AGU MANUSCRIPTS
Submitted to *International Journal of Geomagnetism and Aeronomy*, 2002

# A possible role of the ocean in the interannual variations of the Arctic and Antarctic Oscillations and the ozone layer

E. A. Jadin

Central Aerological Observatory, Dolgoprudny, Moscow Region, Russia

Short title: A POSSIBLE ROLE OF THE OCEAN

**Abstract.** Analysis of the interannual variations of the sea surface temperature (SST) in the North Atlantic and North Pacific as well as the circulation of the polar stratospheric vortex in the Arctic associated with the Arctic Oscillation (AO) are considered for January in 1979–1992. It is shown that the interannual variations of the stratospheric angular momentum in the Arctic had a dipole-like structure in the west and east Arctic caused by the longitudinal asymmetry of the stratospheric warming forcing on the zonal stratospheric winds. Strong correlations of the stratospheric vortex variability with the well defined spatial pattern of the SST anomalies in the North Atlantic and North Pacific are detected. This spatial pattern is characterized by a dipole variations of the SSTs in the centers of action southward from Aleutes and in the vicinity of the Newfoundland (a dipole "across Rocky mountains"), as well as the known SST anomalies in the North Atlantic which are associated with the North Atlantic Oscillation (NAO). A possible mechanism of the Arctic Oscillation generation can be related to the long-term changes of the SST anomalies in this structure, which result in changes of the thermal excitation of planetary waves and its interference with the topographic source. Similar picture is revealed for the SST's dipoles across Andes and South Africa in the Southern Hemisphere in October 1979–1992. The relations between the interannual variations of the SST anomalies, Arctic and Antarctic Oscillations, stratospheric circulation and total ozone changes are discussed.

# Introduction

The ocean–atmosphere interaction on the interannual and decadal time scales is a key element not only for studies of the climate changes, but also for deeper understanding of the causes of the ozone layer trends in the Northern (NH) and Southern (SH) Hemispheres. Long-term changes of the stratospheric dynamics can lead to creation of favorable conditions for known chemical mechanisms of the ozone layer destruction (stronger isolation of the polar vortex in the Antarctic and Arctic, cooling of the lower stratosphere, formation of the polar stratospheric clouds, heterogeneous reactions and a decrease of the eddy ozone exchange with middle latitudes). From this point of view, the occurrence of the ozone hole in the Antarctic and ozone variations at middle and high latitudes in the Northern Hemisphere during the past two decades can be a manifestation of the unusual long-term changes in the coupled ocean-atmosphere system [*Jadin and Lysenko*, 1988].

The decadal signal can be easily detected in the stratosphere because of a large high-frequency noise in the troposphere which is associated with weather systems. Planetary waves penetrating from the troposphere into the stratosphere during winter play a large role in the interannual and decadal variations of the extratropical stratospheric circulation and ozone layer. Stationary planetary waves are generated by topographic source (Rockies, Tibeth in the NH and Andes in the SH) and via a thermal excitation which depends on the sea surface temperature (SST) anomalies. Therefore, there should exist a relationship between the interannual and decadal variations of the SSTs, stratospheric dynamics, and ozone. Indeed, some correlations of the ozone hole development in the Antarctic with the El Niño–Southern Oscillation (ENSO) have been indicated by *Angell* [1988], *Kodera and Yamazaki* [1989], *Komhyr* [1991]. The influence of the ENSO on the total ozone variations seems to be small as compared with the anthropogenic impacts [*WMO*, 1991]. However, *Jadin* [1992] found a high correlation between the interannual SST anomalies in the North Atlantic and total ozone changes over Europe in January 1965–1988. This fact may be an evidence of a large influence of the extratropical SST anomalies on the ozone layer.

Mechanisms of the extratropical SST anomaly forcing on the atmosphere are unknown despite of numerous investigations [*Kushnir et al.,* 2001]. It is believed that the extratropical SST anomalies are generated mainly by the atmospheric wind stresses. The inverse influence of the SST anomalies on the atmosphere is poorly understood. The general circulation model (GCM) experiments with prescribed SST anomalies, as it seems, failed to provide an incontrovertible response of the atmosphere to the SST anomalies [*Kushnir et al.*, 2001]. This is possibly due to the fact that only a small part of the extratropical SST anomalies generates a large atmospheric response; other SSTs create a "noise" in the GCM experiments which can mask strongly a real signal in the model simulations. Possible mechanism of the extratropical SST forcing on the atmosphere may be related to the wave hypothesis [*Jadin*, 1990] explaining the natural ozone and climate changes. The core of the hypothesis is an interference of the thermal and topographic excitations of planetary waves. The numerical experiments in the mechanistic model of stationary wave propagation have shown that the stratospheric wave activity changes depend strongly on the eastward longitudinal shifts of the SST anomalies, but much weaker on their amplitude changes [*Bromberg and Jadin*, 1991; *Jadin*, 1990], Such shifts of the SST anomalies can result in either constructive (an amplification of wave activity in some regions) or destructive interference with the steady topographic (Rocky mountains) source. According to this simple mechanism, strong relations between the interannual and decadal variations of the stratospheric circulation, total ozone, and SST anomalies in the North Pacific and North Atlantic with a well-defined structure should be observed during the wintertime.

*Jadin* [1996, 1999], *Jadin and Diansky* [1996] showed that the interannual zonal mean variations of the total ozone in the extratropics correlate very well with the stratospheric angular momentum (SAM) changes which are defined as the atmospheric angular momentum [*Rosen and Salstein*, 1985] at the 100 hPa- to 0.4 hPa level. Strong relations are observed between the development of the ozone hole in the Antarctic and the SAM variations in the vicinity of the Antarctic polar vortex. Unusual large westerlies have arisen in the subtropical lower stratosphere in 1980 and propagated toward high latitudes resulting in a stronger isolation of the polar vortex in the Antarctic and Arctic during the next years [*Jadin*, 1996]. This displacement is similar to the V-shaped propagation of the low-frequency tropospheric angular momentum variations [*Dickey et al.*, 1992]. The linkage between the total ozone and stratospheric circulation changes cannot be explained by the influence of the ozone reduction on the radiative regime, because the dynamical changes precede the appearance of the ozone hole in September–October [*Jadin*, 1996; *van Loon and Tourpali*, 1995]. A decadal change of the stratospheric circulation in the SH have been noted also by *Kawahira and Hirooka* [1992].

