JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D02303, doi:10.1029/2005JD006091, 2006

Comparison of recent modeled and observed trends in total column ozone

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Received 18 April 2005; revised 18 August 2005; accepted 4 November 2005; published 19 January 2006.

[1] We present a comparison of trends in total column ozone from 10 two-dimensional and 4 three-dimensional models and solar backscatter ultraviolet−2 (SBUV/2) satellite observations from the period 1979−2003. Trends for the past (1979−2000), the recent 7 years (1996−2003), and the future (2000−2050) are compared. We have analyzed the data using both simple linear trends and linear trends derived with a hockey stick method including a turnaround point in 1996. If the last 7 years, 1996−2003, are analyzed in isolation, the SBUV/2 observations show no increase in ozone, and most of the models predict continued depletion, although at a lesser rate. In sharp contrast to this, the recent data show positive trends for the Northern and the Southern Hemispheres if the hockey stick method with a turnaround point in 1996 is employed for the models and observations. The analysis shows that the observed positive trends in both hemispheres in the recent 7-year period are much larger than what is predicted by the models. The trends derived with the hockey stick method are very dependent on the values just before the turnaround point. The analysis of the recent data therefore depends greatly on these years being representative of the overall trend. Most models underestimate the past trends at middle and high latitudes. This is particularly pronounced in the Northern Hemisphere. Quantitatively, there is much disagreement among the models concerning future trends. However, the models agree that future trends are expected to be positive and less than half the magnitude of the past downward trends. Examination of the model projections shows that there is virtually no correlation between the past and future trends from the individual models.

Citation: Andersen, S. B., et al. (2006), Comparison of recent modeled and observed trends in total column ozone, *J. Geophys. Res.*, *111*, D02303, doi:10.1029/2005JD006091.

1. Introduction

[2] Declines in stratospheric ozone amounts have been observed for several decades over large parts of the globe [*Farman et al.*, 1985; *World Meteorological Organization/United Nations Environment Programme* (*WMO/UNEP*), 2003]. Because of the Montreal protocol and its amendments, the amount of ozone depleting substances in the stratosphere is now declining slightly [*WMO/UNEP*, 2003; *Montzka et al.*, 2003; *Barnes et al.*, 2003] and as a consequence an increase in stratospheric ozone may be expected. Ozone recovery is likely to occur in stages. The first signs of recovery are likely to include a reduction in the downward trend followed by positive trends in ozone. Final recovery may be realized as an overall return to predepletion ozone levels or as the determination that ozone levels are no longer being affected by anthropogenic ozone depleting substances. Studies showing the first signs of positive changes in trends in observed ozone amounts both for specific layers and the total column during the recent 7-year period from

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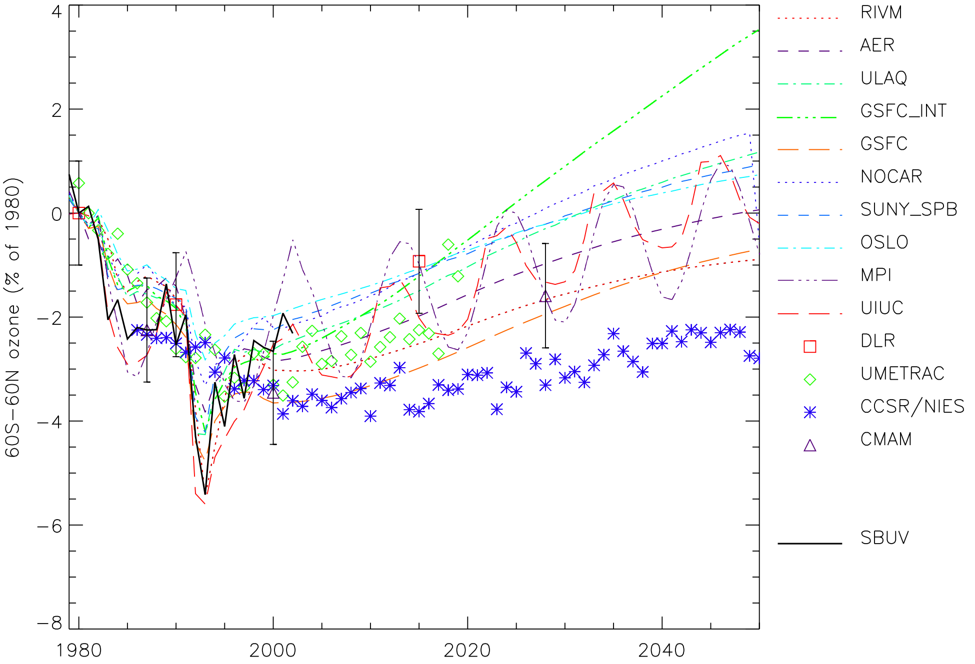

Figure 1. Model projections of the change in yearly average column ozone relative to 1980, averaged over 60°S–60°N. The dashed lines represent the results from ten 2-D models; symbols represent the results from three 3-D models. SBUV/2 observations are indicated by the thick solid line. For the CCSR/NIES and the CMAM models, results are scaled to the observed value in 1987 because they do not have a reference point in 1980.

1996 to 2003 are emerging [*Reinsel*, 2002; *Newchurch et al.*, 2003; *Reinsel et al.*, 2005].

[3] A number of two- and three-dimensional models predicting the future evolution of the stratospheric ozone layer are available. These models represent our current understanding of the chemistry and dynamics that govern ozone levels. All models predict recovery of ozone in the coming decades. However, the predicted positive trends vary significantly, e.g., from about 0.1 DU/year to about 0.5 DU/year at midlatitudes of both hemispheres. Also the date at which the predicted turnaround occurs varies. We present here an overview of the recovery rates for the total column predicted by the models together with observations.

