (arrows), while its meridional gradients are largest in the subtropics at about 10 hPa. Effects of QBO transport ought to be most noticeable where ozone gradients are large.

Regions where amplitudes exceed 2% have dark shading.
Largest amplitudes occur where O3 gradients are also large.



Amplitudes of the sub-biennial terms for ozone. Regions where the amplitudes exceed 2% have darker shading.



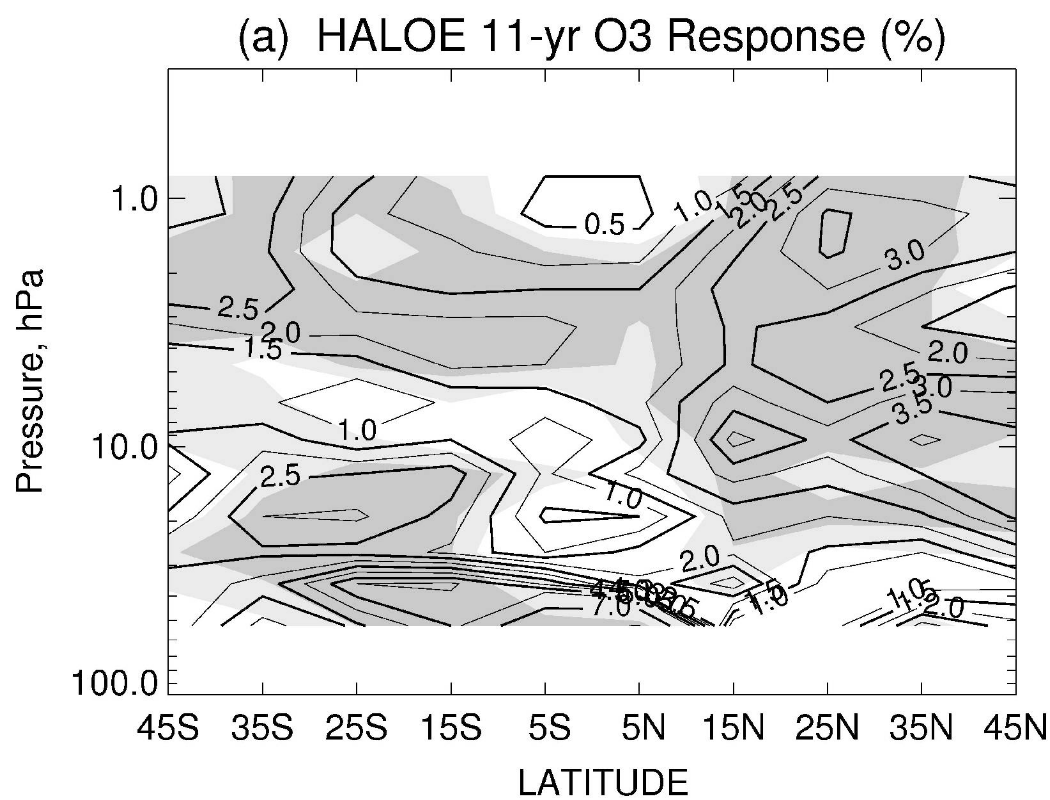
Approach to Analyzing for the 11-yr or Decadal-Scale Term

- Periodic, 11-yr terms were fit to each of the data time series, and their amplitudes AND PHASES are noted in the following two panels.