During recent years, a steady attention is attracted to studies of the relations between the interannual and decadal variations of the troposphere–stratosphere coupling. *Baldwin et al.* [1994] noted that the interannual variations of the stratospheric polar vortex in the Arctic correlate well with the North Atlantic Oscillation (NAO), but not with the other tropospheric teleconnections at the 500 hPa height, although there are some differences between the NAO and the mode which is responsible for their strongest relations. It has been also shown that the zonal mean variations of the zonal winds in the troposphere and stratosphere at high latitudes correlate very strongly with the difference in the 500 hPa height between 62°N, 80°W and 58°N, and 100°E. This can imply that the interhemispheric differences of the middle tropospheric circulation can be a good indicator of the interannual and decadal variability of the atmosphere as a whole. *Thompson and Wallace* [1998] showed that the first leading mode of the long-term changes in the sea level pressure and geopotential at 1000 hPa northward from 20°N is tightly associated with the leading mode of the stratospheric polar vortex variability in the Arctic (Arctic Oscillation (AO)). It was also shown that the time series of the leading mode of the sea level pressure (AO index) changed considerably after the late 1960's. This fact provides an evidences of strong climate changes during the recent decades, the changes being manifested in a stronger isolation of the stratospheric vortex in the Arctic. The basic features of its spatial pattern in the middle troposphere are nearly identical to the NAO in the Atlantic basin, but their time series are slightly different. Thus the AO and NAO are similar to each other and probably are the leading modes controlling the interannual and decadal variations of the extratropical tropospheric circulation and stratospheric polar vortex in the Arctic. The nature of the Arctic Oscillation is currently unknown and discussed intensively [*Baldwin*, 2000].

One can formulate the basic questions concerning the AO as follows:

(1) is the AO a free leading mode of the atmospheric variability, or has it an external excitation (SST anomalies)?

(2) if there is some external source, then what SSTs can influence changes of the atmospheric wave activity and stratospheric polar vortex in the Arctic?

(3) why the AO resembles the NAO in the troposphere and extends on the global scale?

(4) why the Arctic and Antarctic Oscillations resemble each other?

The aim of this work is to study the relations between the interannual variations of the total ozone, stratospheric circulation and SST anomalies on the global scale and to try answering these questions. The data and method are briefly described in the first section of the paper, the following sections contain the results and discussion.

## Data and Method of Analysis

Reanalyzed monthly mean SST variations (COADS data) [*Woodruff et al.*, 1987] were used to analyze the relations between the SST anomalies, stratospheric circulation, and total ozone in 1979–1992.

The interannual variations of the stratospheric angular momentum were calculated for each gridpoint to analyze the circulation changes of the stratosphere. Stratospheric angular momentum (SAM) determined as the atmospheric angular momentum for the 100 hPa- to 0.4 hPa level depends on the zonal wind variations in the stratosphere as a whole and describes the superrotation of the stratosphere relative the solid Earth [*Hide and Dickey*, 1991]. The stratospheric angular momentum changes were calculated using the NMC-NCEP data on zonal wind values at standard levels of 100, 70, 50, 30, 10, 5, 2, 1, and 0.4 hPa.

The monthly mean variations of the total ozone (TOMS, version 7) for January in the NH and October in the SH were used to analyze the relations between the interannual variations of the total ozone and stratospheric circulation in 1979–1992. Deviations from the average in 1979–1992 (anomalies) for each year were calculated for the SST, SAM, and total ozone for January and October.

The analysis of the relations between the SST anomalies and stratospheric vortex circulation was performed calculating empirical orthogonal functions (EOF) and singular value decomposition (SVD). The leading EOFs describe the most important features of the field with the largest contributions to the total variance. The SVD allows to find the modes of two fields which have the strongest non-local correlations. In the same way as in the EOF analysis, it is necessary to consider only the first SVD modes which describe the spatial patterns with their largest correlations of the two fields. Correlations of the expansion coefficients represent the degree of their relations. The mathematics and advantages of the EOF and SVD analyses are described in detail by *Bretherton et al.* [1992].

## Results

The strongest ozone layer depletion on the global scale occurred during the wintertime of 1980–90s [*WMO*, 1999]. The total ozone trends have a strong longitudinal asymmetry especially in the northern winter hemisphere [*Randel and Cobb*, 1994; *Stolarski et al.*, 1991]. During the recent years, a stabilization of the ozone loss and possible recovery of the ozone layer is observed, which can be caused by both a reduction of the freon emissions into the atmosphere and an influence of the long-term dynamical changes associated possibly with development of the Arctic and Antarctic Oscillations. It should be noted that together with the large negative trends over the West Europe, East Siberia, North Pacific, and east coast of USA, an increase of the total ozone over Labrador was observed in January 1979–1992 (Figure 1). Similar features of the longitudinal asymmetry of the total ozone trends have been mentioned by *Stolarski et al.* [1991], *Randel and Cobb* [1994]. Positive trends of the total ozone took place also southward from South Africa in July during 1979–1992 [*Kadygrov and Jadin*, 1999]. These positive trends are associated with low values of the total ozone in these regions in 1979, with high values in January 1982, 1985, and 1991 over Labrador and in July 1988, 1992 between South Africa and Antarctic. Although these positive trends are not statistically significant at the 95% confidence level because of small amplitudes and short period considered, their existence is needed for the explanation considered [*Jadin*, 2001a].

## Northern Hemisphere

The Arctic Oscillation is closely associated with the stratospheric vortex variability in the Arctic, therefore we consider first the relations between the changes of the total ozone and stratospheric angular momentum of the polar vortex (SAMPV) northward from

58°N. Figure 1 shows a linear trend of the total ozone in January 1979–1992, the first EOF (60.5% of the total variance) of the SAMPV expressed as the correlations (in percent) between its time series and anomalies in each point. Variations of the SAMPV at 85°N, 100°W and 85°N, 100°E, total ozone at 57°N, 60°W and the Goos Bay (53°N, 60°W) station are also shown. The Arctic Oscillation in the stratosphere is the first EOF of the 30 hPa height variability [*Thompson and Wallace*, 1998], the expansion coefficient of which is probably responsible for the interannual variations of the 30 hPa level in the center of the polar vortex ($H_{30}PV$). The variations of the letter were revealed by D. Tarasenko and I. Bugaeva using the Free University Berlin data maps (K. Labitzke) and are shown in Figure 1 for January 1964–1997 in relative units.

A striking feature of the stratospheric vortex variability in January 1979–1992 is its dipole-like structure in terms of both longitude and latitude. Easterly (westerly) anomalies of the SAMPV dominated in the west (east) Arctic with the most prominent peculiarities in January 1985 and 1991. This means that the interannual effects of stratospheric warmings during this period had opposite signatures in the west and east Arctic, that is a tendency to a deceleration (acceleration) of the stratospheric zonal wind was observed in the west (east) Arctic during January 1979–1992. An increase (decrease) of the total ozone over Labrador (East Siberia) is tightly associated with this signatures of the Arctic vortex variability [*Jadin*, 2001a, 2001b]. One can see in Figure 1 that the time series of the first EOF have a positive tendency and correlate well with the $H_{30}PV$. For the longer period 1964–1997, negative trends of the both the total ozone at Goos Bay and $H_{30}PV$ are observed. This fact means a stronger isolation of the stratospheric vortex in the Arctic which is associated with the positive tendency of the AO index after the late 1960s [*Thompson et al.*, 2000]. The correlation coefficient between the $H_{30}PV$ and total ozone variations at Goos Bay is equal to 0.6 and statistically significant at the 95% confidence level. The positive peaks in the time series of the first EOF of the SAMPV in

January 1985 and 1991 correspond to the major stratospheric warmings. These findings imply that the Arctic Oscillation is an asymmetric mode even in the stratosphere with a longitudinal seesaw which plays an important role in the interannual variations of the stratospheric dynamics and total ozone [*Jadin*, 2001b].