[4] One objective is to try and assess whether the observed positive trends and changes in trends agree with our current understanding as represented by the models. We present a comparison of model results from 10 two-dimensional (2-D) models and 4 three-dimensional (3-D) models, along with observations.

2. Observations

[5] The observational data used for this study are zonally averaged solar backscatter ultraviolet−2 (SBUV/2) data (version 8) from the period from 1979 to 2003 [*Miller et al.*, 2002]. Total column ozone from the version 8 BUV algorithm should be more applicable to trend studies than total column ozone from Total Ozone Monitoring Spectrometer (TOMS) [*McPeters et al.*, 2004]. The data may be seen in Figure 1 as the thick black line for the 60°S to 60°N average. The data are presented as yearly average values, with no other processing. A decline in ozone has been observed for several decades. Increased ozone depletion due to injection of sulfuric acid particles into the stratosphere led to unusually low ozone in the period following the eruption of Mount Pinatubo in June 1991. Significant amounts of sulfuric acid particles were present until 1996 [*WMO/UNEP*, 2003]. This led to extremely low ozone values in 1992 and especially 1993. In this analysis we have omitted the data from 1993. In recent years, ozone appears to have been increasing. However, it is important to discern the recovery from the Mount Pinatubo aerosols from long-term recovery.

3. Models

[6] This study includes ten 2-D and four 3-D models. The following 2-D models are included: AER [*Rinsland et al.*, 2003], MPI [*Grooß et al.*, 1998], GSFC [*Fleming et al.*, 1999], GSFC_INT [*Rosenfield et al.*, 2002], NOCAR [*Portmann et al.*, 1999], OSLO [*Stordal et al.*, 1985], RIVM [*Velders*, 1995], SUNY-SPB [*Smyshlyaev et al.*, 1998], ULAQ [*Pitari and Rizi*, 1993], and UIUC [*Wuebbles et al.*, 2001]. The following 3-D models are included: UMETRAC [*Austin*, 2002], DLR E39/C [*Schnadt et al.*, 2002], CCSR/NIES [*Nagashima et al.*, 2002], and CMAM [*de Grandpré et al.*, 2000]. UMETRAC and CCSR/NIES are transient simulations, while E39/C and CMAM are time slice simulations. An overview of the models used in the comparison may be found in Table 1. Other models exist [e.g., *Chipperfield and Jones*, 1999]; however, we have chosen to include only models that make future projections.

[7] The 2-D model results are shown for the greenhouse gas scenario MA2 and the baseline halocarbon scenario AB [*WMO/UNEP*, 2003]. Reaction rates are from JPL 2000 [*Sander et al.*, 2000]. All models except RIVM include

Table 1. Models Used in the Comparison[a]

Name	Dimension	Length of Simulation	Horizontal Resolution	Number of Levels/ Upper Boundary	Solar Cycle	Temperature	Aerosol	Reference
RIVM	2-D	1979–2050	9.5°	29/100 km	no	climatology	*WMO/UNEP* [2003]	*Velders* [1995]
AER	2-D	1979–2050	9.5°	51/60 km	no	specified from NCEP	*WMO/UNEP* [2003]	*Rinsland et al.* [2003]
ULAQ	2-D	1979–2050	10°	25/71 km	no	specified from NCAR data set	*WMO/UNEP* [2003]	*Pitari and Rizi* [1993]
GSFC_INT	2-D	1979–2050	10°	46/100 km	no	calculated, interactive with CO_2, O_3, and H_2O	*WMO/UNEP* [2003]	*Rosenfield et al.* [2002]
GSFC	2-D	1979–2050	10°	46/92 km	no	specified from UKMO	*WMO/UNEP* [2003]	*Fleming et al.* [1999]
NOCAR	2-D	1979–2050	5°	55/112 km	no	calculated above 10 hPa (interactive with CO_2, O_3, H_2O, and CH_4); NCEP below 10 hPa	*WMO/UNEP* [2003]	*Portmann et al.* [1999]
SUNY_SPB	2-D	1979–2050	10°	46/90 km	no	specified from NCEP	*WMO/UNEP* [2003]	*Smyshlyaev et al.* [1998]
OSLO	2-D	1979–2050	10°	25/50 km	no	specified	*WMO/UNEP* [2003]	*Stordal et al.* [1985]
MPI	2-D	1979–2050	10°	31/60 km	yes	specified from CIRA/MAP	*WMO/UNEP* [2003]	*Grooß et al.* [1998]
UIUC	2-D	1979–2050	10°		yes	specified from NCEP	*WMO/UNEP* [2003]	*Wuebbles et al.* [2001]
E39/C	3-D	1960, 1980, 1990, 2015	3.75° × 3.75°	39/32 km	no	calculated	*WMO/UNEP* [2003]	*Schnadt et al.* [2002]
UMETRAC	3-D	1980–2020	2.5° × 3.75°	64/80 km	no	calculated	constant 2000 values	*Austin* [2002]
CCSR/NIES	3-D	1986–2050	5.6° × 5.6°	34/80 km	no	calculated	climatology	*Nagashima et al.* [2002]
CMAM	3-D	1980, 2000, 2045	2.5° × 2.5°	65/100 km	no	calculated	climatology, *WMO* [1992]	*de Grandpré et al.* [2000]

[a] All the 2-D models use the greenhouse gas scenario MA2 and the halocarbon scenario AB from *WMO/UNEP* [2003]. All 3-D models use the greenhouse gas scenario IS92a from *Intergovernmental Panel on Climate Change* (*IPCC*) [1992] and the halocarbon scenario Table 12-2 from *WMO* [1999]. Except for greenhouse gases, CMAM uses observations for 1987 and the same values for 2000, and CCSR/NIES uses *WMO* [1999].

polar heterogeneous chemistry, while only MPI and UIUC include the 11-year solar cycle. Aerosols included are monthly averages based on satellite data combined with constant aerosol loading for the future [*WMO/UNEP*, 2003]. The 3-D models are run with halogen amounts from *WMO* [1999], greenhouse gas amounts from IPCC IS92a scenario and base line aerosol loading under the assumptions described by *Austin et al.* [2003]. Because 2-D models have parameterized representations of the three-dimensional atmospheric dynamical processes, their results may be rough estimates for the higher latitudes, where ozone amounts are strongly influenced by zonally asymmetric processes. In general, the 3-D models are thought to be better at estimating dynamical factors.

