A CCM Simulation of the Change in Stratospheric Ozone, Temperature, Zonal-wind, and Breakup Date of the Antarctic Polar Vortex in the Years 1980-2004

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Abstract

The changes in breakup time of the Antarctic polar vortex in the years 1980-2004 are examined using the output of Chemistry-Climate Model (CCM) calculations, data from the National Centers for Environmental Prediction / the National Center for Atmospheric Research (NCEP/NCAR) Reanalysis, and data from the European Centre for Medium Range Weather Forecasts Re-Analysis (ERA40). The CCM used in this study is from the Center for Climate System Research/National Institute for Environmental Studies (CCSR/NIES). The CCM calculations are performed with the two ensemble members for REF1 scenario of the Chemistry Climate Model Validation (CCMVal) and the one ensemble member for the REF2 scenario.

The CCM well simulates the development of the ozone hole from 1982 to 2000 as observed with a Total Ozone Mapping Spectrometer (TOMS), although the year-to-year variation is different from the observation owing to the internal variability of CCM and the ozone decreasing trends of CCM ozone in the two ensemble members of REF1 are underestimated. The trends in temperature and zonal-mean zonal wind are analyzed and compared with the observations. There is consistency among the trends in zonal-mean temperature, zonal-mean zonal wind, and total ozone, but they differ among the ensemble members and observations. The radiation and Eliassen-Palm flux fields are investigated in order to explain the differences. A delay trend in the breakup time of the Antarctic polar vortex is obtained for the period 1980 to 1999 in the NCEP/NCAR and ERA40 data. A similar trend is also obtained from the CCM simulations, with statistical significance in one ensemble member of REF1 and the REF2. Because the trends of the observations in the EP flux from the troposphere and its deposition in the lower stratosphere are advanced, as opposed to delayed, breakup dates of the polar vortex, and because the trends of the CCM simulations are very small, it is highly likely that the Antarctic ozone depletion and greenhouse gas build-up had some effect on the delay during the period 1980 to 1999, by strengthening the polar night jet and the annular mode in the Southern Hemisphere.

From 2000 to 2004, the NCEP/NCAR data show a large variation in breakup time, which makes the delay trend much less important. It is likely that the large variation in wave flux masked the effects of the ozone loss and greenhouse gas build-up during that period. The two ensemble members of the REF1 simulation do not show such a dramatic change in the trend for the period 2000 to 2004, while the REF2 shows a change in the trend for that period.

1. CCSR/NIES CCM

- A CCSR/NIES CCM has been developed from a version 5.4g of CCSR/NIES AGCM, adding the chemical module for the stratosphere.
- T42 horizontal resolution (2.8° × 2.8°) with 34 vertical atmospheric layers of 70 km top.
- 170 gasphase chemical reactions of Ox, HOx, NOx, CHOx, ClOx, and BrOx for the stratosphere
- Bromine budget is increased by adding 1.8 pptv of CHBr3 at the surface, which results in a 5.4 pptv more Bry in the stratosphere than that from the halogen scenario for CCMVal-REF2.
- Heterogeneous reactions on STS, NAT, and ICE [*Sessler et al.*, 1996]
- Gravity wave paremeterization by *Hines* [1997] and Rayleigh friction are included.
- Greenhouse gas scenario, halogen scenario, solar variability, QBO, surface area of the volcanic aerosol are included following the recommendation values for REF1 and REF2 of CCMVal.
- HadISST1 is used for REF1 calculations and SSTs calculated by an atmosphere-ocean coupled model (MIROC, CCSR/NIES/FRCGC) with the IPCC-A1B scenario are used for REF2 calculation.
- Aerosol optical depth data by *Sato et al.* [1993] are used for radiation calculations.

2. The REF1 and REF2 runs

Two REF1 runs and one REF2 run are performed with the T42 CCM. They are named REF1_00, REF1_01, and REF2. The runs started with the initial atmosphere for January 1, 1975, where Cly and Bry in the stratosphere are consistent with the concentration of these source gases at the ground level for 1970. The outputs 1980 to 2004 are analyzed.