According to the wave hypothesis mechanism, there should exist strong relations between the SST anomalies, atmospheric circulation, and ozone changes. Figure 2 shows the first SVD modes of relations between the total ozone and SST anomalies in the Pacific and Atlantic separately, and stratospheric angular momentum variations northward from 10°N. They are expressed as the correlations (in percent) of the corresponding anomalies at each point with the time series of the first SVD mode of the SST anomaly projection onto the total ozone variations. The first SVD mode of the SST anomalies in the Pacific (33% of variance) represents the ENSO with the El Niño events 1982/83, 1987/88, and 1992 and corresponds well to their first EOF (31% of variance). The largest correlations of the ENSO with the stratospheric circulation variations are observed in the subtropics over Central America and Africa, where westerlies take place during the El Niño events. The amplification of the westerlies and strong westerly anomalies of the tropospheric angular momentum during the El Niño 1982/83 in the subtropics were noted by *Rosen et al.* [1984].

The relations of the stratospheric circulation changes at middle and high latitudes with the ENSO are weaker and their spatial pattern does not reproduce the dipole structure of the SAMPV in the Arctic (Figure 1). The first SVD mode of the relations between the SST anomalies in the Pacific and total ozone variations, as well as their time series, are strongly different from those of the leading EOF of the total ozone anomalies [*Kadygrov and Jadin*, 1999]. Thus, the direct influence of the ENSO on the stratospheric circulation and total ozone changes is weak in the northern winter extratropics.

A different picture is observed for the SST anomalies in the Atlantic. The first

SVD mode (21.1% of variance) of the relations between the SSTs and the total ozone corresponds well to their first EOF (24.2% of variance) with a sandwich-shaped spatial pattern [*Wallace et al.*, 1990]. Also their SVD modes of the relations to the SAM and total ozone variations are similar to the leading EOFs of the SAM and total ozone changes. The spatial pattern of the total ozone SVD resembles that of the linear trend (Figure 1), and the dipole structure of the SAMPV in the Arctic is reproduced well in the SVD mode of the SST, total ozone, and SAM relations. The correlations of the interannual SST anomalies in the Atlantic with the stratospheric circulation and total ozone changes in the northern winter extratropics are much stronger than with the ENSO. This does not imply that the SST anomalies in the Pacific provide a small contribution to the interannual variations of the atmospheric wave activity, because the ENSO has a long-term "memory" and can lead to a northward re-routing of the Kuroshio Extension a few years after the El Niño 1982/83, changing the extratropical SST anomalies [*Jacobs et al.*, 1994]. Therefore, the relations to the combined SST anomalies should be studied.

Figure 3 shows the first SVD mode of the relations between the combined SST anomalies in the North Pacific and North Atlantic northward from 20°N, SAM northward from 40°N, and total ozone variations. The features of the spatial pattern of the SST anomalies in the Atlantic basin are similar to those in the Atlantic separately with different time series (Figure 2), but a dipole-like structure with the centers near the Kuroshio and Aleutian Currents appears in the North Pacific. This spatial pattern and its time series are almost identical to those of the third EOF (11% of variance) of the combined SST anomalies in the North Pacific and North Atlantic. There are high correlations between the interannual variations of the stratospheric circulation and total ozone and these dipole seesaws of the SSTs. Thus, only a small part of the SST anomalies with the well-defined structure is tightly associated with the changes of the basic features of the stratospheric dynamics and total ozone trends.

The almost identical structure of the leading EOF of the stratospheric momentum anomalies and structure of its first SVD mode, as well as the excellent agreement of their time series, provide a strong evidences of significant relations between the interannual SST anomalies in the North Atlantic and North Pacific (their structure is shown in Figure 3) with the stratospheric vortex changes in the Arctic. This structure of the SSTs is characterized by the dipole seesaw of the SST anomalies at high latitudes of the North Pacific (the center of action is located southward from Aleutian Islands) and North Atlantic (the center of action is located southward from Greenland). Variations in these centers of action can play an important role in the external thermal excitation of the Arctic Oscillation, therefore the difference SST(52°N, 150°W)–SST(52°N, 35°W) is called "a dipole across Rocky mountains." The dipole-like SST variations in the North Atlantic correspond to the well-known changes which are probably linked to the NAO [*Wallace et al.* 1990]. Figure 4 illustrates the differences of the SST anomalies in the following dipoles: across Rockies, SST(35°N, 60°W)–SST(52°N, 35°W), and SST(52°N, 150°W)–SST(40°N, 150°E). The behavior of the dipole in the North Atlantic is almost identical to the dipole across Rockies and their similarity can explain the close linkage of the AO and NAO in the Atlantic basin. The largest differences between the dipole associated with the Kuroshio and others shown in Figure 4 occurred in 1979/80, 1982/83, and 1986/87, i.e. during the El Niño events.

## Southern Hemisphere

There are strong differences in the interannual and decadal variations of the total ozone and atmospheric circulation between the NH and SH which are caused by the differences in the topographic and thermal excitation of planetary waves. More frequent occurrence of major stratospheric warmings in the NH is associated with these differences.

As it has been mentioned above, the interannual variations of the ozone hole in the Antarctic are strongly linked to the stratospheric circulation changes outside the antarctic polar vortex in the 40°S–60°S belt [*Jadin*, 1999]. Figure 5 shows the monthly mean (October) variations of the zonal mean SAM and total ozone anomalies in 1979–1992. It should be noticed that only the October values are shown; other values are a consequence of graphic interpolation. An abrupt transition to a new decadal regime in the stratospheric dynamics occurred in 1980 with strong westerly SAM anomalies which propagated toward the polar regions following the V-shaped propagation (its southern branch) during the subsequent years. There exist very strong relations between the interannual variations at middle latitudes and the total ozone changes in the Antarctic. A decrease (increase) of the total ozone corresponds very well to the westerly (easterly) SAM anomalies in the vicinity of the antarctic polar vortex. The correlations between the total ozone over Antarctic and SAM at 50°S are very high (higher than 90%) and statistically significant at the 95% confidence level despite of a short period considered. The analysis of the zonal wind variations of the stratosphere showed that their largest trends are observed in June-August prior to the ozone hole appearance, therefore they cannot be caused by the influence of the radiative regime changes due to ozone reduction. These results provide evidences that an important role in the interannual ozone hole variations and even in its occurrence is played by the long-term dynamical changes at low and middle southern latitudes.