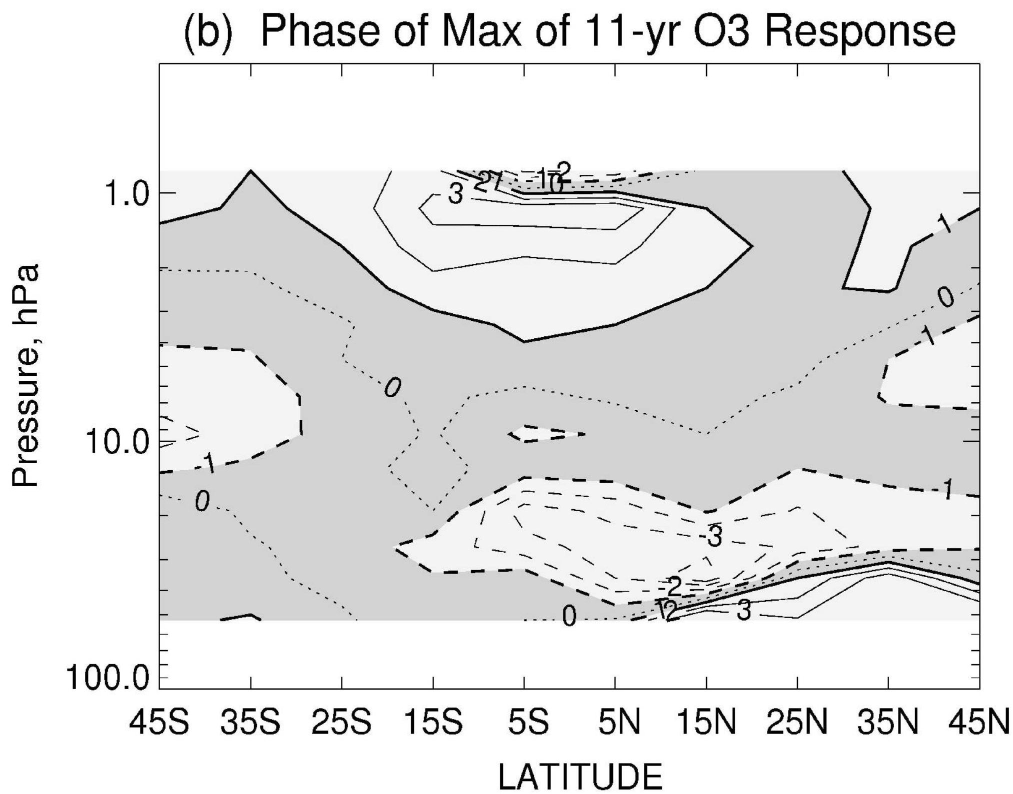
- Amplitudes in the upper stratosphere have highly significant, max minus min values of order 2% from about 2 to 5 hPa.

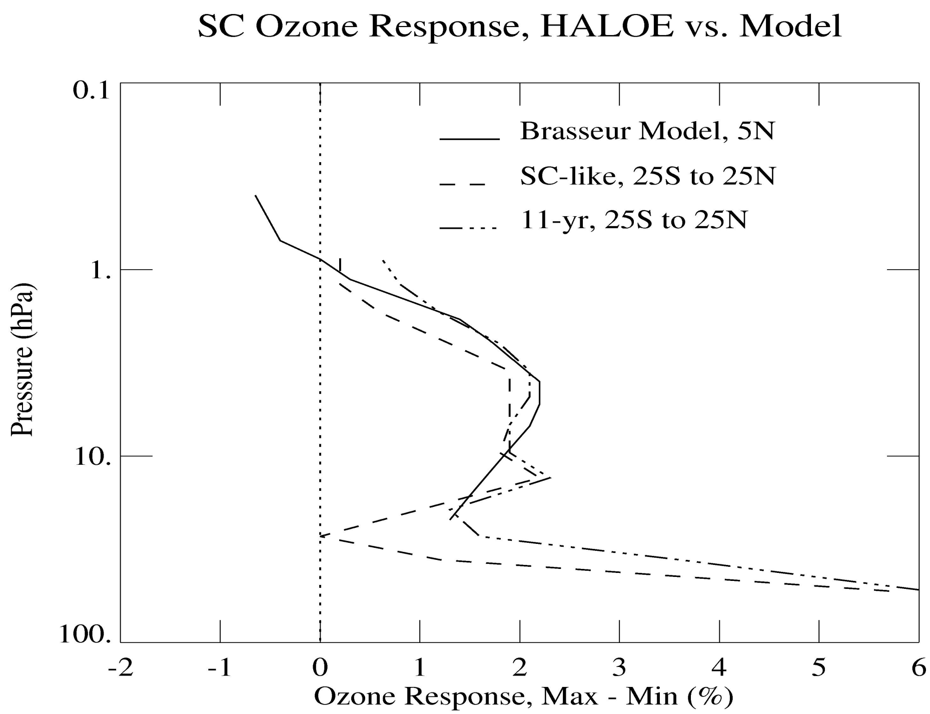
- And their responses are in-phase with solar flux maximum.

Contours are the 11-yr, max minus min responses in percent. Darker shading denotes where responses have a confidence interval exceeding 90%.



Contour plot of the phase of the 11-yr term (in years from Jan. 1991). Phases that are within ±1 yr of Jan. 1991 (or of 2002) have darker shading. Positive O3 phases lag solar flux max.