[8] All the 2-D models simulate the whole period from 1979 to 2050. Different periods and time slices are available for the 3-D models; UMETRAC simulates the period 1979–2020; NIES simulates the period 1986–2050, DLR

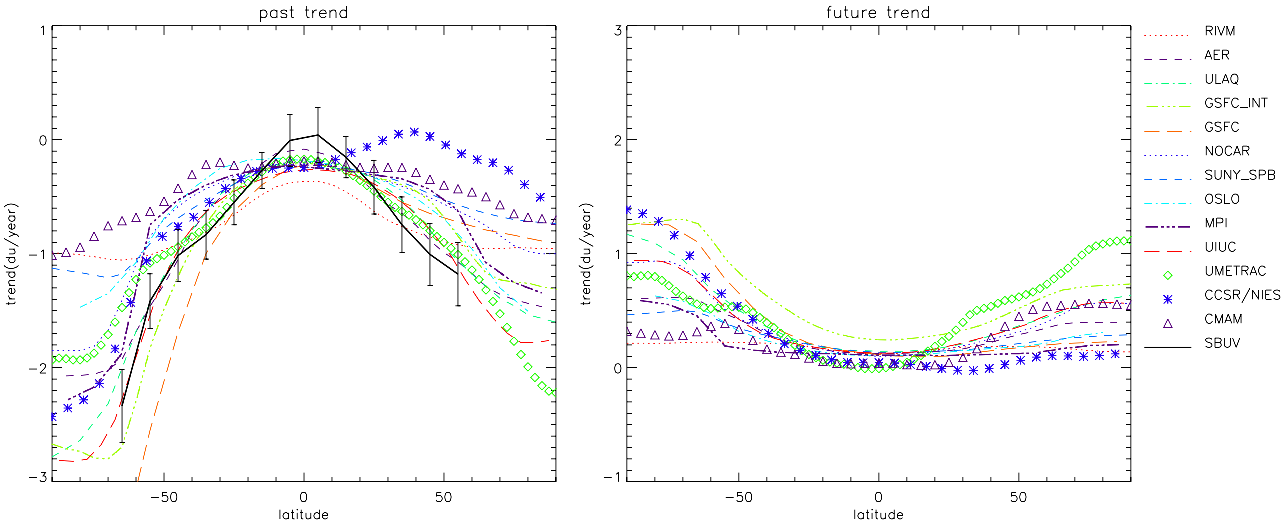

Figure 2. Modeled past (1979–2000) and future (2000–2050) trends in ozone as a function of latitude. The dashed lines represent the results from ten 2-D models; symbols represent the results from three 3-D models. SBUV/2 observations are indicated by the thick solid line. Note that for the 3-D models, not all years were available for the analysis. Indication of which years were used for the 3-D models may be found in the text.