In order to investigate the relations between the interannual variations of the total ozone, SAM as a function of the longitude and latitude, and SST anomalies in the Pacific, Atlantic, and Indian oceans (separately and combined), the EOF and SVD modes of these fields were calculated. The analysis showed a weak correlations of the ENSO with the total ozone and SAM variations in the southern extratropics as well as in the Northern Hemisphere. Higher correlations were obtained for the SSTs in the Atlantic and Indian ocean. However the strongest linkage was found between the interannual variations of the total ozone, stratospheric circulation, and combined SST anomalies in the southern Pacific, Atlantic, and Indian oceans. Figure 6 shows the first EOF of the total ozone anomalies and the first SVD modes of the relations between the SAM and SST anomalies and also their expansion coefficients. The first EOF of the total ozone describes mainly the development of the ozone hole in the Antarctic with some recovery in October 1988. The dipole seesaw of the total ozone variations over the South Pacific and South Atlantic should be also noted.

The first SVD mode (63.1% of variance) of the relations between the total ozone and combined SST anomalies is almost identical to the first EOF of the total ozone anomalies. Only a small part of the SST anomalies (14.3% of variance) in the South Oceans is strongly associated with the development of the ozone hole in the Antarctic and total ozone anomalies at middle latitudes. The spatial pattern and time series of the first SVD mode of SSTs correspond well to those of their second EOF (not shown). The most prominent features of these modes are the dipole SST's seesaws across Andes and across South Africa. The analysis showed that these SVD1 and EOF2 modes of the SST anomalies are also responsible for the strongest relations between the SAM and SST anomalies [*Jadin*, 2001c]. It was shown also that the total ozone variations over Antarctic correlate weakly with the SAM changes within the polar vortex, rather the ozone hole development depends strongly on the interannual variations at southern middle latitudes (see Figure 5). This is in contrast with the situation in the Arctic, where strong relations are observed between the changes of the stratospheric vortex dynamics and the total ozone at high northern latitudes (Figure 1). The cause of this difference is related to the differences in stratospheric warming occurrences in the Northern and Southern Hemispheres.

Figure 7 illustrates the relations of the total ozone, SAM, and SST anomalies at the critical points. Strong negative correlations are seen between the total ozone variations at the Halley Bay and Syowa stations and stratospheric momentum changes outside the polar vortex. The behavior of the SSTs in the dipoles across Andes and across South Africa resembles well the development of the ozone hole in the Antarctic during October 1979–1992. *Smith et al.* [1994] noted strong changes of SSTs in the South Oceans.

## Discussion

The results of the analysis testify to strong relations between the interannaul and intra-decadal variations of the total ozone, stratospheric circulation, and SST anomalies of the well-defined structure both in the extratropical Northern and Southern Hemispheres. One can hardly believe that these relations can be caused by the observed ozone trends as it has been suggested in the GCM simulations of the Arctic Oscillation [*Volodin and Galin*, 1998]. The radiative regime changes in the stratosphere are too small to result really in the significant observed changes in the troposphere. In an opposite way, The result presented above can be interpreted as a response of the stratospheric circulation and ozone to the interannual and decadal variations of the atmospheric wave activity caused by the extratropical SST anomalies with the dipole seesaws across Rockies in the NH and across Andes and South Africa in the SH. These results confirm the reality of the wave hypothesis mechanism which is based on the interference of the topographic and thermal sources of planetary waves. It should be emphasized that this simple mechanism does not require large SST anomalies to obtain a significant response of the atmosphere to SST anomalies, because the interference of these sources depends strongly on their phase differences (longitudinal migration of SST anomalies in the dipole seesaws) similar to the interference of two sources in the optics. *Honda et al.* [2001] pointed out to the importance for the climate changes of the interannual seesaw between the Aleutian and

Icelandic lows in the troposphere which can be associated with the dipole of SSTs across Rockies. As these SST anomalies are strongly linked to the interannual variations of the stratospheric vortex in the Arctic (Figure 1 and 3), this can mean that the Arctic Oscillation is a result of the external excitation by the SST anomalies in the dipole across Rockies [*Jadin*, 2001c]. The close similarity of the first SVD spatial pattern in the North Atlantic (Figure 3) and its first EOF (Figure 2) and also of their time series can explain the similarity of the AO and NAO in the Atlantic basin. Also, the resemblance of the Arctic and Antarctic Oscillations can be a result of the identical mechanism of the external excitation by the SST anomalies in the dipoles across Rockies, Andes and Africa.

The strong relations between the interannual variations of the total ozone over Labrador and stratospheric circulation (Figure 1) provide evidences of a large role of the natural dynamical factors in the ozone layer changes at high northern latitudes. During the wintertime 1979–1992, an increase of the $H_{30}PV$ and weaker isolation of the polar vortex were observed in the west Arctic. This led to a positive total ozone trends at Goos Bay which could not be caused by the anthropogenic factors. During the longer period 1964–1997, the total ozone trends in this region are negative, but it is related to the positive tendency of the AO index and to the cooling of the surface air temperature in this region [*Thompson et al.*, 2000]. These relations make it possible to use the total ozone data for weather predictions [*Jadin and Kadygrov*, 2002].

Future simulations in scope of the general circulation model can provide an explanation of relations between the SST anomalies, stratospheric and tropospheric coupling, and ozone layer changes on decadal timescales.

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E. A. Jadin, Central Aerological Observatory, Dolgoprudny, 3 Pervomayskaya Str., 141700 Moscow Region, Russia. (ejadin@mail.ru)

(Received 11 December 2001)