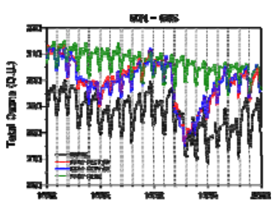


Fig.1 Time series of the total ozone averaged over 60°N - 60°S. Black, red, blue, and green lines denote TOMS data, CCM-REF1_00, CCM-REF1_01, and CCM-REF2, respectively. ←

3. Model validation – regression analysis of trends

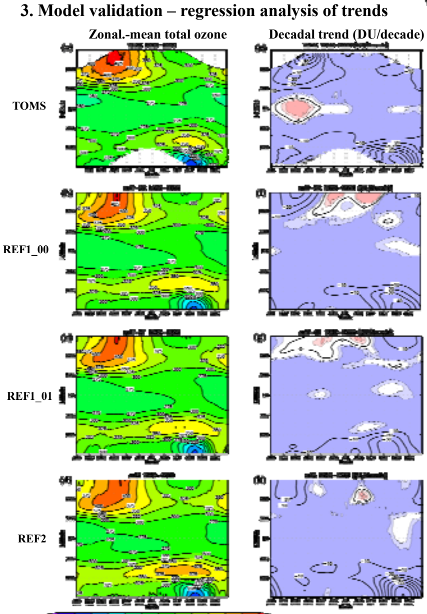


Fig.2 Time series Month-latitude section of the zonal-mean total ozone averaged over 1980-1999 (left) and the decadal trend for that period (right). (a) TOMS data. (b) CCM-REF1_00. (c) CCM-REF1_01. (d) CCM-REF2. (e) Trend in total ozone of TOMS data (DU/decade). (f) The trend of CCM-REF1_00. (g) The trend of CCM-REF1_01. (h) The trend of CCM-REF2. The color scale for the total ozone map (the left panels (a)-(d)) is shown at the bottom left and the contour interval is 25 DU. The contour interval for the right panels ((e)-(h)) is 10 DU decade-1. Light and dark shadings in the right panels denote the 95 and 99% significance levels for Student's t-test, respectively. ←

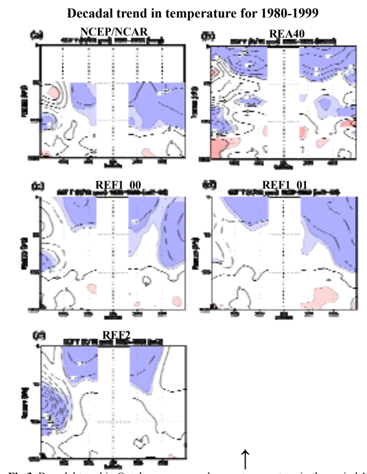
Regression analysis [*Ziemke et al.*, 1997]

$$Y(t) = C_0 + a\,t + b\ \mathrm{solar}(t) + d\ \mathrm{QBO}(t) + d'\mathrm{QBO}(t\text{-7-months}) + e\ \mathrm{ENSO}(t) + f\ \mathrm{Volcanic}(t) + R(t),$$

t=1, 2, …, 180 (month, for Jan.1980 to Dec.2004), C_0 is a constant, and a is the linear trend term.

$$a = A_0 + a_1 \cos(2\pi t/12) + a_1' \sin(2\pi t/12) + a_2 \cos(2\pi t/6) + a_2' \sin(2\pi t/6) + a_3 \cos(2\pi t/4) + a_3' \sin(2\pi t/4),$$

where A_0 is the trend shown here.



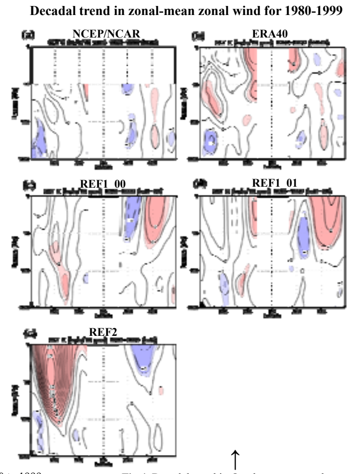


Fig.3 Decadal trend in October-mean zonal-mean temperature in the period 1980 to 1999 as a function of the latitude and pressure level (hPa). (a) NCEP/NCAR data. (b) ERA40 data. (c) CCM-REF1_00. (d) CCM-REF1_01. (e) CCM-REF2. The contour interval is 1 K decade-1, and the negative values are indicated by dotted lines. Light and dark shadings denote the 95 and 99% significance levels for Student's t-test, respectively. The trend calculation is not performed at 20°S-20°N

Fig.4 Decadal trend in October-mean zonal-mean zonal wind in the period 1980 to 1999 as a function of the latitude and pressure level (hPa).