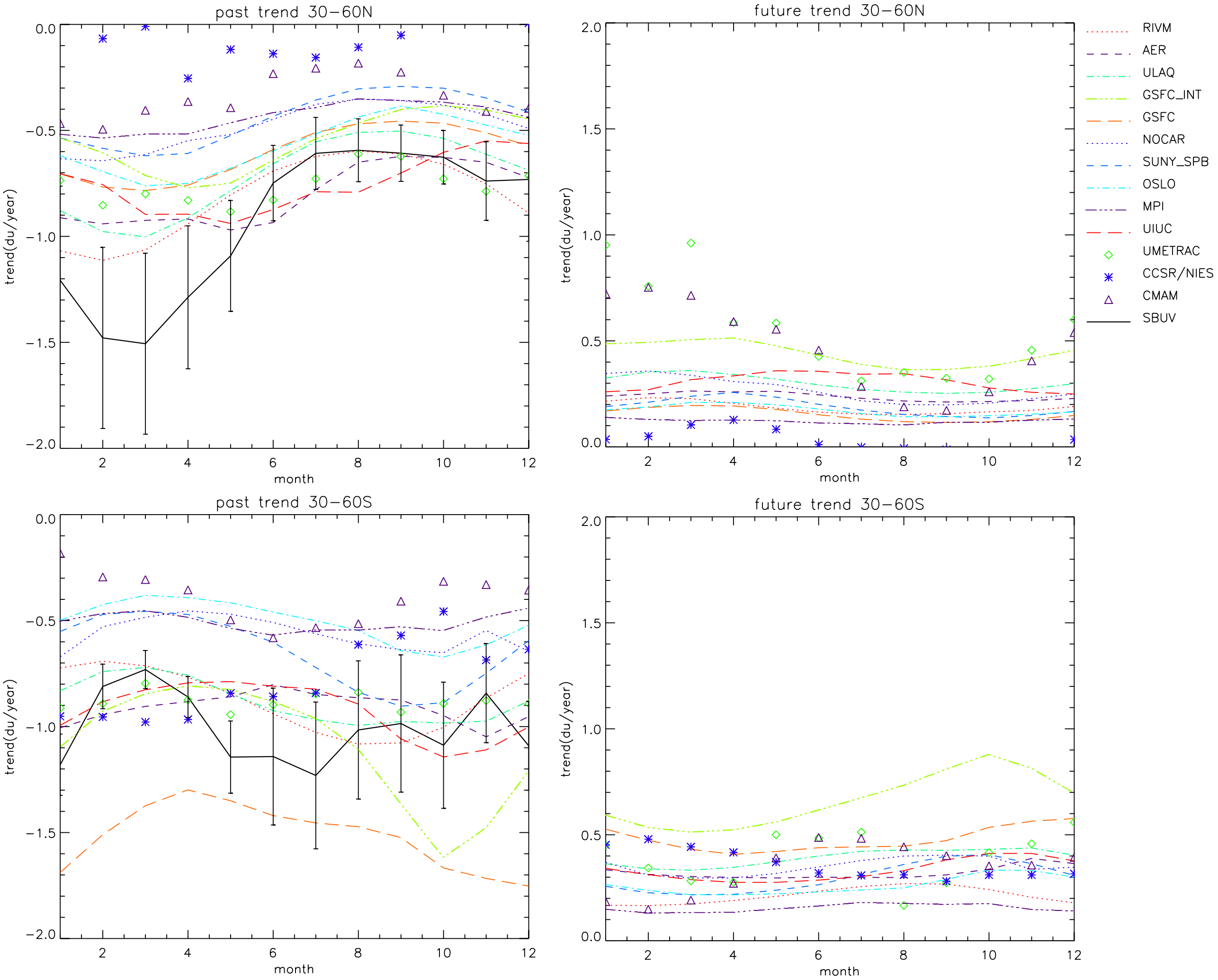

Figure 3. Modeled past (1979–2000) and future (2000–2050) trends in ozone as a function of season for the latitude bands 30°–60°N and 30°–60°S. The dashed lines represent the results from ten 2-D models; symbols represent the results from three 3-D models. SBUV/2 observations are indicated by the solid line. Error bars signify the 1σ uncertainty. Note that for the 3-D models, not all years were available for the analysis. Indication of which years were used for the 3-D models may be found in the text.

have time slices for the years 1960, 1980, 1990 and 2015; CMAM have time slices for the years 1987, 2000 and 2028. For the time slice simulations linear trends are assumed between the time slices.

[9] Figure 1 shows the change in total column ozone relative to 1980 for the latitude range 60°S to 60°N for all 2-D and 3-D models together with observations. For 60°S to 60°N, there is generally good qualitive agreement in the predictions for recovery. For instance, the models tend to indicate ozone minimums in the mid-1990s, followed by a slow, gradual increase. Ozone values in 2020 are lower than the 1980 values for all models. The 2-D model simulations used in the 2002 assessment [*WMO/UNEP*, 2003] differed from those in the prior WMO assessments in that they predict a more rapid recovery than what was presented in the 1998 Ozone assessment. About half of the models indicate recovery to 1980 levels by 2050. The results from the 2-D models for the midlatitudes indicate a range of recovery rates, from about 0.1 DU/year to about 0.5 DU/year at midlatitudes.

[10] The different 3-D model results indicate quite different future ozone levels from each other and the 2-D models. UMETRAC makes predictions through 2020. The predictions indicate slow recovery of a few percent between 2000 and 2020. CMAM makes estimates for 1987 and 2000 and a prediction for 2028. The CMAM prediction indicates slow recovery of a few percent between 2000 and 2028. E39/C makes estimates for 1960, 1980 and 1990, and a prediction for 2015. The 1960 estimates are about 6% higher than the 1980 modeled values. This large decrease from 1960 to 1980 has not been seen in measurements. The same rate of decrease is seen from 1980 to 1990. The 2015 results show improvement to levels above 1980 but lower than 1960. NIES, which makes predictions from 1986 through 2050, indicates very small trends over the whole period.

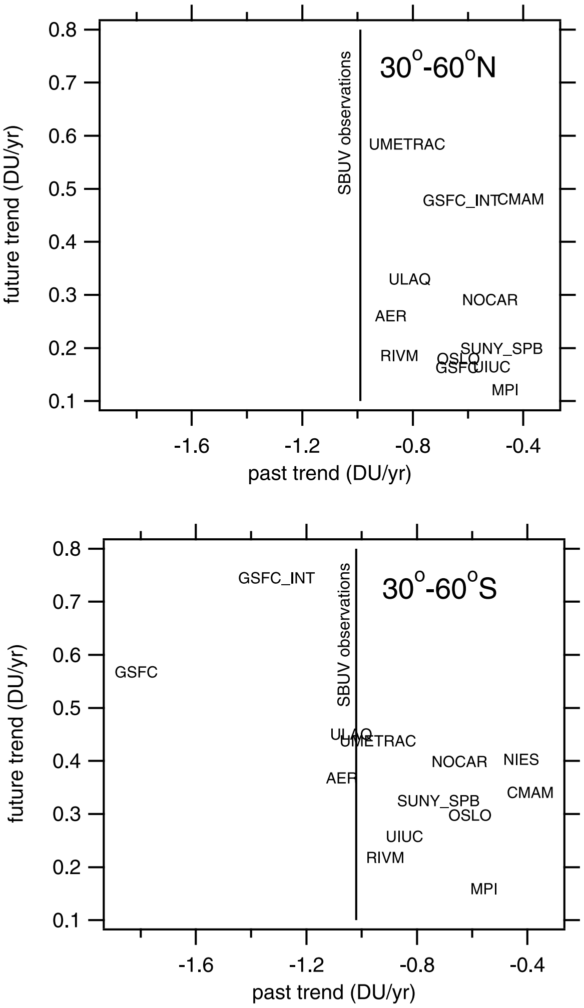

Figure 4. Scatterplot of future versus past trends in ozone for the latitude bands 30°–60°N and 30°–60°S. No correlation between past and future trends in ozone is found.

The CMAM and CCSR/NIES models have been scaled to the observed value in 1987 because they do not have a reference point in 1980.