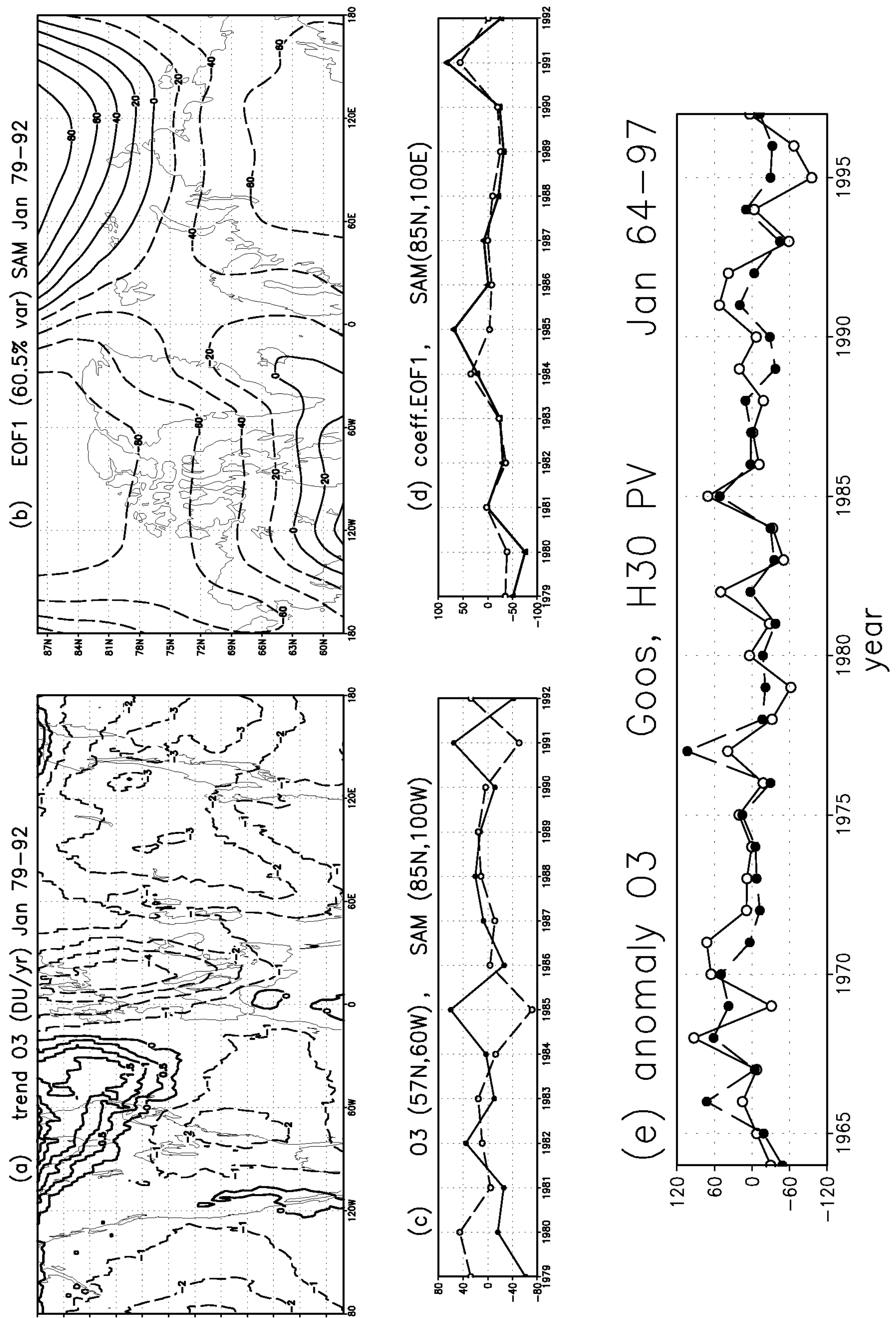
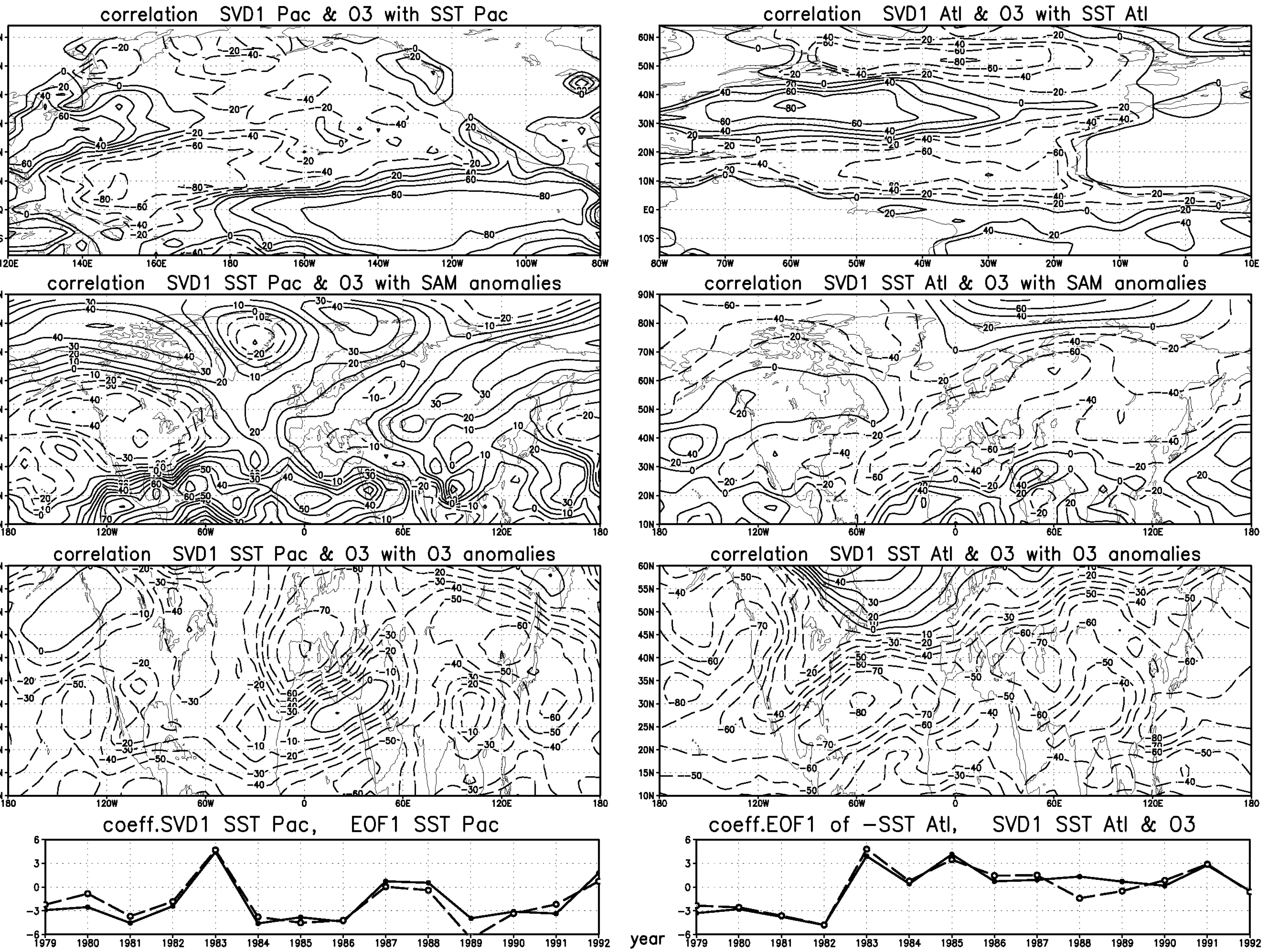

(a) trend O3 (DU/yr) Jan 79−92
(b) EOF1 (60.5% var) SAM Jan 79−92
(c) O3 (57N,60W), SAM (85N,100W)
(d) coeff.EOF1, SAM(85N,100E)
(e) anomaly O3 Goos, H30 PV Jan 64−97
year
60N
57N
54N
51N
48N
45N
42N
39N
36N
33N
30N
27N
87N
84N
81N
78N
75N
72N
69N
66N
63N
60N
180
120W
60W
0
60E
120E
180
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
80
40
0
−40
−80
100
50
0
−50
−100
120
60
0
−60
−120
1965
1970
1975
1980
1985
1990
1995