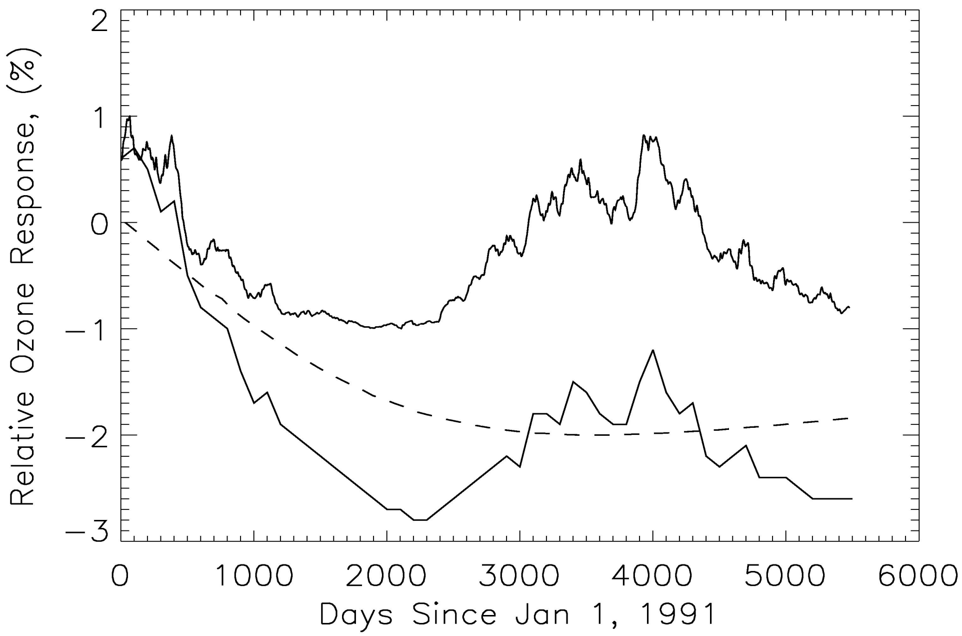
Profiles of both the 11-yr and the SC-like, max minus min responses (in %) for the tropical to subtropical ozone from HALOE. The SC-like response is its 11-yr response, but adjusted for any lack of phase coherence with the time of the max for the uv-flux. The solid curve is the model result for 5N from Brasseur [JGR, 1993].

Trend Terms in O3 for the MLR models

- Some analysts have fit a term to the ozone time series based on the variation of an associated proxy for either reactive or total chlorine (its so-called EESC proxy). Reactions with chlorine are the dominant chemical loss term for O3 in the upper stratosphere.

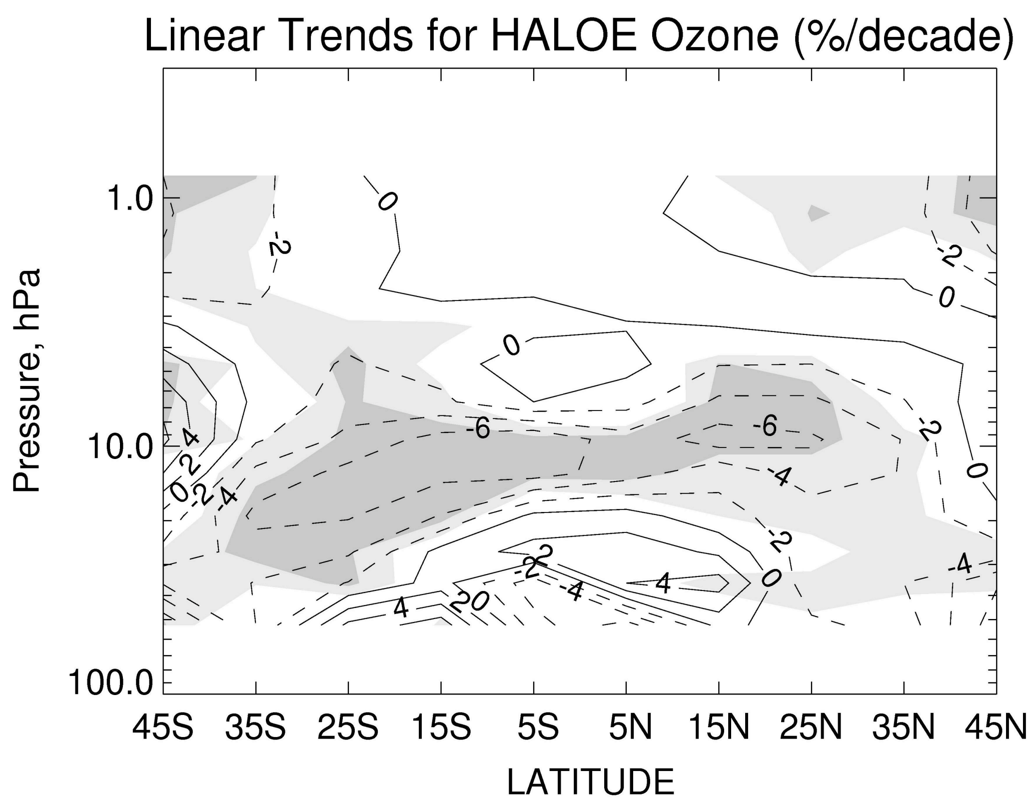
- The HALOE ozone was measured during a period when the effect of the chlorine was leveling off and/or beginning to decline slowly. The next panel illustrates the potentially confounding effects of an F10.7 cm solar flux proxy plus the negative forcing of an EESC proxy.