4. Past Trends in Total Ozone

[11] Figure 2 shows the past (1979–2000) trends and the future (2000–2050) trends as a function of latitude. For the observations trends were calculated with the assumption of autoregressive components in the noise with one-month time lag. When examining the past trends as a function of latitude, there is not good quantitative agreement, in contrast to Figure 1. The relative magnitudes of the trends as a function of latitude show large differences from model to model. Most, but not all, models show a greater trend for the southern polar region than for the northern polar region. The deviations of the models with respect to each other and with respect to the observations are larger at higher latitudes suggesting that perhaps the polar ozone depletion is not simulated well or that the transport between poles and midlatitudes is not well understood. For CCSR/NIES and CMAM the past trends are calculated starting from 1986 and 1987 respectively. Thus the comparison with the observed trend for these models may be somewhat misleading. Especially for high latitudes since the Antarctic ozone hole was already established at the start of the calculations.

[12] Most models underestimate the past trend at middle and high latitudes. This is particularly pronounced in the Northern Hemisphere. At the equator and tropical latitudes, the past trends are within the error bars of SBUV/2 measurements for most models. However, the models systematically have larger trends than the observations. This may relate to an overestimate of transport across the equator. The combination of overestimating in some areas and underestimating in other areas gives the false impression of good agreement in a 60°S to 60°N average. This aspect is true of both the 2-D and 3-D models.

[13] In Figure 3 the past trends as a function of season for the northern and southern midlatitudes are shown. Observations of ozone trends at middle and high northern latitudes are marked by a strong annual cycle, with a peak occurring during the springtime and a decrease occurring in late summer and throughout the autumn months. The models reproduce this qualitatively; however, both 2-D and 3-D models underestimate the magnitude of this seasonal cycle. In the Southern Hemisphere midlatitudes this seasonal cycle in trend is much weaker and the models in better agreement with observations regarding the magnitude of the seasonal cycle. However, the spread in the modeled trends is larger in the Southern Hemisphere.

[14] The underestimation of the past trends may be partly due to the effect of aerosols related to the Mount Pinatubo eruption [*Solomon et al.*, 1998; *Miller et al.*, 2002]. However, the facts that data from 1993 were left out and past trends are calculated including the year 2000 should reduce the influence on the trends considerably.

[15] It is important to note that the observed past trends also exhibit an inherent uncertainty, both due to calibration issues and variability not directly related to ozone-depleting substances.

5. Future Trends in Total Ozone

[16] Similar to the past trends, the latitudinal shape of the expected future trends differs from model to model (Figure 2). Some of the models do not have calculations till 2050 (DLR ends in 2015, UMETRAC ends in 2020 and CMAM ends in 2028). However, the future trends appear approximately linear for the 60°N to 60°S average, and therefore comparing trends from different length models runs is valid to some degree.

[17] The models generally show a minimum in the trend at the equator, showing either a small positive or near-zero trend. The 3-D models set the upper and lower limits for projections at higher latitudes. In general, the model-to-model spread is comparable to the spread for the modeled past trends. At all latitudes, the expected future trends are positive but are much shallower than the depletion observed in the past. These slower recovery rates suggest that recovery may be more difficult to detect than the past depletion.

[18] The fact that past trends have been underestimated lends doubt to the magnitude of the future trends. This underestimation may be linked to the models' failure to