**Figure 1.** Linear trend of the total ozone (DU/year) in January 1979–1992 (a), the interannual variations of the stratospheric angular momentum in the Arctic (b), its correlations (in percents) with the expansion coefficient of its first empirical orthogonal function (d, solid line), total ozone at 57°N, 60°W (c, solid line) and stratospheric angular momentum anomalies at 85°N, 10°W (c, dashed line); the total ozone anomalies at Goos Bay (solid line) and the 30 hPa height variations (dashed line) in the center of the polar vortex in the Arctic in January 1964–1997 (e). Units are arbitrary.



correlation SVD1 Pac & O3 with SST Pac

correlation SVD1 Atl & O3 with SST Atl

correlation SVD1 SST Pac & O3 with SAM anomalies

correlation SVD1 SST Atl & O3 with SAM anomalies

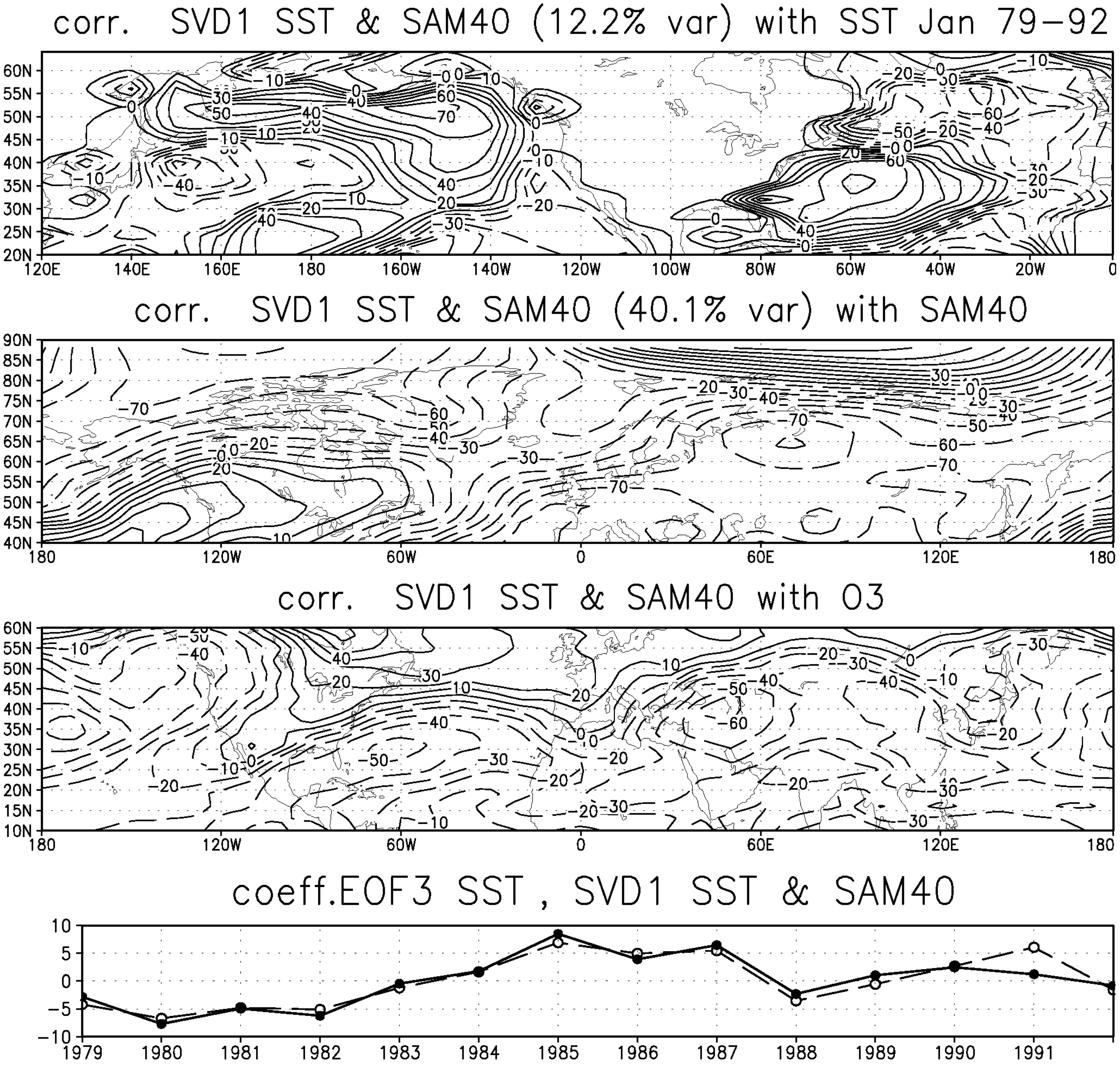
correlation SVD1 SST Pac & O3 with O3 anomalies

correlation SVD1 SST Atl & O3 with O3 anomalies

coeff.SVD1 SST Pac, EOF1 SST Pac

coeff.EOF1 of −SST Atl, SVD1 SST Atl & O3

**Figure 2.** The first SVD modes of the relations between the monthly mean (January) SST anomalies in the Pacific (left) and Atlantic (right) and the total ozone and stratospheric momentum in 1979–1992.



corr. SVD1 SST & SAM40 (12.2% var) with SST Jan 79−92

corr. SVD1 SST & SAM40 (40.1% var) with SAM40

corr. SVD1 SST & SAM40 with O3

coeff.EOF3 SST , SVD1 SST & SAM40

**Figure 3.** The first SVD modes of the relations between the interannual variations of the stratospheric momentum northward from 40°N and the combined SST anomalies in the North Pacific and North Atlantic. The correlations of the total ozone anomalies with the first SVD mode coefficient are also shown.