For 2000-2004, **the trends of NCEP/NCAR show a substantial change due to the unusually unstable Antarctic polar vortex in 2002.**

4. Trends in the breakup time of the Antarctic polar vortex, EP-flux, and the EP-flux divergence

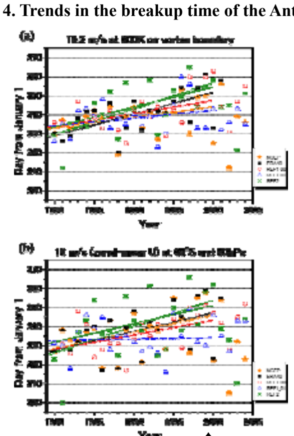


Fig.5 Breakup dates of the Antarctic polar vortex as a function of the years 1980-2004. (a) Breakup dates calculated by the method of *Nash et al.* [1996] with a critical value of the horizontal wind speed of 15.2 ms-1. Closed orange stars, closed black squares, open red circles, open blue triangles, and green crosses denote the breakup dates calculated from the NCEP/NCAR data, the ERA40 data, CCM-REF1_00, CCM-REF1_01, and CCM-REF2, respectively. The dashed straight lines are linear regressions of the symbols for the period 1980 to 1999, corresponding to each color. The green solid straight line indicates the linear regressions excluding 1981 of REF2. (b) Same as (a), but the breakup dates are calculated by the method of *Langematz and Kunze* [2006] using the zonal-mean zonal wind at 65°S and 50 hPa with a threshold value of 10 ms-1.

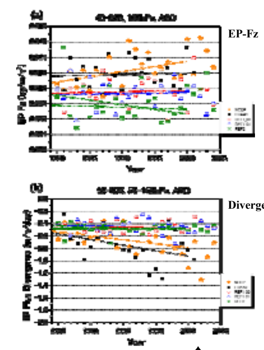


Fig.6 (a) August-September-October mean vertical component of EP flux (kg m-1 s-2) averaged at 40-80°S and 100 hPa as a function of the years 1980-2004. Closed orange stars, closed black squares, open red circles, open blue triangles, and green crosses denote the *EP-Fz* calculated from the NCEP/NCAR data, the ERA40 data, CCM-REF1_00, CCM-REF1_01, and CCM-REF2, respectively. The dashed straight lines are linear regressions of the symbols for the period 1980 to 1999, corresponding to each color. The green solid straight line indicates the linear regressions excluding 1981 of REF2. (b) August-September-October mean EP flux divergence (m s-1 day-1) averaged at 40-80°S and 50-150 hPa as a function of the years 1980-2004. The EP flux divergence of NCEP/NCAR is an average at 100-150 hPa

5. Summary

Blue: Consistent with the delay trend in the breakup time of Antarctic polar vortex with statistical significance of one standard deviation
Red: Not consistent with the delay trend with the statistical significance Black: no trend

	NCEP/NCAR	ERA40	REF1_00	REF1_01	REF2
Breakup Date (at polar vortex boundary on 500 K) **(day/year)**	**0.56±0.30**	**1.14±0.31**	**0.71±0.31**	**0.42±0.36**	**1.36±0.40** ***1.07±0.38**
Breakup Date (at 65°S and 50 hPa) **(day/year)**	**0.88±0.42**	**1.00±0.42**	**0.78±0.33**	0.08±0.35	**1.39±0.53** ***0.97±0.50**
Diabatic Heating Rate at 70-90°S, 50 hPa, Oct. **(K/day /year)**			**-0.0094±0.0025**	**-0.0074±0.0017**	**-0.0057±0.0025** ***-0.0083±0.0020**
EP-Fz at 100 hPa, Aug.-Sep.- Oct. **(kg/m/s /year)**	**(1.34±0.70)×10-4**	(0.14±0.71)×10-4	(0.18±0.62)×10-4	(0.15±0.68)×10-4	**(-1.21±0.93)×10-4** *(-0.25±0.75)×10-4
EP-Fz at 100hPa, Nov.-Dec. **(kg/m/s /year)**	**(0.91±0.42)×10-4**	(0.51±0.52)×10-4	(-0.24±0.82)×10-4	(-0.34±0.83)×10-4	(-0.25±1.18)×10-4 *(-1.04±1.16)×10-4
EP flux convergence at 50-150 hPa, Aug.- Sep.- Oct. **(m/s/day /year)**	**(1.26±0.57)×10-2**	**(1.79±1.06)×10-2**	(-0.12±0.38)×10-2	(0.11±0.46)×10-2	(0.007±0.36)×10-2 *(0.32±0.32)×10-2
EP flux convergence at 50-150 hPa, Nov.- Dec. **(m/s/day /year)**	**(0.83±0.73)×10-2**	**(1.74±0.73)×10-2**	**(-0.98±0.79)×10-2**	(-0.004±0.68)×10-2	**(-2.39±1.21)×10-2** ***(-2.62±1.31)×10-2**

*** 1981 of REF2 is excluded.**