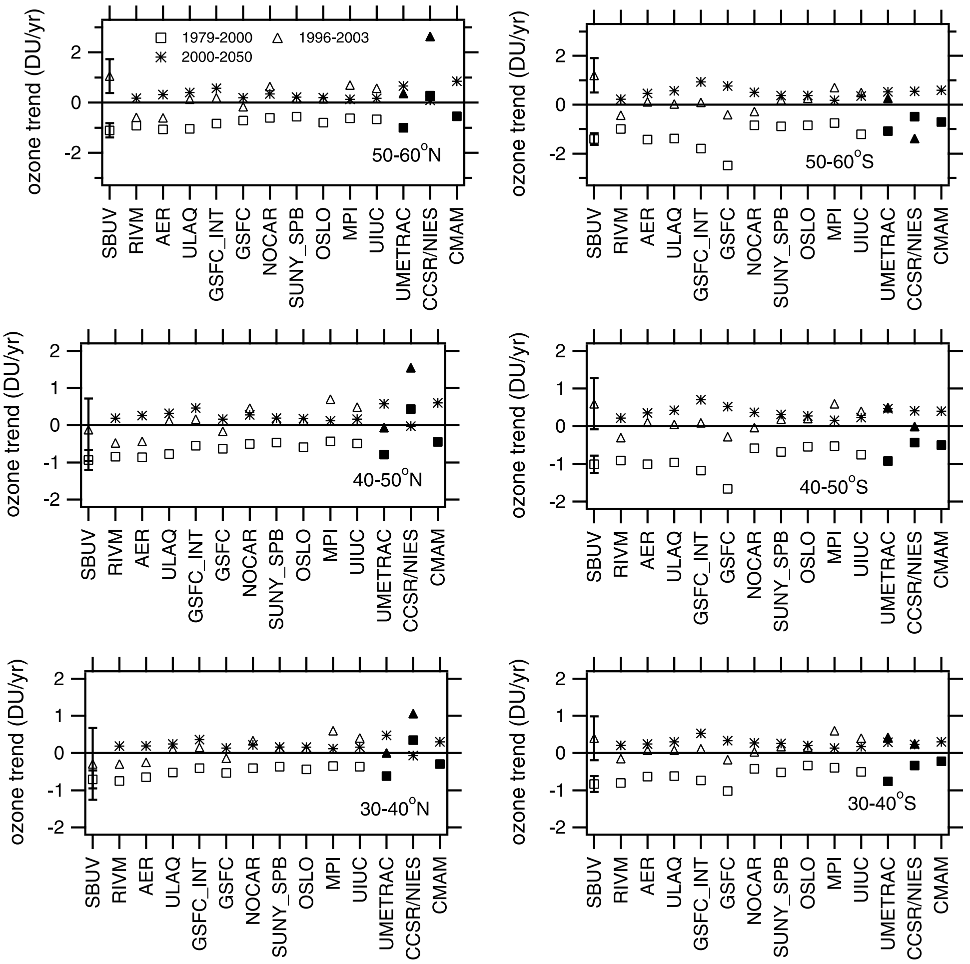

Figure 5. Observed and modeled ozone trends for three periods. The boxes represent the 1979–2000 time period, while the triangles represent the 1996–2003 time period and the stars represent the 2000–2050 projections. The SBUV/2 trend is included as the first point. The 3-D models may be distinguished as the three solid symbols at the end. A simple linear trend with no hockey stick or QSUM but with solar cycle and QBO subtracted was used. Error bars signify the 1σ uncertainty.

properly incorporate chemistry, dynamics, or other causes. If a factor is missing from the model and is likely to remain in future, the currently predicted trends may be too high. If a factor is missing from the models but is likely to change in the future (for instance, a decline in bromine concentrations), recovery rates may be more rapid than those estimated by the models.

[19] Stratospheric ozone undergoes large interannual variability. Each model may be considered a simulation or range of simulations of how ozone may evolve. The fact that the models differ from observations may be due to chaotic variability as opposed to variability introduced by external forcing such as CFCs or greenhouse gasses should also be considered.

[20] It is tempting to believe that models predicting a slower depletion would predict a slower recovery. However, examination of the model projections shows that there is virtually no correlation between the past and future trends (Figure 4). At higher latitudes, the models reporting the greatest expected future trends are not necessarily the ones reporting the greatest past trends. This lack of correlation is observed for both the 2-D and 3-D models and holds true no matter what latitude range is examined. It is also tempting to hope that the models which perform at a certain aspect, for instance the seasonal cycle or ozone at a particular latitude, would be more reliable in projecting the overall past trends; however, this is not the case. Models that did well simulating the timing and latitude of the springtime highs did not do any better at predicting the depletion. The ability of the models to reproduce autumn total ozone levels was also not correlated with their ability to simulate depletion. Overall, the ability to reproduce climatology did not correspond with a model's ability to accurately simulate past trends (not shown). Furthermore, no model consistently performed better across all parameters and no grouping of models, either 2-D or 3-D or of similar origin, was consistent in terms of overall behavior [*Andersen et al.*, 2004].

6. Analysis of Recent Data: 7-Year Trends

[21] There is substantial interest in examining the emerging data, particularly since 1996, for signs of recovery. Some models are predicting more rapid recovery during these years, perhaps due to the responses to short-lived

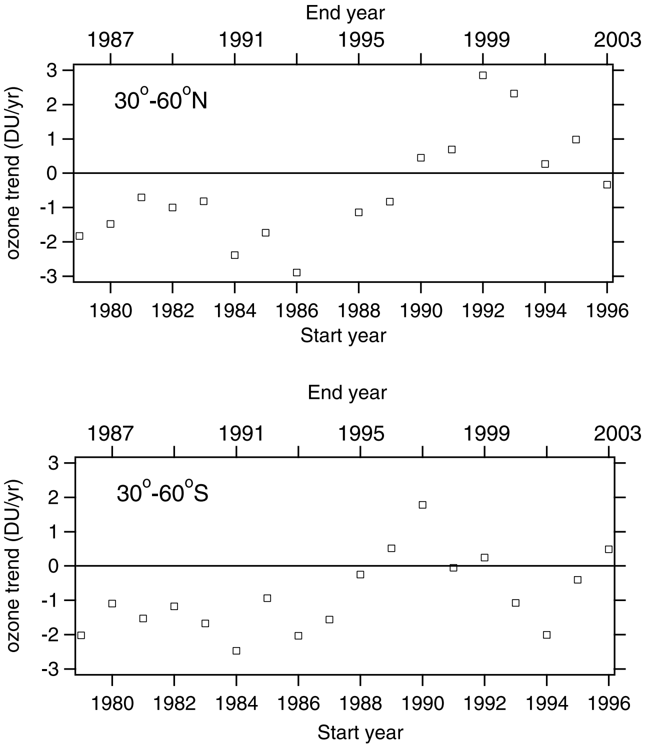

Figure 6. SBUV/2 trends for 7-year periods for the latitude bands 30°–60°N and 30°–60°S. A simple linear trend with no hockey stick or QSUM but with solar cycle and QBO subtracted was used. First point was calculated from start point January 1979 to end point December 1985, next point was calculated from January 1980 to end point December 1986, and so on.

halogens. However, most models suggest a more gradual recovery with an increasing magnitude of recovery rates over time. Previous studies including *Reinsel* [2002] and *Newchurch et al.* [2003] have examined changes in the ozone profile as well as total column ozone. There is some concern as to how much information can be derived from 7 years of data. In particular there is concern about whether 7 years of data are representative of a long-term trend.

[22] We examined the 1979–2050 results from the existing models as shown in Figure 5. The boxes represent the past trends while the triangles represent the 1996–2003 time period and the stars represent the 2000–2050 projections. The observed SBUV/2 trend is included as the first point. For the derived trends, the 1996–2003 data were analyzed in isolation: No hockey stick or CUSUM model was used. Both QBO and solar cycle were included in the trend model for the observations.

[23] For the period 1996–2003 the observations for the middle latitude Northern Hemisphere shows a small but continued depletion, this trend is in fact lower than what any of the models predict. This depletion shows large dependence on latitude with the data at 30°–40°N showing continued depletion and the data at 50°–60°N showing an upward trend of about 1 DU/year, which is larger than what the models predict. For the Southern Hemisphere the data show about a 1.5 DU/year trend, which is larger than what the models predict. The trends were derived both with and without the unusual Southern Hemisphere year 2002. Exclusion of this year did not make a significant difference in the trend results. Some of the models show continued depletion during the 1996–2003 time period. For most models, the trend is near zero.