- Nevertheless, the effects of a simple linear fit are instructive for the present analysis and are essentially zero for the upper stratosphere, as shown in the second following panel.

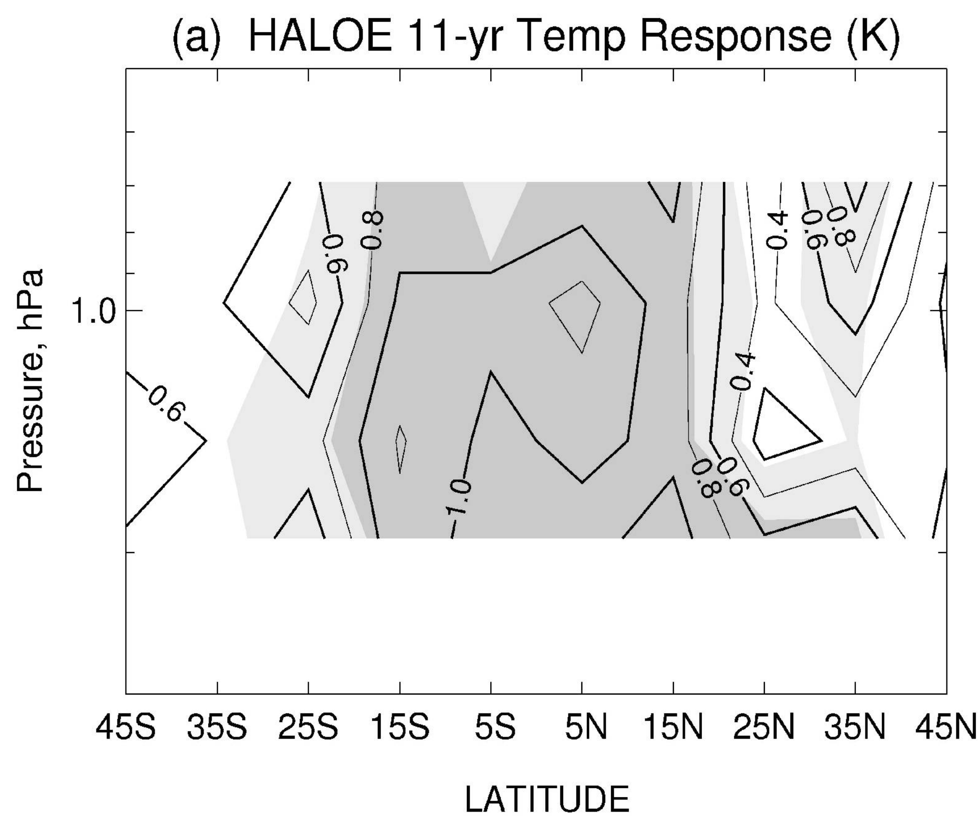


Top curve is the estimated response of ozone to a solar flux forcing. The dashed curve is the estimated response to the negative of an EESC proxy having a 4.5-yr age-of-air. The bottom solid curve is the sum of those two effects. Days 0 and 4000 are near solar max and day 2000 is near solar min.

Contour interval is 2%. The positive and zero trend contours are solid, while the negative trends are dashed. Darker shading denotes regions where the trends have a confidence interval exceeding 90%.



Associated, 11-yr max-minus-min temperature response from 2 to 0.7 hPa from the HALOE dataset. Contour interval is 0.2 K, and darker shading denotes where its significance is greater than 90% and is also in-phase with solar flux max.



Findings from the Analyses of the HALOE Ozone

- The diagnosed QBO and sub-biennial terms are reasonable physically.

- The diagnosed, 11-yr periodic terms are in-phase with the maximum for the solar uv-flux forcing in the middle to upper stratosphere, although they may be confounded somewhat by the effects of the changing chlorine.

- The amplitudes and patterns for the solar cycle (or SC-like) terms are reasonable; the response profiles of ozone from some chemistry/climate models agree with these HALOE results in the middle and upper stratosphere. Decadal-scale dynamical effects appear to be more dominant in the lower stratosphere.

- Solar occultation sampling is adequate for monitoring the seasonal and longer-term changes of ozone for the middle atmosphere.