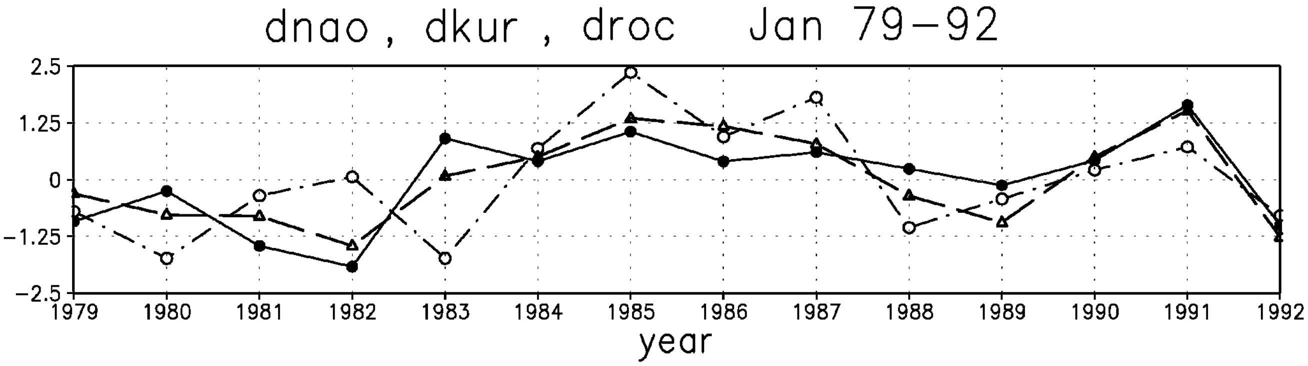
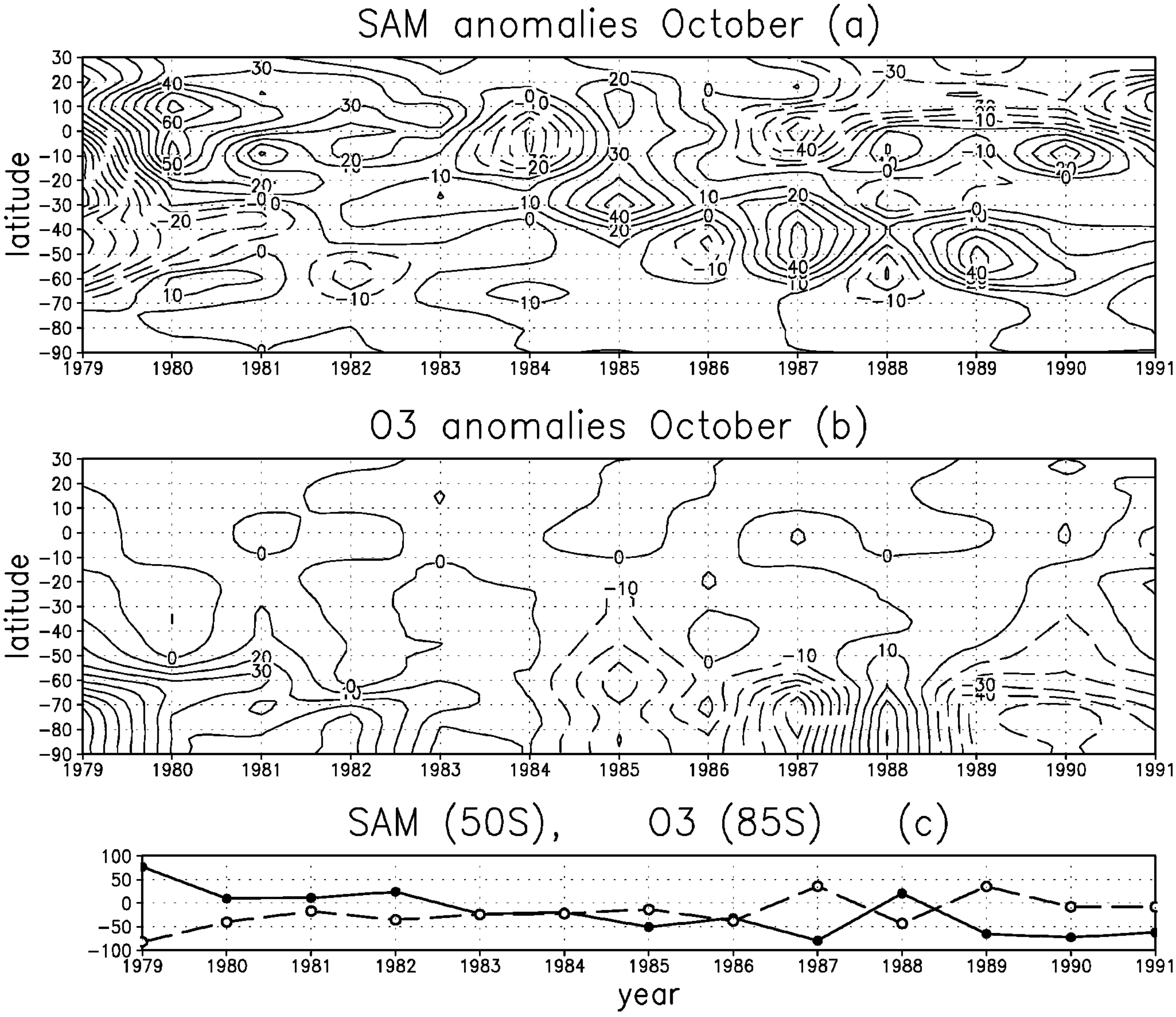


**Figure 4.** Interannual variations of the SSTs in the dipole across Rocky mountains SST(52°N, 50°W)–SST(50°N, 160°W) (droc) (solid line), at the centers of action in the Atlantic (dnao) (dashed line) and in the North Pacific (dkur) (dashed-dotted line). See the text for explanations.