[24] The existing 24-year SBUV/2 data set (1979–2003) was analyzed by deriving trends on successive 7-year periods. The results for 30°–60°N and 30°–60°S are shown in Figure 6. The results show predominantly negative trends for the first 15 years of data, consistent with the fact that a long-term downward trend was observed. The last 7 years of data do not look particularly unusual and show a near zero trend. The scatter observed in these plots illustrates how one 7-year period can suggest trends that are not representative of the long-term trend. Larger 7-year trends have been observed in several periods other than the most recent 7 years.

[25] The two most common methods of analyzing the ozone data for recovery are the "hockey stick" and CUSUM. *Reinsel* [2002] used a "hockey stick" model looking at deviations from what would be expected on the basis of past trends. *Newchurch et al.* [2003] used the CUSUM to assess changes in trends in the 40 km altitude region. These models analyze emerging data relative to past, allowing the past data to have downward trend.

[26] The "hockey stick" method which we will examine here is a piecewise linear trend model. From the start of the data to a turnaround point a simple linear trend (ω_1) is employed. From the turnaround point to the end point a second trend (ω_2) is introduced such that the overall trend from the turnaround point to the end point will be the sum of the two trends ($\omega_1 + \omega_2$). The method is described in detail by *Reinsel et al.* [2002].

[27] In particular for the hockey stick model, a trend may be derived through the end of 1995 leaving out the period immediately after Pinatubo [*Reinsel et al.*, 2005]. The years 1994 and 1995 therefore become critical references against which the recent data are compared. The analysis of the recent data depends greatly on the representativeness of these 2 years.

[28] Figure 7 shows the results of using the hockey stick method with a turnaround point in January 1996 for the data and models. The boxes represent the trends (ω_1) in the 1979–1996 time period while the triangles represent the trends ($\omega_1 + \omega_2$) in the 1996–2003 time period. In sharp contrast to the prior Figure 5 the recent data show positive trends for the Northern and Southern Hemispheres if the hockey stick is employed for both models and observations. The analysis shows that the observed recovery rate is steeper than any of the model predictions for the Northern Hemisphere and the Southern Hemisphere midlatitudes. The emerging data show an increase relative to the turnaround point. However, if the 7 years of data are examined in isolation, as in our analysis, virtually no trend is observed.

[29] Figure 8 shows the effect of employing the hockey stick method on the SBUV/2 data but using different years as a turning point. The results show that derived trend is relatively insensitive to the anchor point. The results show that trends derived using the hockey stick method with a turning point any time after 1991 are positive. This is because all the recent data are being evaluated relative to the very low ozone values in the early 1990s. Positive trends

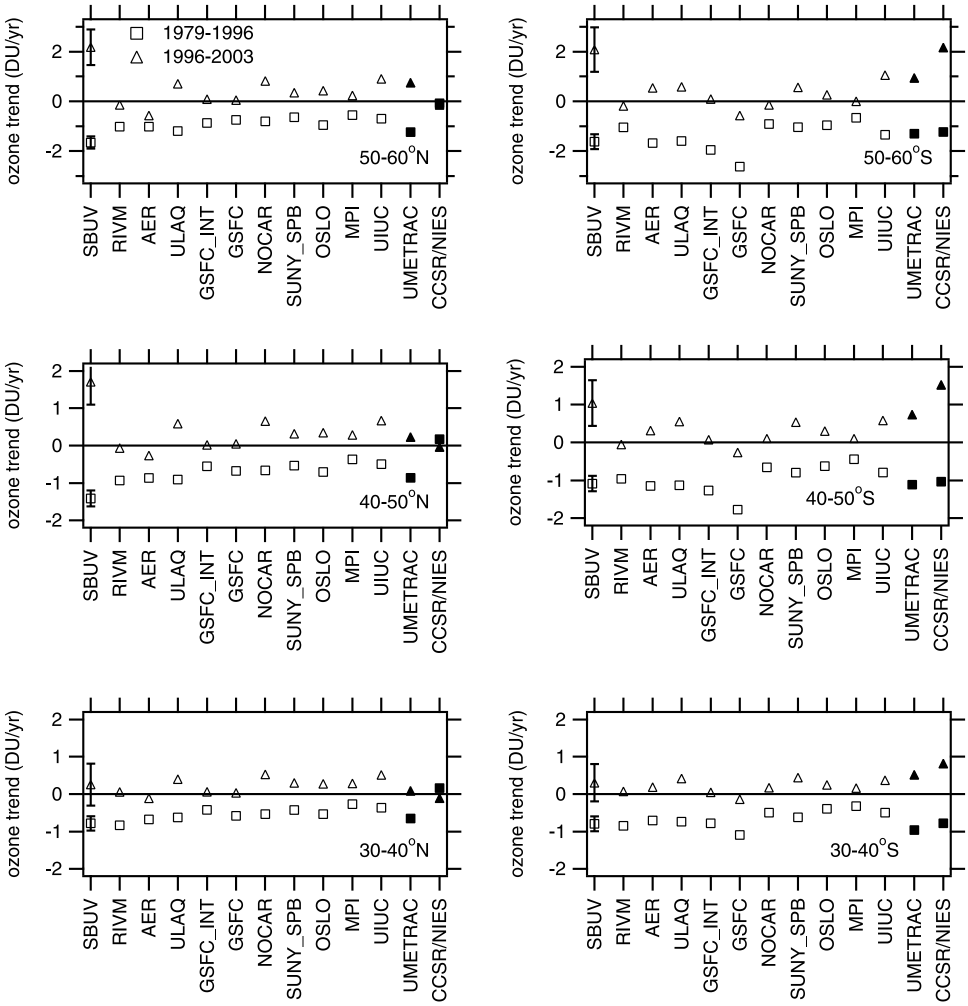

Figure 7. Observed and modeled ozone trends derived using the hockey stick method with a turn point in January 1996. Solar cycle and QBO were subtracted. The boxes represent the trend for the 1979–1996 time period (ω_1), while the triangles represent the trend for the period 1996–2003 ($\omega_1 + \omega_2$). The SBUV/2 trend is included as the first point. Error bars signify the 1σ uncertainty.

are derived if the data are evaluated relative to the early 1990s data yet near zero trends are derived if the data are evaluated in isolation. This underscores the importance of the representativeness of the values in the early and middle 1990s. When comparing the observations with the models, we find that the observed values were lower than the models predicted. This underestimation may be partly due to the effect of aerosols related to the Mount Pinatubo eruption. For the Northern Hemisphere another explanation may be the very low polar stratospheric temperatures experienced during these years [*Pawson and Naujokat*, 1997].

[30] When comparing the observed and modeled ozone trends for recent years derived using the hockey stick method, we find that there is a mismatch mainly due to the low observed values in the early and middle 1990s. There are two possible explanations for this mismatch. Either the observed values in the early and middle 1990s were not representative of the overall trend, meaning that a trend derived using these years as anchor point may not be reliable, or the models are missing important chemistry, dynamics or other factors.

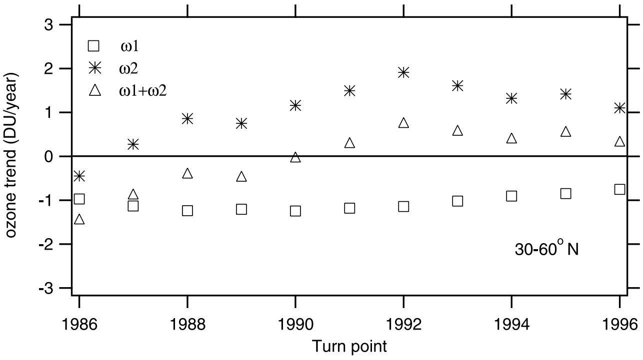

Figure 8. SBUV/2 trends derived using the hockey stick method with varying turn point. Solar cycle and QBO were subtracted. The squares represent the trend from 1979 to the turn point, the asterisks represent the change in trend, and the triangles represent the resulting trend from the turn point and 7 years ahead.

[31] Attribution of any increases during the most recent years is even more important than identification of the change itself. The positive trends particularly at high northern latitudes are larger than would be expected because of the small decrease in halogen loading of the atmosphere. In the Arctic a series of very cold winters in the early and middle 1990s resulting in large ozone depletion have been followed by a series of very warm winters with less ozone depletion in recent years [*Manney et al.*, 2005]. Since the Arctic ozone loss has a significant influence at midlatitudes this may influence the ozone trends significantly [*Knudsen and Andersen*, 2001]. Other factors may also have contributed to lower ozone levels in the early and middle 1990s and higher levels in the recent years. Some increase in total column ozone is expected during the most recent 7 years because the 11-year solar cycle peaked in 2000–2002, as can be seen in the models including the solar cycle recent observations showing a peak in global ozone around 2003 and a decrease after that. The increase in ozone during the recent 7 years is therefore partly due to the solar cycle [*Steinbrecht et al.*, 2004; *Claude et al.*, 2005] (the latter is available at http://www.dwd.de/de/FundE/Observator/MOHP/hp2/ozon/bulletin.htm). The amount of influence is still uncertain, however, since there is a large scatter in the different data sets and models. The volcanic aerosol loading of the stratosphere has been very low in recent years, which may contribute to increased ozone amounts.

7. Conclusion

[32] The models offer a qualitative understanding of what will happen to ozone in the coming years. Quantitatively, there is much disagreement among the models, both in terms of climatology and trends. However, the models agree that future trends are expected to be positive and less than half the magnitude of past downward trends. Efforts to identify models that perform better in terms of climatological aspects of ozone as well as in terms of past trends failed. It is therefore difficult to establish which models will produce the most likely or realistic future trends.

[33] Most models underestimate the past trend at middle and high latitudes. This is particularly pronounced in the Northern Hemisphere springtime. There is virtually no correlation between the past and future trends of the individual models. Thus a model that calculated a steep past trend will not necessarily predict a steep recovery.

[34] We have analyzed the models and data in order to assess if the recent positive trends or changes in trends observed agree with our current understanding as represented by the models. If the last 7 years, 1996–2003, are analyzed in isolation, the SBUV/2 observations show no ozone recovery and most of the models predict continued depletion, although at a lesser rate. In sharp contrast to this the recent data show positive trends for the Northern and Southern Hemispheres if the hockey stick method with a turnaround point in 1996 is employed for the models and observations. The analysis shows that the observed increase is much steeper than what is seen in any of the models for both the Northern Hemisphere and the Southern Hemisphere. The trends derived with the hockey stick method are very dependent on the values just before the turnaround point. The analysis of the recent data therefore depends greatly on these years being representative of the overall trend.

[35] In general the observed trends at middle and high latitudes seem to be underestimated by the models. This is the case both for the past negative trends and the positive trends in the recent 7 years. There may be several reasons for this underestimation. The models may be missing important chemistry, dynamics or other factors. Aerosols related to the Mount Pinatubo eruption will have affected the years before 1996 significantly. The increase due to the solar cycle is uncertain and not included in many of the models. The observed values close to the selected turnaround point in 1996 may not be representative of the long-term trend.

[36] **Acknowledgment.** This work was supported by the Danish National Science Foundation, EU project CANDIDOZ (EVK2-2001-00024), EPA, and NASA and was performed partly in the United States with support from the Danish-American Fulbright commission.

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