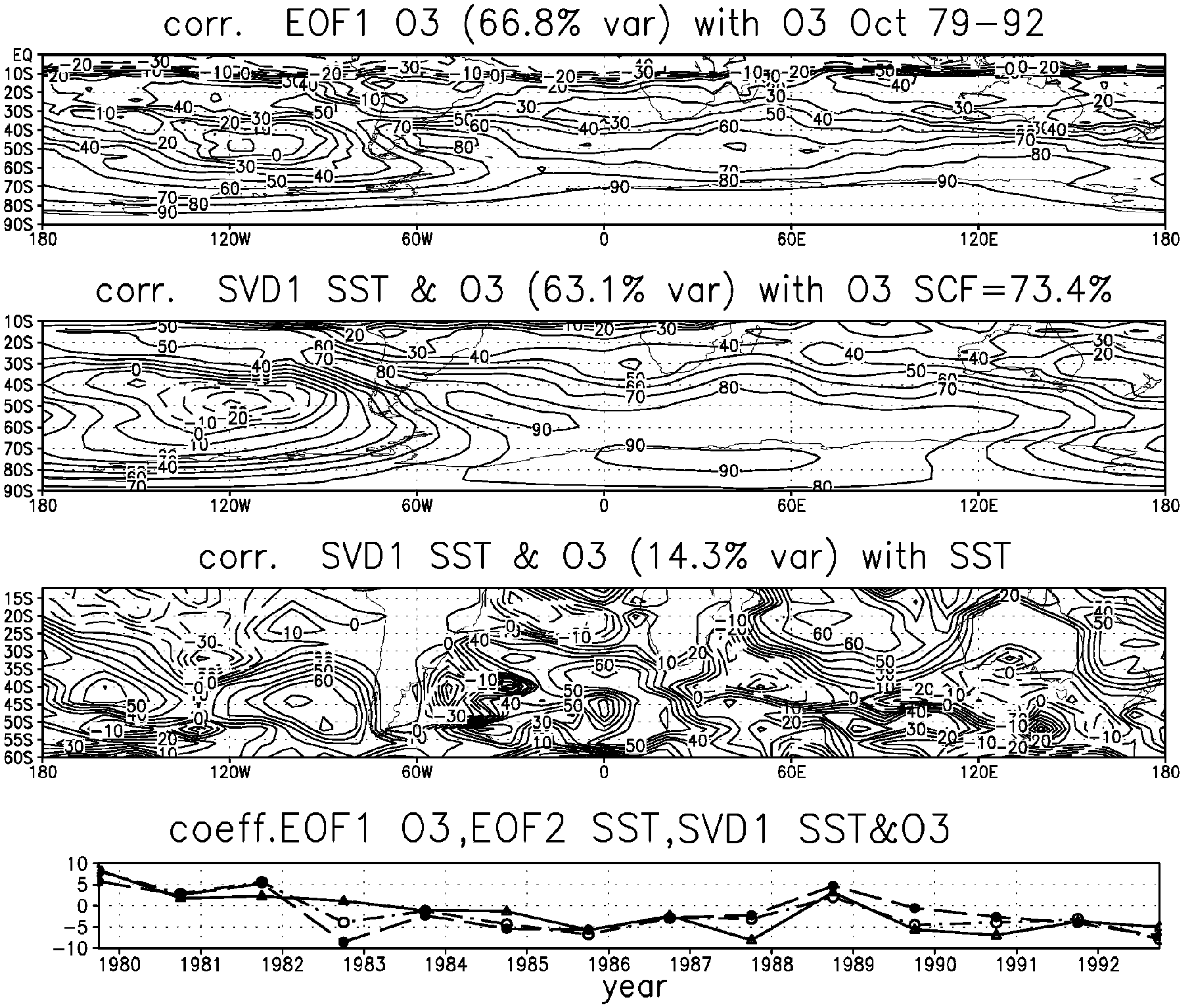


SAM anomalies October (a)

O3 anomalies October (b)

SAM (50S), O3 (85S) (c)

**Figure 5.** Monthly mean (October) zonally average anomalies of the stratospheric angular momentum (a), the total ozone (DU) anomalies (b) and their behavior at 50°S and 85°S (c).


corr. EOF1 O3 (66.8% var) with O3 Oct 79-92

corr. SVD1 SST & O3 (63.1% var) with O3 SCF=73.4%

corr. SVD1 SST & O3 (14.3% var) with SST

coeff.EOF1 O3,EOF2 SST,SVD1 SST&O3

**Figure 6.** The first EOF of the total ozone variations for October 1979–1992 (top panel) and first SVD modes of the relations between the interannual SST anomalies in the South Oceans and the total ozone variations in October 1979–1992 (middle panels) and their time series (bottom panel).

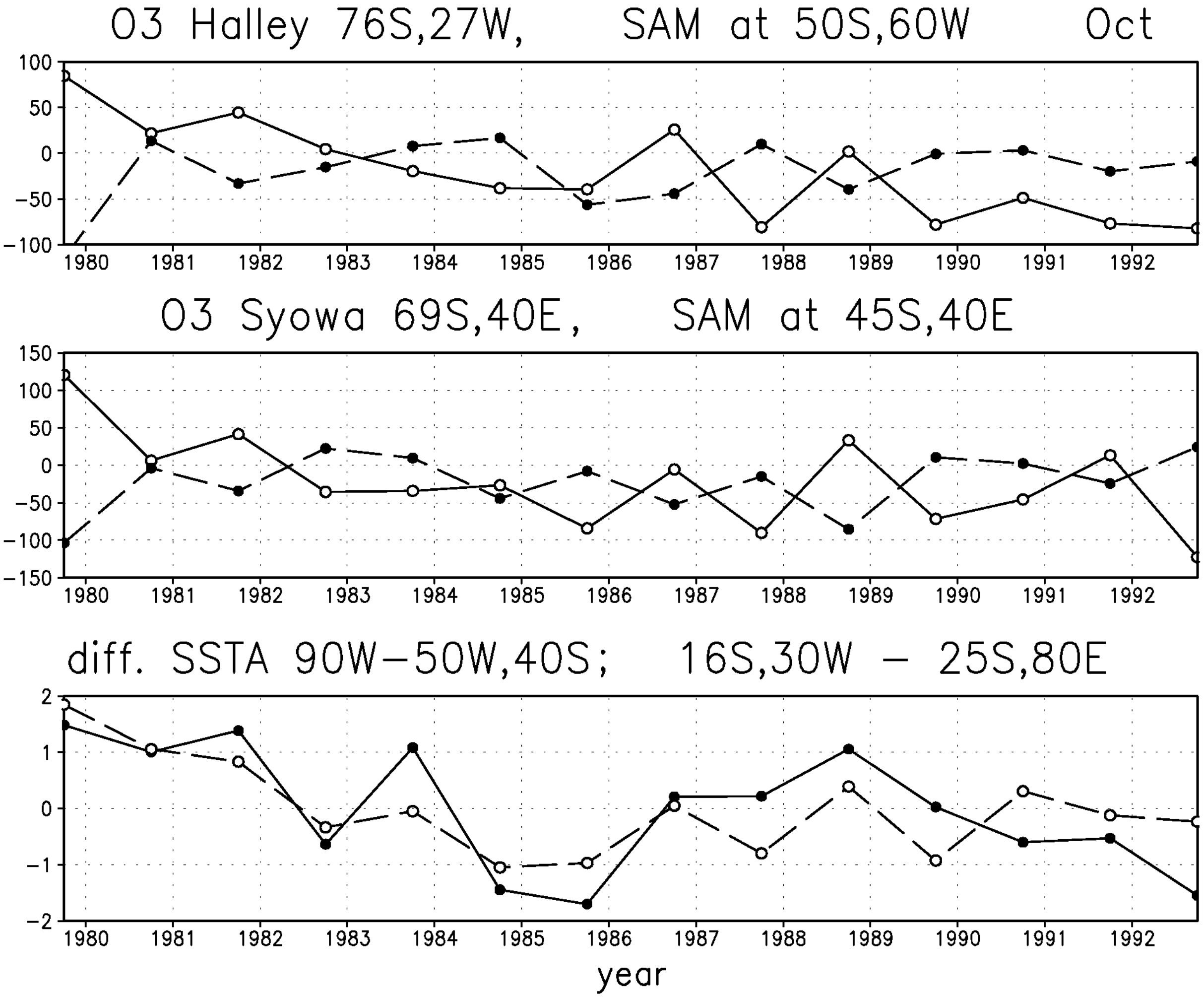


**Figure 7.** Interannual variations of the total ozone anomalies at the Halley Bay and Syowa stations and the stratospheric angular momentum at the critical points (top panels). The SST anomaly differences in the dipoles across Andes (solid line) and South Africa (dashed line) (bottom panel).